



NAVAL POSTGRADUATE SCHOOL

MONTEREY, CALIFORNIA

THESIS

**NEXT GENERATION SHIP-BORNE ASW-SYSTEM: AN
EXEMPLARY EXERTION OF METHODOLOGIES AND
TOOLS APPLIED ACCORDING TO THE GERMAN
MILITARY ACQUISITION GUIDELINES**

by

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June 2013

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REPORT DOCUMENTATION PAGE			<i>Form Approved OMB No. 0704-0188</i>	
Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instruction, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302, and to the Office of Management and Budget, Paperwork Reduction Project (0704-0188) Washington DC 20503.				
1. AGENCY USE ONLY (Leave blank)		2. REPORT DATE June 2013	3. REPORT TYPE AND DATES COVERED Master's Thesis	
4. TITLE AND SUBTITLE NEXT GENERATION SHIP-BORNE ASW-SYSTEM: AN EXEMPLARY EXERTION OF METHODOLOGIES AND TOOLS APPLIED ACCORDING TO THE GERMAN MILITARY ACQUISITION GUIDELINES			5. FUNDING NUMBERS	
6. AUTHOR(S) Helmut Rodler				
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) Naval Postgraduate School Monterey, CA 93943-5000			8. PERFORMING ORGANIZATION REPORT NUMBER	
9. SPONSORING /MONITORING AGENCY NAME(S) AND ADDRESS(ES) N/A			10. SPONSORING/MONITORING AGENCY REPORT NUMBER	
11. SUPPLEMENTARY NOTES The views expressed in this thesis are those of the author and do not reflect the official policy or position of the Department of Defense or the U.S. Government. IRB Protocol number ____N/A____.				
12a. DISTRIBUTION / AVAILABILITY STATEMENT Approved for public release; distribution is unlimited			12b. DISTRIBUTION CODE A	
13. ABSTRACT (maximum 200 words) The German Armed forces acquisition guideline, the Customer Product Management (CPM), regulates the principal acquisition process steps including the responsibilities between civil and military departments. Many of the CPM's specified deliverables, like formulating needs, writing requirements and conducting analysis, are created and managed by military personnel that are assigned to support the acquisition management. These military personnel are not always familiar with the common systems engineering and acquisition methodologies and tools. The capabilities of the German armed forces are derived based on missions and tasks. The variation and number of needed capabilities leads to a greater likelihood of risk, threat and funding. ASW missions currently are no longer considered primary capabilities of the German Navy. The ASW ships in service cannot accommodate the future ASW helicopter (MH90), which will cause the loss of utilization of this primary warfighting ASW sensor and weapon. On the other hand ships without any ASW capabilities, like the F125, can accommodate ASW helicopters. This dilemma is still unresolved by naval leaders. This thesis shall examine the German basic acquisition guidelines and present applicable systems engineering methodologies and tools considering existing regulations. A basic systems engineering process will be demonstrated using a possible German Navy next generation ship-borne ASW-system through the presented methodologies.				
14. SUBJECT TERMS German Armed forces acquisition guideline, CPM, ASW, next generation ship borne ASW-system, Needs, Requirements, Analysis, systems engineering, design process, analysis of alternatives			15. NUMBER OF PAGES 171	
			16. PRICE CODE	
17. SECURITY CLASSIFICATION OF REPORT Unclassified	18. SECURITY CLASSIFICATION OF THIS PAGE Unclassified	19. SECURITY CLASSIFICATION OF ABSTRACT Unclassified	20. LIMITATION OF ABSTRACT UU	

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EXERTION OF METHODOLOGIES AND TOOLS APPLIED ACCORDING TO
THE GERMAN MILITARY ACQUISITION GUIDELINES**

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Submitted in partial fulfillment of the
requirements for the degree of

MASTER OF BUSINESS ADMINISTRATION

from the

**NAVAL POSTGRADUATE SCHOOL
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ABSTRACT

The German Armed forces acquisition guideline, the Customer Product Management (CPM), regulates the principal acquisition process steps including the responsibilities between civil and military departments. Many of the CPM's specified deliverables, like formulating needs, writing requirements and conducting analysis, are created and managed by military personnel that are assigned to support the acquisition management. These military personnel are not always familiar with the common systems engineering and acquisition methodologies and tools.

The capabilities of the German armed forces are derived based on missions and tasks. The variation and number of needed capabilities leads to a greater likelihood of risk, threat and funding. ASW missions currently are no longer considered primary capabilities of the German Navy. The ASW ships in service cannot accommodate the future ASW helicopter (MH90), which will cause the loss of utilization of this primary warfighting ASW sensor and weapon. On the other hand ships without any ASW capabilities, like the F125, can accommodate ASW helicopters. This dilemma is still unresolved by naval leaders. This thesis shall examine the German basic acquisition guidelines and present applicable systems engineering methodologies and tools considering existing regulations. A basic systems engineering process will be demonstrated using a possible German Navy next generation ship-borne ASW-system through the presented methodologies.

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LIST OF ACRONYMS AND ABBREVIATIONS

AAW	Anti-Air Warfare
AIP	Air Independent Propulsion
AO	Area of Operation
Ao	Operational Availability
AOA	Analysis of Alternatives
ATAM	Architectural Tradeoff Analysis Methodology
ASROC	Anti-Submarine Rocket
ASW	Anti-Submarine Warfare
ASuW	Anti-Surface Warfare
BAAINBw	Federal Office of Bundeswehr Equipment, Information Technology and In-Service Support)
BWB	Federal Office for Military Technology and Procurement
CBA	Cost Benefit Analysis
CE	Cost Effectiveness
CEA	Cost Effectiveness Analysis
CoS	Chief of the Federal Armed Forces Staff
CPM	Customer Product Management
DAU	Defense Acquisition University
DDCU	Digital Distribution Communication Unit
DoD	Department of Defense
DT&E	Developmental, Test and Evaluation
EASA	European Aviation Safety Agency
EO/IR	Electro-Optical and Infrared Sensor
EWS	Electronic Warfare System
FAA	U.S. Federal Aviation Administration
FFF	Capability Gap and Functional Requirements
FLIR	Forward Looking Infrared
FMECA	Failure Mode, Effects, and Criticality Analysis
GAO	General Accountability Office
GP F&Mgmt	Capabilities Management Process

HF	High Frequency
ICD	Initial Capability Document
IPP	Integrated Planning Process
IPPD	Integrated Product and Process Development
IPT	Integrated Project Team
KPP	Key Performance Parameters
kts (IAS)	Knots (Indicated Airspeed)
LCC	Life-Cycle Cost
LOS	Line of Sight
MC	Mission Capable
MCM	Mine Counter Measure
MDT	Maintenance Down Time
MoD	Ministry of Defence
MoF	Federal Ministry of Finance
MOE	Measure of Effectiveness
MOP	Measure of Performance
MTBM	Mean Time Between Maintenance
MUIRS	Maintainability, Upgradeability, Interoperability, Reliability, Security/Safety
MW	Mine Warfare
NATO	North Atlantic Treaty Organization
OR	Operations Research
OT&E	Operational Testing and Evaluation
O&S	Operation and Support
PlgABw	Bundeswehr Planning Office
PM	Program Manager
RFI	Request for Information
SEDP	Systems Engineering Design Processes
SEI	Software Engineering Institute
SEP	Systems Engineering Process
SOF	Special Operation Forces
SSK	Conventional Submarine

SSN	Nuclear Submarine
TPM	Technical Performance Measure
TRL	Technology Readiness Level
UAS	Unmanned Aerial Systems
UAV	Unmanned Aerial Vehicle
UHF	Ultra High Frequency
VHF	Very High Frequency
WBS	Work Breakdown Structure
WTD	Defense Technology Departments
ZV	Agreement on Objectives

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ACKNOWLEDGMENTS

I am sincerely thankful to my thesis advisors, John T. Dillard and Clifford Whitcomb, who gave me guidance and support from the initial to the final stages of research and enabled me to make this thesis possible.

Furthermore, I am thankful to my editor, Margaret Beresik, who gave me great support in English grammar and did an awesome job in editing my thesis.

Lastly, I offer my thanks and blessings to my wife, who supported me in every respect during the completion of this thesis.

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I. INTRODUCTION

A. THESIS BACKGROUND

The German armed forces have experienced several reduction and transformation processes, and the last transformation process of the forces just started last year and is intended to endure until 2015. As an outcome of the transformation, the procurement and acquisition processes and guidelines have also been changed. The most important current guideline is the Customer Product Management (CPM) and it regulates the principal steps within an acquisition program and the responsibilities between civil and military departments. In the German armed forces no US DoD 5000 comparable series exists to regulate and guide programs involving civil and military personnel. Many of the CPM's specified deliverables, like formulating needs, writing requirements and conducting analyses, are created and managed by the military workforce. Military personnel usually support all acquisition processes within the civil procurement agency at all levels. The German service member is usually not familiar with the most well-known methodologies and tools applicable to project and program management.

The current German Defense Guidelines (2011) define the role of the German armed forces in accordance with current and likely future threats. The capabilities will be adapted with respect to the new missions and tasks (German Ministry of Defense, 2011). The capabilities of the German armed forces are derived from its missions and tasks. The variation and number of needed capabilities impact the likelihood of risk, threat and funding.

Anti-submarine warfare (ASW) missions are currently no longer considered as primary capabilities of the German Navy. The ASW ships in service cannot accommodate the future ASW helicopter (MH90) due to their limited hangar space. This will cause the loss of the opportunity to deploy these ship borne aerial ASW sensors and weapons. On the other hand, ships without any existing ASW capabilities, like the F125, can accommodate ASW helicopters. This dilemma is still unresolved by naval leaders.

B. THESIS OBJECTIVE

The objective of this thesis is to examine basic German acquisition guidelines, namely the CPM, and present systems engineering methodologies and tools which are applicable within the German military acquisition system in accordance with their regulations. A basic systems engineering process with respect to a possible German Navy next generation ship borne ASW-system shall be presented. This will enable an explanation of the application of these systems engineering methodologies and tools in the context of a real matter of concern, and will simplify the demonstration in order to provide a basis to understand how to implement a systems engineering processes in accordance to the CPM.

C. RESEARCH QUESTIONS

The thesis shall answer the question:

Which of today's widely recognized, taught and applied methodologies, practices and tools used in military acquisition management, and in particular in systems engineering, apply within the German forces acquisition system and are in accordance to regulations, specifics, guidelines?

Furthermore, the thesis shall answer:

Where and how, within the acquisition process, do they fit into the German acquisition guidelines to fulfill the CPM's list of to-do requirements?

Additionally the thesis shall illuminate and clarify the basic problem of a possible need for a next generation ship borne ASW-system for the German Navy ASW ships.

D. SCOPE

The scope of the thesis is limited to examining the German acquisition guidelines with respect to the CPM's analysis phases. It is not intended to deliver a comprehensive program management work plan and detailed report structure. The thesis scope is to research the systems engineering methodologies and apply them in accordance with the CPM only. Therefore, the CPM will not be examined on "right or wrong" approach, ut

instead present options for what could be altered or improved in the German acquisition process.

The ASW problem serves mainly as a story-board to present the methodologies in an adequate and understandable way. It is not in this thesis' scope to conduct a real and comprehensive systems engineering process on a real matter which delivers credible detailed numbers, figures and facts concerning the problem in order to draw real conclusions. The ASW problem shall only illuminate the problem on a basic level, since no credible data are available and the extension of such a work would be outside the scope of the single person's thesis.

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II. BACKGROUND

A. GENERAL

Since the reunification of Germany, the German armed forces have experienced several reduction and transformation processes. The most recent transformation process of the forces started last year and is intended to continue until 2015. In 2010 the former Minister of Defense zu Guttenberg initiated a comprehensive reform of the Bundeswehr (that is, the German armed forces and civil departments under the Ministry of Defense). The main goal of this reform effort is to transform the armed forces into a smaller, but more modern and more effective force. The reform effort has been prompted by a demographic issue: the unfavorable ratio of young to old people in the next few years. Additionally, the economic problems that began in 2008 have caused a more restrictive federal budget currently, while future budgets will be constrained by the legal requirement to limit annual federal debts to 3% in 2016.

The starting point for the reform of the Bundeswehr was a report produced by a commission tasked to survey the current situation and structure of the Bundeswehr. The report of the Weise Commission (2010) also described the current situation of the armament process in the Bundeswehr and says:

The previous process, based on the Customer Product Management Guidelines of the Bundeswehr, has been approved in general, but there are some negative attendant circumstances.

These are the:

- lack of a capability management over the whole procurement process,
- long lasting verification and decision processes by consensus,
- rising cost of procurement,
- opaque processes caused by fragmented responsibilities and areas of competencies and cumbersome communication structures.

In another report, the Chief of Federal Armed Forces Staff, Volker Wierer (2010), criticized the whole procurement process. Wierer found problems with the fragmented responsibilities, existing procedures, outside influences and insufficient

funding. Furthermore, he criticized all major procurement programs for failing to stay on schedule, for exceeding the funded budget and for failing to deliver the requested capabilities. Subsequently, the current Minister of Defense recommended the restructuring and optimization of the procurement process as part of the reform of the Bundeswehr.

B. THE PROCUREMENT, TEST AND EVALUATION ORGANISATIONS IN THE BUNDESWEHR

As one result of the reform process in the German Bundeswehr the new Bundesamt für Ausrüstung, Informationstechnologie und Nutzung der Bundeswehr (BAAINBw, Federal Office of Bundeswehr Equipment, Information Technology and In-Service Support) has been established from the former Bundesamt für Wehrbeschaffung (BWB, Federal Office for Military Technology and Procurement). All Research & Technology activities, the procurement and acquisition of any equipment and weapon systems, as well as management during the usage phase are the responsibility of the BAAINBw, a civilian controlled federal office under the direction of the Minister of Defense.

The BAAINBw is in charge of conducting all military procurement programs. Therefore, a project manager (PM) of the BAAINBw is in charge the program. In the past the project manager was always a civilian employee. This understanding of the Basic Law for the Federal Republic of Germany has changed. Today the important aspect is that the Federal Office of Bundeswehr Equipment, Information Technology and In-Service Support is part of the civil organizational area of the Bundeswehr (see Figure 1). Military personnel and civil servants can serve in this office and become project managers. The core competencies of the BAAINBw are development, test and evaluation, and procurement of military equipment. With military personnel the core competencies have been extended to include management capabilities for the usage phase of the equipment of the Bundeswehr. The test and evaluation competency lies within the responsibility of the Wehrtechnische Dienststellen (WTD, Defense Technology Departments), which are an organizational part of the BAAINBw. During the

development and the production phases as well as for already introduced and procured equipment, the WTDs test, evaluate and certify equipment in order of the BAAINBw.

In particular the WTDs are responsible for the following tasks:

- test and evaluation (procedure of proof)
- functional support of all weapon systems and their armaments
- certification of military weapon systems, equipment, and armaments
- coordination and work on the development and technology program concerning military systems.

WTDs are in principle only tasked with development, testing and evaluation (DT&E) and act as a technology specialist within the German armed forces. The WTDs are not tasked with any operational testing and evaluation OT&E activities. OT&E activities, according to the German procurement guidelines, are a responsibility of the PM, but these activities are conducted by the user (or future user) of any weapon system. The Bundeswehr has no comparable agencies to those in the U.S. services. Usually a lead unit, such as the first unit to be equipped with a new system, or a weapon school is tasked to conduct OT&E. In the past, many schools, especially those associated with the army and the joint support service, had a department for concepts, development and OT&E, but with the new structure these departments are often eliminated.

C. THE GERMAN MILITARY PROCUREMENT PROCESS

In October 2012 the new structures were implemented, and the former Federal Office responsible for the procurement of the Bundeswehr, the BWB, was reestablished as BAAINBw. As an outcome of the reorganization and transformation the processes and guidelines for the planning and armament processes have been changed significantly. The most important current procurement guideline is called Customer Product Management (CPM), and it regulates the principal steps within a procurement program as well as the responsibilities between departments of the MoD, the organizational areas and the BAAINBw.

Furthermore, the organization structure of the MoD has also been transformed, including the processes of monitoring, analyzing, and planning of recognized capability gaps (need). A new integrated planning process (IPP) (Bundesministerium für Verteidigung 2012) has been developed and is currently in implementation. The IPP regulates inter alia the processes like the process of monitoring and analyzing the political strategic settings, developing a prioritized capability profile and analyzing existing capabilities against this prioritized capability profile. This process will be conducted integrally, which means that aspects and issues of all services and civil departments will be taken into consideration and will be weighed between them.

1. Responsibilities and Order of Events within the Procurement Processes according to the IPP

The capabilities management process aims to recognize capability gaps and to derive and define the needs of the forces, and is, therefore, an important and necessary step before a procurement program can be initiated. This process is called Geschäftsprozess Fähigkeitsmanagement (GP FäMgmt, capabilities management process) and is conducted by the MoD, the Planungsamt der Bundeswehr (PlgABw, Bundeswehr Planning Office), BAAINBw, and by the services. The process provides oversight for the current capability position of the Bundeswehr and enables the FäMgmt to control the current capability position (see Figure 1).

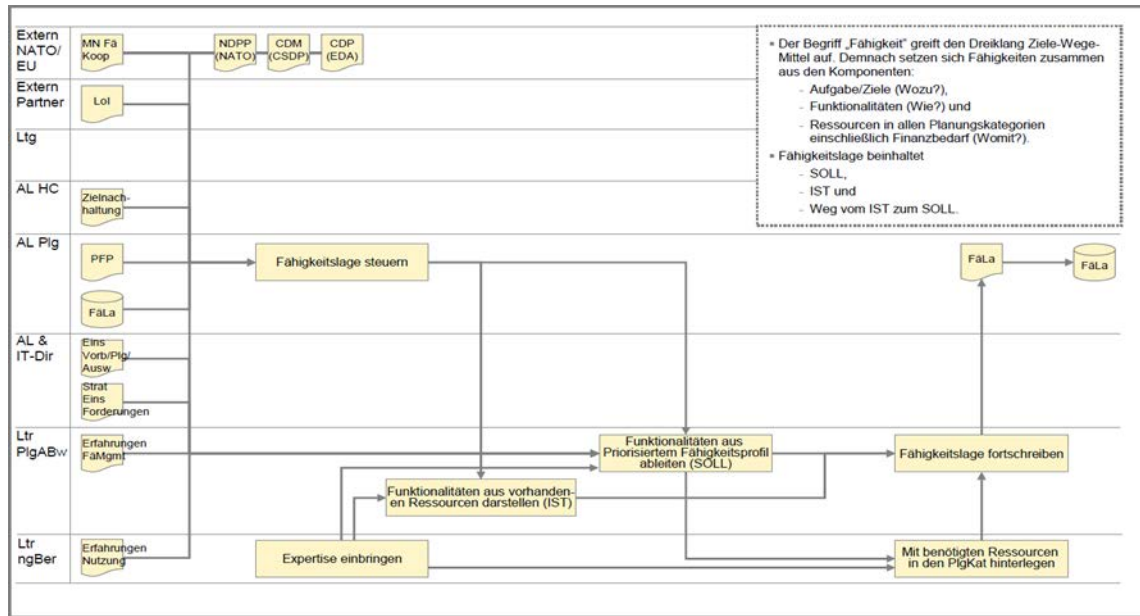


Figure 1. IPP: Flow diagram control of capability position (Fähigkeitslage führen).

In a top-down approach, taking external settings into consideration, needs will be derived by continuously monitoring and analyzing previously determined and prioritized principle capabilities, which are necessary to fulfill future tasks. In a second step, already existing resources and capabilities will be continuously monitored, analyzed and displayed, too. The results identify the current available capabilities (see Figure 2).

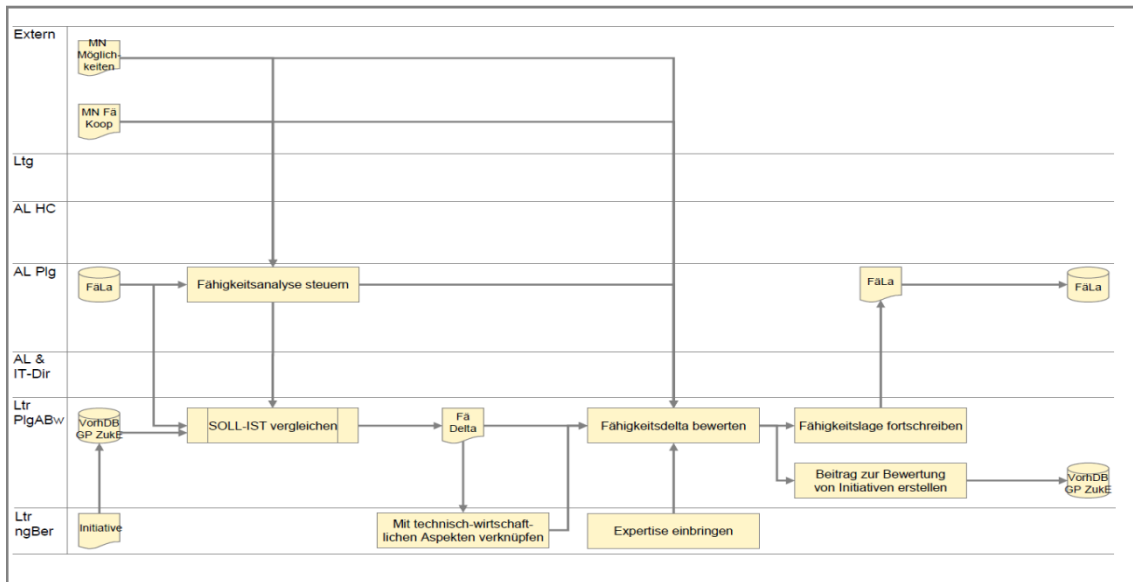


Figure 2. IPP: Conduct analysis of capability (Fähigkeitsanalyse durchführen).

Both results (that is, the recognized needs and the current capabilities) will be pictured through the current capability position that allows an identification of a capability gap and the derivation of a need (see Figure 3).

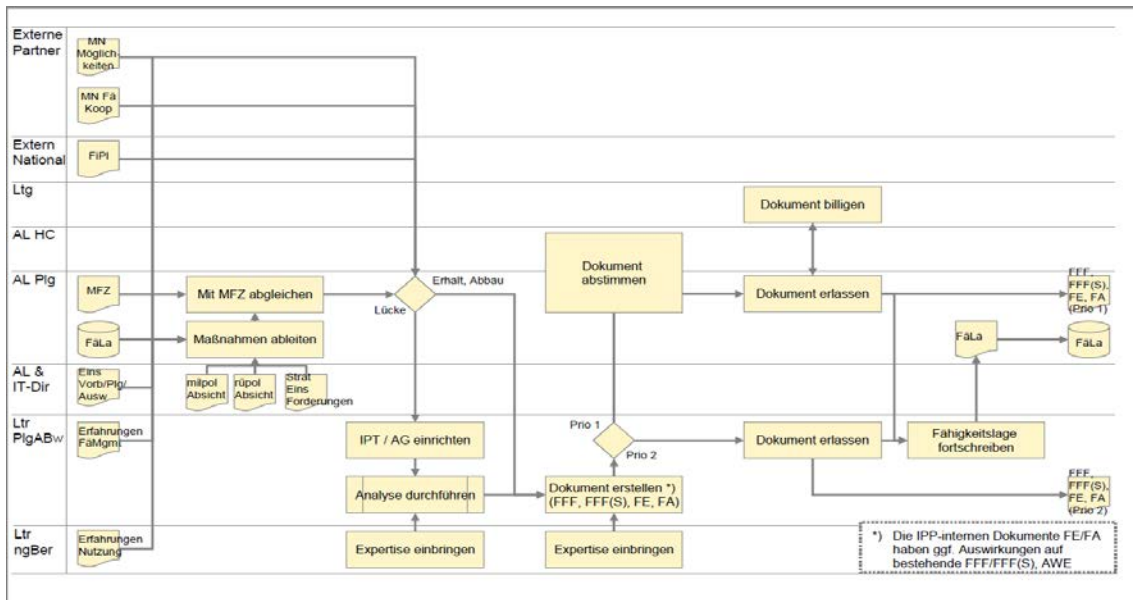


Figure 3. IPP: Adaption of the capability profile (Fähigkeitsprofil anpassen).

The recognized need will be thoroughly analyzed and assessed in respect to its significance. If the capability gap is deemed unacceptable and an appropriate financial framework is available, further steps within the process will be induced and measures initiated to offset the need. When it is possible to satisfy the need with a material solution, then the PlgABw sets up an IPT. The PlgABw has leadership over the IPT and will be supported by personnel resources from other federal offices and all services. The IPT is responsible for drawing up the CPM document, “Fähigkeitslücke und Funktionale Forderung” (FFF, capability gap and functional requirements). This document describes the capability gap and develops functional requirements concerning the need.

When the FFF is approved, the next step within the process is to develop different solutions and to prepare a selection decision of the proposed alternatives (see Figure 4).

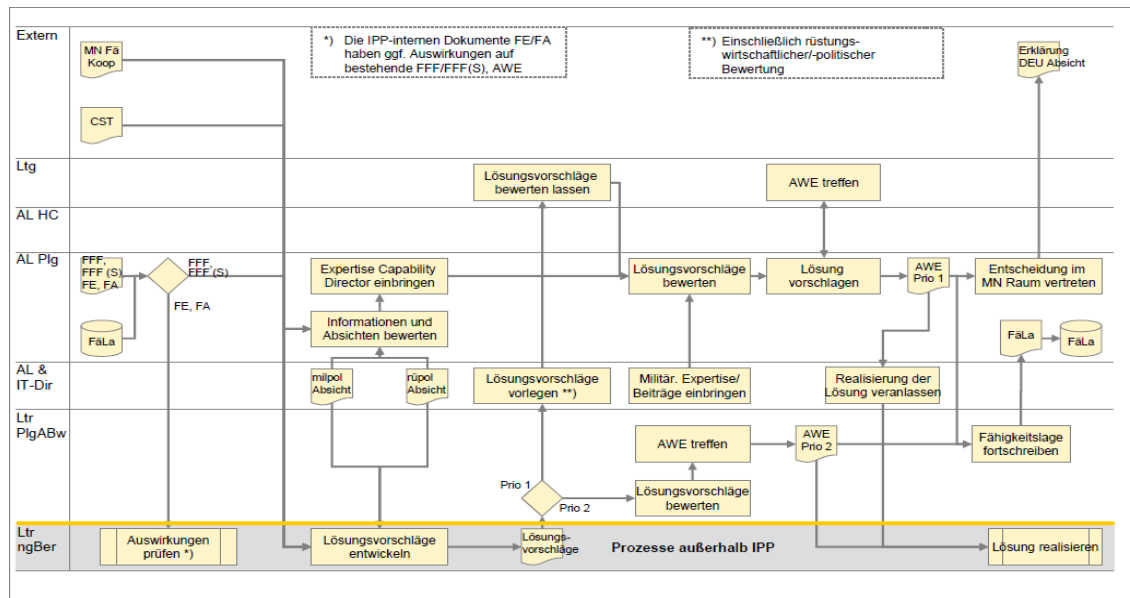


Figure 4. IPP: Prepare selection decision (Auswahlentscheidung vorbereiten).

A level A or B project (projects with superordinate importance, like major weapon systems) will be in principle decided by the Chief of Federal Armed Forces Staff. All other projects will be decided by the PlgABw.

If a decision in favor of one alternative is approved and funded, then the solution will be implemented as a program by the BAABw. A program manager and his IPT are in charge of the program, which must be conducted according the CPM guidelines.

2. The Procurement Processes According to the CPM Guidelines

As an outcome of the transformation the procurement processes and guidelines have been changed. The most important current guideline is called Customer Product Management (CPM), and it regulates the principal steps within an acquisition program, the responsibilities between departments as well as between the forces and the BAAINBw. The Customer Product Management (CPM) is an MoD internal guideline concerning the need-investigation, need-cover, and utilization/in-service support processes of any weapon systems in the German armed forces. As soon as a materiel solution is determined by the PlgABw and approved by the MoD for cases with high priority, the PlgABw conducts the previously described FFF process, which is the first part of the analysis process. After the FFF is approved by the Chief of Federal Armed Forces Staff, the leadership of a program changes from PlgABw to the BAAINBw, which has to develop at least three alternative solutions according to the FFF functional requirements. This is the second part of the analysis process that presents the actual initiation of a procurement program (see Figure 6).

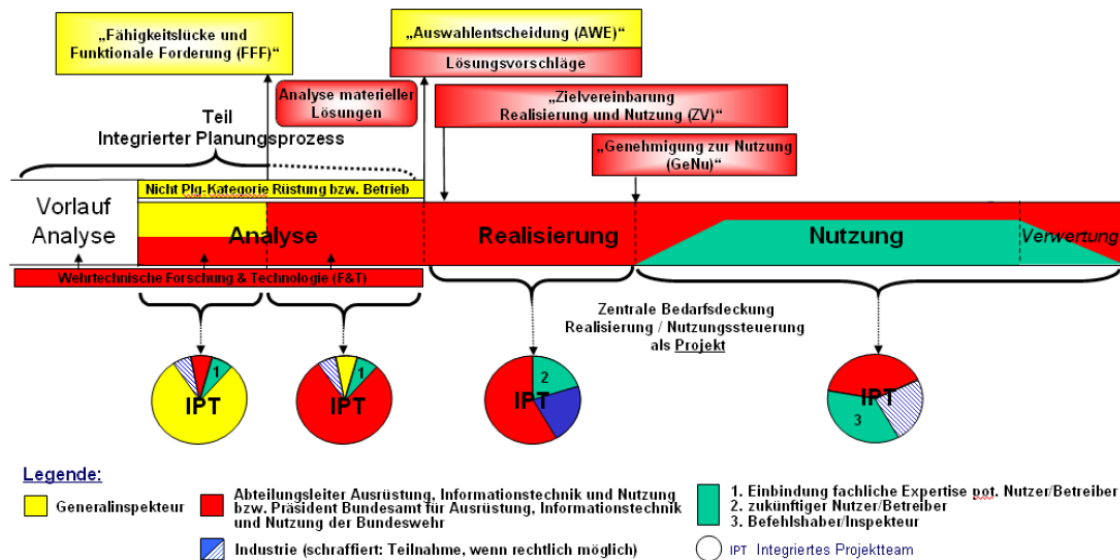


Figure 5. CPM: Schematic order of sequence of a procurement program.

When an alternative solution is eventually selected, approved, and funded by the MoD, the aforementioned IPT is again in charge of implementing the approved solution

and introducing the product. The IPT will also be responsible for all of the product's life-cycle issues. The composition of the IPT will be adjusted during a program as illustrated in Figure 5.

a. *Analysis Phase*

The first part of the analysis phase aims for identification of capability gaps and prioritization of measures to close, reduce or even accept a gap. If a gap has to be closed, then all possibilities to close it will be analyzed and documented. This includes changes in organization, in personnel and training, in infrastructure, as well as in improvements in maintenance and use of matériel solutions. Only matériel solutions are covered by the CPM process. When a matériel solution is requested, then the IPT has to work out an FFF. An incorporation of experience and knowledge is required, with particular consideration concerning:

- deployments
- allies and partners
- operation and maintenance
- products already existing, available or in development (COTS; CGM)
- international procurement cooperation
- results from research and development (R&D)
- results from research papers

The FFF describes the capability gap and the functional requirements. Additionally the following information shall be included:

- designation of the required capability (need)
- extrapolation of the capability from reference documents and a description of capability gap in the system context of the Bundeswehr
- description of the functional requirements and project elements
- information about time-frame and life-cycle costs
- information about amount, duration of usage, and future users /operators
- financial requirements for the analysis phase
- determination if fundamental national interest is concerned

The FFF shall in principle be able to develop solutions that may consider commercial products and components. It shall not anticipate any technical solutions. Only an approved FFF frees funding for R&D for the second part of CPM's analysis phase.

The second part of the analysis phase contains the development of an alternative solutions proposal. The solutions can be differentiated in already available products and services, improvement of "in-service" systems, and development of new products. The IPT, under the direction of the BAAINBw, has to provide at least one solution that meets all the functional requirements as well as other solutions that meet at least the time and cost frame of the FFF.

The following tasks, among others, need to be conducted within this phase:

- perform market surveys and assessments of available products and services
- analyze and assess possible improvement of "in-service" systems, possible national and international cooperation and possible development of new products
- show risks and impact on procurement and operation of a system
- determine amount and life-cycle costs and economic analysis (efficiency)
- predict time frame and financial funding for procurement and operation

- assess effectiveness of the functional requirements with respect to quality and quantity
- plan the procurement and operation phase

Possible solutions are analyzed and assessed against the background of performance, time, costs, and risk. Findings derived from technical assessments of the defense systems of other nations will also be considered. The proposed solutions must contain following information:

- the demand amount
- the quality and quantity of the requirement fulfillment
- the time and cost requirements
- the costs for operations (including personnel, infrastructure, etc.)
- the operating efficiency over the life-cycle
- a defense economic and political assessment
- a risk assessment

The proposal of all alternative solutions will be presented to the Chief of the Federal Armed Forces Staff (CoS) by the MoD Directorate of Equipment, Information Technology and In-Service Support. The CoS decides which solution will be selected and continued as a procurement program.

b. Product Realization Phase

This phase of the CPM is intended to provide a product and/or service that is suitable in time and operational mature. The work processes and activities in this phase describe the principal responsibilities and deliverables concerning the program manager (PM). The CPM relies solely on the professional expertise of the members of his IPT, who must deliver the preliminary work and bear the brunt of the program workload.

When the Zielvereinbarung (ZV, the agreement on objectives) is signed by the MoD and BAaINBw no changes of already agreed upon requirements within the program process are allowed. Exceptions for changes are justified only if new experiences and knowledge derived from deployments or other “disturbances” within the program process arise that lead to an exceeding of predefined parameters. Such conditions would cause an adaption in performance, costs, and schedule.

Another CPM highlighted issue is the Integrierte Nachweisführung (integrated compliance demonstration) during the realization phase. It concerns all the proofs and documents delivered through the contractor, as well as the evaluation of product parameters, operational test and functional limits. The product will be handed over to the designated operational user only when operational testing is successfully conducted according FFF. This task to establish operational viability, capability and readiness is also part of the responsibility of the PM in the BAAINBw. During the proofing procedure any shortcomings will be identified and taken into consideration.

c. Operational Phase/ In-Service Phase

After a successful product delivery, the responsibility to maintain the product's operational viability, capability and readiness still lies with the BAAINBw and the IPT.

The Director of the Federal Office of Bundeswehr Equipment, Information Technology and In-Service Support has “material responsibility for operational viability” over the whole usage/in-service phase until the retirement of the product. Some of the ongoing tasks are product improvement, obsolescence management, operations data analysis concerning maintenance, and software maintenance and improvements. However, the “daily” operational responsibility, like providing spare parts or performing line maintenance, changes over to the services.

d. Summary

The acquisition and procurement phases of the CPM shows a today typical structure and in many respects comparable to the US DoD 5000 series, but gives just a guideline on a top-level. More detailed guidance how to conduct the phases are not available and could be supported by systems engineering methodologies and tools.

III. WHY SYSTEMS ENGINEERING IS CRUCIAL IN MILITARY PROCUREMENT

A. INTRODUCTION

The IPT's composition according to CPM involves mostly the military workforce. Military personnel typically support all acquisition processes within the civil procurement agency at all levels, but its members receive only a three-week education in program management concerning the regulations according to the CPM. Military personnel involved in procurement usually serve in forces command as well as in the logistics and matériel offices. Its members may also have experience as pilots or maintenance personnel. The German service member is not familiar with most well-known practices and tools applicable to project management. As a result, and due to the absence of more detailed acquisition regulations and guidelines, many important acquisition programs were often inefficient or unsuccessful in the past.

Applying knowledge and tools appropriate to military program management can help to avoid getting bad products. The existing tools in program management are not simply derived from one or two research disciplines, rather the tools come from a wide range of research areas of business and engineering. Simulation and modeling, supply-chain management, logistics engineering, decision making, cost-benefit analysis, testing and evaluation, quality management and management soft-skill disciplines are just some of the areas from which the tools are derived. Meanwhile this indispensable and necessary knowledge about the methodologies and tools makes program management in military acquisition very comprehensive and complex work.

Systems engineering is already a proven work process that is well established and widely used in the industry. Systems Engineering Design Processes (SEDP) support understanding a problem before proposing solutions, examining alternative potential solutions and verifying the correctness of proposed solutions. SEDP must also consider the delivery of solutions within the constraints of a project. The INCOSE handbook (Haskins, Forsberg, Krueger 2010) describes systems engineering as follows:

Systems engineering is an interdisciplinary approach and means to enable the realization of successful systems. It focuses on defining customer needs and required functionality early in the development cycle, documenting requirements, then proceeding with design synthesis and system validation while considering the complete problem.

Furthermore the INCOSE handbook states that:

Systems engineering integrates all the disciplines and specialty groups into a team effort forming a structured development process that proceeds from concept to production to operation. Systems engineering considers both the business and the technical needs of all customers with the goal of providing a quality product that meets the users needs.

Systems engineering is a matter of applying fundamental principles, methodologies, and is a certain way of thinking. Therefore, many different systems engineering process models are in use today, as is shown in Figures 15, 16 and 17. Even in these different schemes, several common themes to approaching complex problems can be found. In particular the interdisciplinary character of it and also the many specialty groups involved in the systems engineering process requires a team to form a structured development process that proceeds from concept to production to operation (see Figure 17). It is important to understand that there is not a certain systems engineering process that applies for every project. Thus, the systems engineering process (SEP) is a custom tailored process of methodologies and tools which applies only to a particular project. Today knowledge of systems engineering methodologies is crucial for all personnel in military acquisition programs, and thus it is required in the U.S. Department of Defense (DoD)-5000 series.

Systems engineering needs business, technical and managerial knowledge and skills. A simple way to explain the principle steps within an SEDP is shown Figure 6 (Sage, Armstrong 2000).

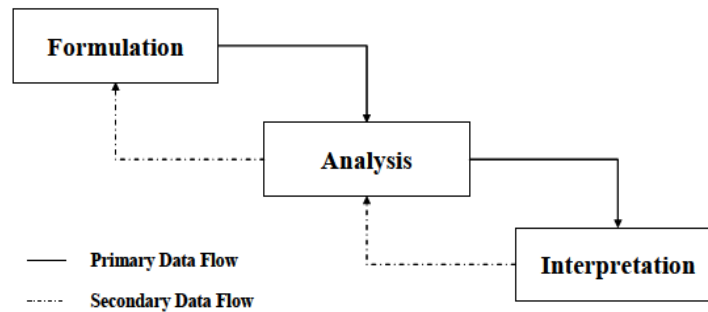


Figure 6. Systems engineering steps according to Sage and Armstrong.

The United States General Accounting Office (GAO 2001) states that systems engineering tools are critical for identifying gaps between the developer's resources and customer's expectations.

Systems engineering is a process that not only translates customer wants into specific capabilities, such as individual technologies and manufacturing processes, but also provides knowledge that enables a developer to identify and resolve gaps before product development begins. It is defined as a logical sequence of activities that transforms a customer want into specific product characteristics and functions and ultimately into a preferred design. It is not necessarily the use of systems engineering in the development of a new product or weapon system, but when it is used that distinguishes it as a best practice.

The systems engineering processes described earlier are shown in Figure 7.

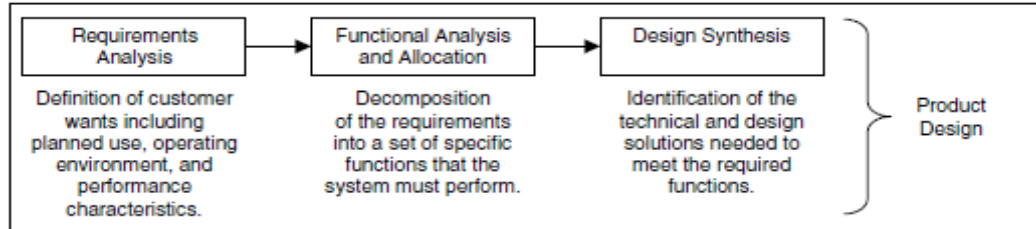


Figure 7. SE process for customer needs analysis according to the GAO report.

The V-model depicted in the DAU PM Tool Kit (Under Secretary of Defense 2009) illustrates the systems engineering processes in relationship to the technical management processes.

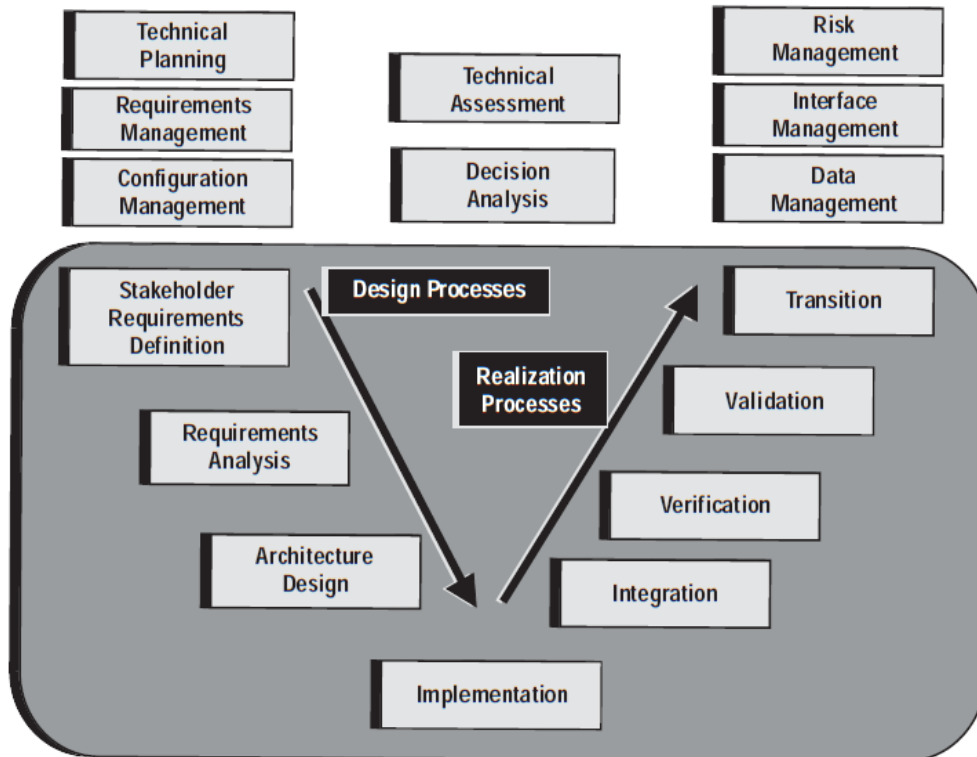


Figure 8. Systems engineering process in relation to technical management processes.

The SEP as shown in Figure 9 (by Professor Eugene Paulo, not published) considers all influences, such as history, culture, ethics, politics, technology, and

economics, within a program. It shows a more general but comprehensive picture of systems engineering.

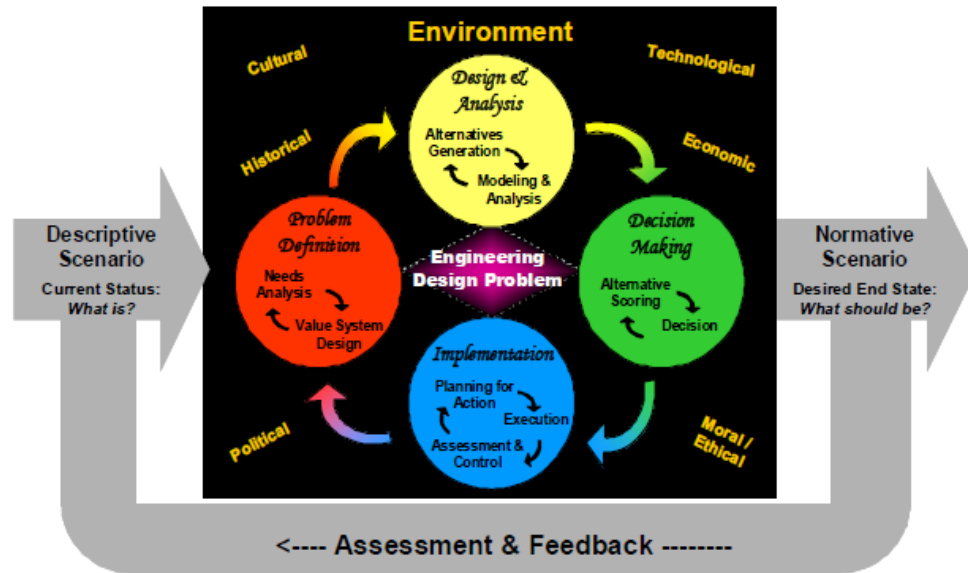


Figure 9. SEP by Systems Engineering Department, NPS.

The DoD *Defense Acquisition Guidebook* (Under Secretary of Defense 2011) summarizes systems engineering in military procurement as a set of overarching processes that a program team applies to develop an operationally effective and suitable system from a stated capability need. The Guidebook concludes that systems engineering processes apply across the acquisition life-cycle (adapted to each phase) and serve as a mechanism for integrating capability needs, design considerations, design constraints, and risk, as well as limitations imposed by technology, budget, and schedule. Thus, systems engineering processes should be applied during concept definition and then continuously throughout the life-cycle. Systems engineering in the U.S. DoD acquisitions stands for the principal way to achieve the best solution without involving military and political rules and regulations.

The defense acquisition guidebook (Under Secretary of Defense 2011) states that:

Balanced system solutions are best achieved by applying established systems engineering processes to the planning, development, and sustainment of a system or a system-of-systems (SoS) acquisition in an Integrated Product and Process Development (IPPD) framework. Systems engineering offers a technical framework to enable sound decision making relative to trade studies, system performance, risk, cost, and schedule. The successful instantiation of proven, disciplined systems engineering processes results in a total system solution that is adaptive to changing technical, production, and operating environments and to the needs of the use and is balanced among the multiple requirements, design considerations, design constraints, and program budgets.

The general validity of systems engineering for a project and its independence from different national regulations and rules makes it also applicable and valuable to the German procurement system.

No series comparable to the “DoD 5000” exists in the German Bundeswehr to regulate and guide civilian and military personnel involved in procurement and acquisition programs, but by applying the systems engineering procedures these personnel can lead a program to success nonetheless.

B. ANALYSIS OF THE GERMAN PROCUREMENT PROCESSES

The organizational structures of the Bundeswehr provide, in general, the possibility for the agencies to work together more closely than in the past. With a new interpretation concerning the separation of responsibilities in procurement from the military tasks given by law, it is now possible to concentrate on technical (often provided by civil servants) and operational experience (provided by military personnel) under one organizational ceiling, the BAAINBw. The German DT&E, conducted by WTDs concerned with contracted specifications and certification, is professional and important. The absence of OT&E agencies, particularly their organizational structures and their experience, in the German forces is a disadvantage in any procurement program and its management. Only an experienced OT&E agency involved early in a program is able to support a PM concerning all operational matters and enable him/her to deliver a mature and operationally useful product on time and within the cost schedule. Consequently, because of this lack of project organization structure the PM has only limited possibilities to form a powerful project team, called the IPT.

Strategic planning, including monitoring, analyzing, and defining capability gaps and needs, is now conducted by the PLABw under the supervision of the MoD, the top military and defense political level of the Bundeswehr and the government, whereas procurement processes are more generally delegated by the Director of the Federal Office of Bundeswehr Equipment, Information Technology and In-Service Support to the BAAINBw.

The new approach of allocating responsibilities and power according to the IPP establishes a more direct and clearer way, and it attempts to involve as few as possible within the process to minimize disturbances and to highlight the positions of responsibility. Additionally, it is recognized and acknowledged that professional expertise within the process steps is crucial and always required. The introduction of variable IPTs particularly emphasizes this consideration. Also, the strengthening of the PM's responsibilities and power in decision making proves that unsuccessful experiences from the past have been taken into account.

The CPM and its segments and processes are, in principle, like processes shown in the U.S. DoD 5000, project management literature, and systems engineering handbooks. Working steps within the CPM are, of course, tailored to Bundeswehr organizational requirements, but compared to the U.S. DoD 5000 or other project management publications, the CPM has a new approach concerning the duration of a program because a program still exists as a program even when it is handed over to the user. The PM and his IPT have to care about many issues, for example, improvement, obsolescence, operations analysis concerning maintenance and software maintenance improvements over the life time of a product. The user cares “only” about operational wear and tear and the maintenance on an operational level. This means the program actually ends when the process of disposal and withdrawal has been finished.

In particular complex weapon systems today undergo a constant improvement, adaption and obsolescence process to keep them up to state-of-the-art conditions. For example, an Apache AH 64A helicopter cannot be considered the same as today’s AH 64D (or soon the E) version. Often before a mature and deployment-readiness level is achieved, the requirements for the next update of a system have already been launched. Therefore, the program’s objective will never really be achieved. The new Bundeswehr approach took that into account. On the other hand, this approach is not in accordance with the aim that the procurement process should be faster and avoid major requirement changes during the procurement process. The idea is to have good performance if not the required performance in time and within the budget framework. One indication of this aspect is the lack of a change management procedure as part of the CPM.

The fundamental procurement and program management processes follow today’s research knowledge and connect or adapt it to the Bundeswehr organizational requirements. Neither of the IPP and CPM document dives deeper into actual work processes nor explains or determines how the requested deliverables can be realized. This thesis shall complement the described processes in that matter.

IV. SYSTEMS ENGINEERING AND THE CPM'S ANALYSIS PHASE: PART 1

A. ANALYSIS PHASE PART 1: FFF PHASE

The CPM depicted in Figure 5 shows the schematic order of sequence of a procurement program. The initial analysis phase shown is conducted by the Planungsamt, which is responsible for the principal capability management in the Bundeswehr. The capabilities management process aims to recognize capability gaps and to derive and define needs of the forces. The Planungsamt has oversight for the current capability position by continuously monitoring and analyzing the current capabilities of the Bundeswehr. When a capability gap is identified, the need is to derive, formulate, analyze and assess it in respect to its significance in respect to the overall capabilities of the German armed forces. When a matériel solution is requested, a tasked IPT has to work out an FFF. The FFF describes the capability gap and the functional requirements.

The following information must be included in the FFF paper:

- Designation of the required capability (need)
- Extrapolation of the capability from reference documents and a description of capability gap in the system context of the Bundeswehr
- Description of the functional requirements and project elements
- Information about time-frame and life-cycle costs
- Information about amount, duration of usage, and future users /operators
- Financial requirements for analysis phase
- Determination if fundamental national interests are concerned

In addition, the following tasks are conducted within this phase.

- Market surveys and assessments of available products and services
- Analysis and assessment of an improvement of “in service”- systems of possible national and international cooperation and the feasibility of developing new products
- Show risks and impact on procurement and operation of a system
- Determine amount and life-cycle costs and economic analysis (efficiency)
- Predict time frame and financial funding for procurement and operation
- Assessment of effectiveness of the functional requirements with respect to quality and quantity
- Planning of procurement and operation phase

The required information and processes delivered in the FFF document can be found and defined by applying systems engineering methodologies and their tools.

B. APPLYING SYSTEMS ENGINEERING

1. Needs Analysis

In systems engineering the CPM's analysis phase is called needs analysis. The most important issue in this phase is to identify and understand the problem and then to derive the need correctly. Usually, in an early stage of the CPM's initial analysis phase, it is very unlikely that a clear picture exists of what exactly these scenarios are and what the gap between them may be. If the early analysis process fails to identify and to understand the problem properly, the future solution might not solve the problem and cover the need. The purpose of this phase in systems engineering is to ensure that the right need and not the "want" is captured, as well as to agree on the problem of where the need is derived from. A systems engineering approach requires a review of the current environment and current system in use. The purpose of this review is to determine the level of the current system's requirement fulfillment in respect to the initial problem statement (primitive need), and through a needs analysis, to develop a revised problem statement (effective need).

Blanchard and Fabrycky (2011) describe the problem definition and need identification as follows:

It is important to commence by first defining the "problem" and then defining the need for a specific system capability that (hopefully is responsive. It is not uncommon to first identify some "perceived" need which, in the end, doesn't really solve the problem at hand. In other words, why is this particular system capability needed? Given the problem definition, anew system requirement is defined along with the priority for introduction, the date when the new system capability is required for customer use, and an estimate of the resources necessary for its acquisition. To ensure a good start, a comprehensive statement of the problem should be presented in specific qualitative and quantitative terms and in enough detail to justify progressing to the next step. It is essential that the process begin by defining a "real" problem and its importance.

Therefore, the first step in the needs analysis is to conduct a background research in respect to the Anti-Submarine Warfare.

2. Anti-Submarine Warfare

a. Introduction

Today the world's economy relies on the free trade and transportation of goods. Accordingly, Admiral Gary Roughhead, General James T. Conway and Admiral Thad W. Allen stated in 2007:

Because the maritime domain—the world's oceans, seas, bays, estuaries, islands, coastal areas, littorals, and the airspace above them—supports 90% of the world's trade, it carries the lifeblood of a global system that links every country on earth.

The current German Defense Policy Guidelines (German Ministry of Defense 2011) address that concern as follows:

Free trade routes and a secure supply of raw materials are crucial for the future of Germany and Europe. Around the globe, changes are taking place in markets, channels of distribution, and the ways in which natural resources are developed, secured and accessed. The scarcity of energy sources and other commodities required for high-technology products will have implications for the international community. Restricted access can trigger conflicts. Disruptions of transport routes and the flow of raw materials and commodities, e.g., by piracy or the sabotage of air transport, pose a threat to security and prosperity. This is why transport and energy security and related issues will play an increasingly important role for our security.

In accordance with the economic importance of the sea and maritime transportation of goods, nations established naval forces to enable a free maritime transport worldwide. Only naval forces are able to ensure and to protect the transport on sea. This is especially true for the leading economic powers, like the U.S., China and many European countries (see Figure 10). Subsequently, their naval forces must have the capability to handle a significant challenge, the growing number of nations operating submarines. Only when it is equipped with the necessary products and knowledge, can the U.S. Navy operate freely at sea (Admiral Roughhead, General Conway, Admiral Allen, 2007):

The ability to operate freely at sea is one of the most important enablers of joint and interagency operations, and sea control requires capabilities in all aspects of the maritime domain, including space and cyberspace. There are many challenges to our ability to exercise sea control, perhaps none as significant as the growing number of nations operating submarines, both advanced diesel-electric and nuclear propelled. We will continue to hone the tactics, training and technologies needed to neutralize this threat.

The threat caused by submarines during World War II and some years later by the submarines of the former UDSSR during the Cold War emphasizes this conclusion in principle. This conclusion is true for the German Navy as a NATO member, too. The following picture shows the known nations which have operational submarines in their forces.

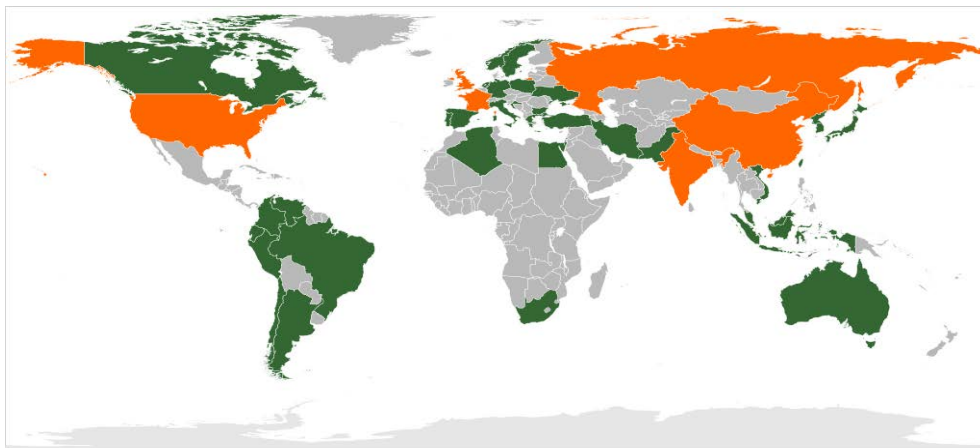


Figure 10. Countries with submarines. Green depicts countries with conventional armed submarines, orange depicts countries with ballistic armed submarines.

The routes for the transport of goods on sea are shown in Figure 11 (Martrans, 2011). Except the routes on the Atlantic Ocean, between Europe and the U.S., many main routes are located close to shorelines and use narrow straits and canals. Especially small submarines with diesel or air-independent-propulsion (AIP) are able to operate in shallow waters (brown waters) to disturb and even stop international sea traffic at these vulnerable routes. Therefore, the capability to protect worldwide maritime shipping from threat by submarines is crucial and a basic requirement for naval forces of these countries. This capability is known as Anti-Submarine-Warfare (ASW).

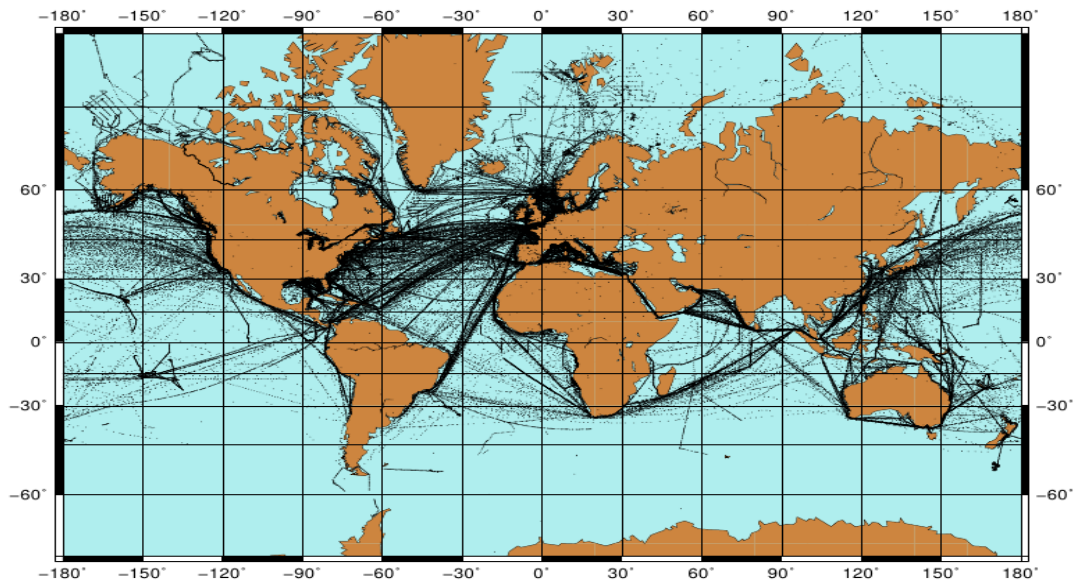


Figure 11. Map of world maritime transportation routes.

b. Definition of ASW

According to “Littoral Undersea Warfare in 2025,” thesis report (2005) ASW means denying the enemy the “effective” use of its submarines and deterring an enemy submarine from its mission, and if needed, destroying it.

To render an enemy submarine “ineffective” requires the ability to detect, track, localize, and destroy. This goal is achievable through a mix of naval platforms such as aircraft, surface ships, friendly submarines, and the application of operational tactics and doctrines. Furthermore the paper states that in the near future, various unmanned vehicles will likely also join this list of platforms to support this warfare.

3. ASW in the German Navy

a. Historical Context

The German Navy has a long and well known history with respect to submarine warfare. In World War I and II German submarines operated very successfully. In particular, during the years 1939 to 1942 German submarines operated in the North and South Atlantic, in the Mediterranean, the Baltic Sea and the North Sea to

disturb the convoys transporting resources and military goods from the U.S. to their European allies. From 1943 until 1945 the use of new ASW tactics in combination with sea and air weapon systems led to the massive loss of German submarines, and these tactics disabled them from operating effectively. The German submarines were then hunted and were no longer able to threaten the allied sea transports seriously (Wikipedia, 2013). However, having the knowledge and experience to operate a submarine very effectively enabled the Bundesmarine (Federal German Navy, founded in 1956) to rebuild and to establish a new the submarine weapon.

The Bundesmarine was designed as a NATO naval force, and their task was to blockade the sea routes into and out of the Baltic Sea, to escort convoys and to protect their routes from the U.S., whereby the North Sea was the main operating area (Sander-Nagashima, 2006). The ASW capabilities of the Bundesmarine were constantly enhanced and included all major weapon systems necessary for conducting ASW comprehensively and effectively. Interactive training and knowledge, exchanged between German and NATO submarines, formed the German Navy's ASW units and personnel to one of the best in the NATO concerning operations in shallow waters.

The following naval weapon systems were used in a well composed and sufficient number to establish an enduring ASW-mission together with other NATO ASW-assets:

- Maritime Patrol Aircraft (MPA)
- ASW helicopters (an organic part of ASW frigates)
- ASW frigates
- submarines
- minesweepers (also used for placing sea-mines)

Since the reunification of Germany and the end of the Cold War the strategic concept and extent of the Bundeswehr has changed several times. The current valid German Defense Guidelines (2011) define the role of the German armed forces in accordance with current and likely future threats. The capabilities will be adapted in respect to the new missions and tasks (German Ministry of Defence, 2011).

The capabilities of the Bundeswehr are derived from its mission and tasks, with the national level of ambition acting as a guideline. A prioritization

within the capability spectrum is based on the likelihood of risks and threats that require a military contribution, on the time needed to provide these capabilities, on an assessment of national interests, and on the availability of funds.

That means that not all necessary capabilities will be available in form of weapon systems.

The variation and number of needed capabilities underlie the likelihood of risk, threat and funding. ASW missions currently are no longer considered as primary capabilities of the German Navy, but the capabilities and the knowledge will be preserved. The principal capabilities to conduct ASW missions are still available. Accordingly, the German Navy's present ASW assets are MPA, ASW helicopters, submarines and the F-123 class frigate (4 units). Except for the helicopters, however, the number of ASW systems has been reduced significantly and does not allow for well composed, interactive and enduring ASW missions due to the reduced numbers.

4. Overview of Current German Navy ASW Assets

a. Subsurface ASW assets

Four type 212 submarines (batch 1) are already in service (Figure12), and two more (batch 2) have been ordered and will enter service in 2015. The submarines are equipped with AIP technology for long-distance submerged passaging to the area of operation and long-term submerged operations in the area of operation. The main tasks are attack and surveillance operations. The submarines have six 533mm tubes for DM2A4 torpedoes (Naval-technology, 2013).



Figure 12. German Navy U 212 Class submarine.

b. Surface ASW assets

The four frigates of the F123 “Brandenburg” class (Figure 13) were designed and built for ASW operations, but this type is also capable of contributing to anti-air defense and enables the tactical command of group forces and surface operations. In respect to ASW operations the F123 type is equipped with a sonar type DSQS-23BZ, Mk 46 (in the future, MU 90) torpedoes, and two “Sea Lynx” Mk 88A helicopters (F123, 2013).



Figure 13. Frigate “Brandenburg” (F 215) F123-class.

The primary role and weaponry of the three frigates of the F124 “Sachsen” class (Figure 14) is Anti-Air warfare (AAW), but this type is also capable of conducting ASW tasks because it is equipped with a sonar type DSQS-24B, Mk 46 (in future, MU 90) torpedoes, and two “Sea Lynx” Mk 88A helicopters (F124, 2013).



Figure 14. Frigate “Sachsen” (F 219) F124 class.

Other German Navy ships in service, such as the EGV702 “Berlin” class supply ships and the K130 “Braunschweig” class corvettes, and ships already in acquisition, such as the new F125 “Baden-Württemberg” class frigates, are not designed and equipped for ASW missions, but they do have a landing deck and a hangar capacity for two helicopters. In contrast, the five K130 corvettes have a helicopter landing deck, but they can only accommodate small unmanned aerial vehicles (UAVs) due to limited hangar size. The planned MKZ 180-type corvette will not be designed for ASW missions primarily, but could be equipped with ASW technology by exchanging modules. These vessels will have a flight deck and hangar for only one helicopter.

c. Aerial ASW assets

The “Sea Lynx” Mk 88 A helicopter (Figure 15) is embarked on the frigates F123 and F124 class and is the mainstay ASW system in the German Navy and is the extended ASW sensor-end weapons of the ships. Accordingly, the helicopter’s sensors and weapons have been tailored to its ASW task. It is equipped with radar, an FLIR turret, an AQS-18(V)-5 dipping sonar system for active and passive detection, and two Mk 46 (in future, MU90) torpedoes (Deutsche Marine, 2013a). Twenty two of these helicopters are currently in service but only 12 ASW kits (dipping sonar) were purchased, and even fewer are available. Usually two “Sea Lynx” helicopters are embarked on a frigate, whereby due to endurance and weight limitations one helicopter is usually equipped with a dipping sonar (called Dipper), and the other carries the torpedoes (called pony) only.



Figure 15. German Navy “Sea Lynx” Mk 88A.

As a replacement for the 22 aging Sea Lynx “Mk 88A and 21 “Sea King Mk 41 (which have no ASW capabilities, and thus are not described here) helicopter fleet, the German Navy plans to procure currently one type only. In all, 18 NHI MH-90 helicopters (Figure 16) will replace the Sea Lynx and Sea King types and take over their duties. This new helicopter needs to be a multi-mission helicopter to fulfill the requirements and capabilities derived from both of the aging helicopter types.



Figure 16. Netherland NFH (equivalent to the German MH-90).

The P-3C “Orion” (Figure 17) is a maritime patrol aircraft (MPA). In 2006 eight used aircraft of this type were purchased from the Netherland’s Navy. This aircraft’s primary mission is ASW and anti- surface warfare (SuW), but it is also capable for tactical command and surveillance missions.

The P-3C is equipped with radar, an MX 20 FLIR system, a MAD-sensor and a sonobuoys dispenser. This MPA can deploy Mk 46 (in future, MU90) torpedoes, water-bombs and sea-mines (Deutsche Marine, 2013b).



Figure 17. German Navy P-3C “Orion.”

5. Analyzing the Threat Caused by Submarines

Conducting a threat analysis is a crucial step within the needs analysis. Only when the threat analysis is comprehensively and thoroughly conducted can that threat be set and compared to the political, military, economic terms and conditions. Much research analysis has been written and published concerning the threat caused by submarines. Conducting a comprehensive threat analysis would be beyond the scope of this thesis because it could easily extend to a thesis itself. Therefore, some of the published sources which address the submarine threat have been used as reference in this thesis. Accordingly, this thesis does not conduct a comprehensive submarine threat analysis. Rather, it gathers the already known results and summarizes this information.

As the current German Defense Policy Guidelines indicate, free trade on the sea is crucial to Germany and Europe. The threat caused by submarines in respect to the freedom of free trade and transport of goods on sea was proved barbarously in the past by the German Navy itself in two world wars. Accordingly, Jane's states, "The protection of sea lines against underwater attack is vital for the safe carriage of imports and exports (food and materials and, during hostilities, reinforcements to support the war effort), as was evidenced during the First and Second World Wars (Watts, 2005).

Table 1 underlines the vulnerability of free trade and transport of oil. In particular the Strait of Hormuz shows the vulnerability due to its significance in respect to the amount of oil flow per day through key world transit points and its proximity to Iran.

Geographic Transit Point	Oil Flow (million barrels/day)	Primary Oil Destination	Significance of Oil Transit Point
Bab el Mandeb	3.3	Europe, United States, & Asia.	Closure would raise transit time and shipping costs.
Bosporous	1.4	Western and Southern Europe.	Difficult to navigate
Panama Canal	0.6	Atlantic & Pacific Transfer Point	Closure would impact shipping costs and transit time.
Strait of Hormuz	14.0	United States & Western Europe	Closure would raise shipping costs if alternative routes were available.
Strait of Malacca	8.2	South Korea, Japan, China & Pacific Rim Nations	Closure would raise shipping costs.
Suez Canal	3.1	Europe & the United States	Alternative route is around south tip of Africa.

Table 1. Oil flow through significant world transit points. From Energy Information Administration.

Jane's counted in the year 2004 that 455 submarines were in use in 44 countries. The proliferation of mostly conventional (diesel-electric and Air Independent Propulsion powered) submarines, called SSKs, enables countries, such as Iran and North Korea, which are currently considered as potential threats, to disturb or even interrupt free trade on the sea and to exert tremendous influence on the world safety and economy.

Jane's asserts that modern submarines are the most powerful weapons in today's navies and that they provide considerable fighting potential. Increasing speeds and fitting of Air Independent Propulsion (AIP) systems in SSKs enhances their capability. Modern submarines, in particular SSKs, are also extremely quiet, and many newly built boats use acoustic cladding to further reduce their signature. Jane's summarizes that the high underwater speed, extended cruising range, powerful weapons (like modern torpedoes and also submerged launchable cruise missiles, and anti-aircraft missiles) and acoustic discretion enable the submarine to take maximum advantage of the underwater environment, and therefore, the submarine is, and will remain, a viable and extremely potent weapon system. It will be available for use in an ever increasing number of roles. Jane's conclude that the potential submarine threat is still alive and real and is becoming ever more elusive for the hunter to detect. Secondly, the threat to the pursuer from these

submarines is becoming severe as submarines deploy a wider range of more sophisticated weaponry and counter-measures. LCDR Jorgensen (U.S. Navy) concluded in his thesis about P-3C capabilities in ASW missions as follows (Jorgensen, 2002).

The submarine has a wide variety of weapons available to use against surface and air platforms. This wide assortment of weaponry makes the submarine an excellent platform for a navy to influence events in a region by using torpedoes, mines, and cruise missiles offensively. Also, the addition of AAW missiles allows a submarine to defend itself close in from ASW aircraft. The ability of a nuclear submarine to remain submerged for long periods of time remains a great challenge to ASW aircraft. Meanwhile, changes in technology have made diesel submarines extremely more challenging for ASW aircraft to prosecute.

The last time submarines played a major role in a war was during the Falklands War between Argentina and Britain in 1982. Commander Karl A. Rader (1994) researched the Falklands War concerning the submarine activities. Only some submarines on both sides caused the fleets to change their strategy significantly or required major efforts to keep their fleet safe from underwater attacks. A successful torpedo attack by the British SSN submarine “HMS Conqueror” on the Argentine’s Navy cruiser “Belgrano” resulted in the loss of the cruiser and hundreds of dead sailors. Yet the British fleet also feared an attack by the Argentine submarines. Accordingly, the British engaged over 20 helicopters and 10 ships just to drive off the “Sun Luis.” Only some defects of the torpedoes and the submarine spared the British from the loss of ships. If these attacks were successful then most likely the British efforts to free the Falklands could have failed, due to the submarine threat only.

Rader (1994) summarized that:

The Argentines lost local sea control due to shortcomings in hardware. Their plan to defeat the British fleet, a combined strike by carrier aircraft, surface ships, and submarines, was sound. Their shortcomings in ASW hardware left them vulnerable to British submarines. This vulnerability had profound physical and moral effects on the Argentine Navy's operational performance. The Royal Navy's successful power projection operation also suffered from hardware shortages. Land and sea based maritime patrol aircraft, and airborne early warning aircraft, were unable to reach the AO. They accepted considerable risk, counting on their

perceived superior skill and the added advantage of operating SSN's. The British ASW effort against a single diesel submarine was a draw—the submarine retired safely without sinking any British ships.

Summarizing the knowledge gained from the referenced sources enables one to derive the major threats caused by submarines:

- Threat to the civil economy by disturbing/stopping sea transport (free trade)
- Threat to military operations on land and sea by disturbing the military sea supply chain
- Threat to military sea operations by denying a ship or fleet entry/stay in the area of operation (AO)
- Threat to military operations on land by land-target attack capabilities (conventional or nuclear missiles)
- Threat to military sea and land operations by supporting covered special operation forces (SOF) operations
- Threat to aerial ASW operations due to SAM capabilities

All these threats have implications on a strategic level. It is clear that many more ships and aerial assets are required to achieve the same threat level of the submarine, and these forces are subject to much greater risks than a submarine. These factors make the submarine a very desirable, efficient and effective weapon with strategic value for a country.

6. Analyzing the Current and Future (Planned) ASW Capabilities of the German Navy in Respect to its ASW Assets

The German navy's war fighting capabilities during the cold war were mainly optimized for ASW. The navy had specialized ASW frigates, submarines, mine warfare (MW/MCM) units and ASW specialized helicopters. This specialization was reasoned in the threat caused by the Soviet submarine threat, and because Germany's navy was tasked to protect NATO's supply routes and vessels to the European war theater in case of war.

After the end of the Cold War, Germany was facing asymmetric terrorist activities, wars caused by the disintegration of states, such as the former Yugoslavia, and by piracy. The threat of submarines disappeared from the strategic picture of politics and the military. Since the end of the Cold War, the ships with ASW capabilities were withdrawn and not replaced in the same numbers. Most mine warfare and mine counter

measure (MW, MCM) vessels were withdrawn without any replacement. Others were reengineered for other tasks. The new F125 frigates and K130 corvettes have no ASW capabilities at all and a future planned corvette (MZK 180) will get some ASW capabilities from ASW modules only, but it is not purely designed for ASW. The German Navy already realized that due to its size the MH90 does not fit into the hangars of the only remaining ASW frigates, the F123, thus these ships will see no embarked flight operations with MH90's. Concerning F124 class frigates, a navy internal study stated that only a significant redesign of its hangars enables these frigates to embark and service at least one, maybe two MH90's, as far as it is technically feasible and affordable. The F124 frigates may lose their helicopters as the main ASW sensor and weapons when the "Sea Lynx" is decommissioned in the next few years.

The new MH90 helicopter is far more capable in all mission areas, particularly in ASW missions. MH90 variants have already proved capable of enduring approximately four hours of flight, including simultaneously carrying a dipping-sonar, sonar buoys, two ASW operator consoles, a data-link system and at least one torpedo. In contrast, the in-service "Sea Lynx" cannot deploy sonar buoys at all, has no data-link capability and can perform only two hours of flight even when carrying no torpedoes, which means it must operate in parallel with another torpedo carrying "Sea Lynx." In direct comparison one MH90 doubles almost the ASW capabilities of two current "Sea Lynx" helicopters through more modern and sophisticated technical equipment and better flight performance. The trade-off concerning the MH90 is that due to its logistic footprint and size this helicopter type cannot be embarked on small ships or on the F123/F124 frigates which have limited hangar size. Controversies concerning that issue are already going on in the German Navy. Some leaders prefer a second, smaller ASW helicopter like the newly developed Augusta-Westland "Wildcat" AW 159 (the successor of the "Sea Lynx"); others prefer a one-helicopter solution, like the multi-mission MH90

The P-3C "Orion" was purchased, and is meanwhile operational, only in a small number of eight as the successor for twenty Breguet-Atlantic 1 MPAs. The P-3C is still a capable ASW asset and able to conduct up to 14-hour missions, but due to its low numbers only two or three units can be deployed at once. The remaining aircraft are

needed for training or are in maintenance. It is nearly impossible with only eight airframes to deploy, to maintain eight aircraft, and train the crews properly in all possible mission areas of the aircraft, especially in the very challenging ASW missions. Today, the aircraft is mainly used for ISR and ASuW missions.

7. Summary

On the one hand the German Navy will keep up all capabilities and knowledge, as it becomes even more flexible for current and future threats like piracy, but on the other hand it has reduced personnel, vessels and aerial assets due to financial constraints and limited funding. There are ASW ships, which cannot accommodate the MH90 ASW helicopter, and that will cause the loss of their main ASW sensor and weapon. On the other hand ships without any ASW capabilities, like the F125, can accommodate ASW helicopters. This dilemma is still unsolved by naval leaders. No decisions have been made yet as to what the future ASW capabilities will look like in the German Navy.

8. Conclusion

An ASW ship and helicopter form an organic team. A typical ASW mission needs all available assets to work together closely and in a well-orchestrated manner to detect or at least to deny a submarine access to a certain mission area. An ASW ship without its helicopter-based main sensor and weapon cannot act effectively in ASW missions. It is dependent on other aerial ASW assets from other ships or land bases.

To emphasize that, U.S. Admiral Morgan (1998) delineates “three fundamental truths about ASW” that are worth mentioning:

- ASW is critically important to our strategy of sea control, power projection, and direct support to land campaigns.
- ASW is a team sport, requiring a complex mosaic of diverse capabilities in a highly variable physical environment. No single ASW platform, system, or weapon will work all the time. We will need a spectrum of undersea, surface, airborne and space based systems to ensure that we maintain...full dimensional protection.
- ASW is hard. The near shore regional/littoral operating environment poses a very challenging ASW problem.

To underline the need for a close relationship between ship and helicopter during the Falklands War, in his monograph, Commander Karl A. Rader (1994) states:

“An aspect of ASW that has not changed since World War I1 is the numerical imbalance between submarines and the assets required to find and destroy them. The British experienced a similar imbalance in the Falklands against a defending submarine. It took the efforts of over 20 helicopters and 10 ships to eventually drive off the ‘San Luis’.”

Only one SSK submarine of the Argentine Navy caused a serious threat to the British expeditionary fleet. The submarine primarily attempted to disturb or destroy the British AAW defense screen by attacking these ships to free the way for air attacks. Due to the remote location of the Falklands, fixed-wing ASW assets were not available. The British expeditionary fleet had to rely on ships and helicopters only to protect the fleet from the imminent submarine threat.

Jane’s (Watts, 2005) states that modern submarines, whether SSN or SSK, pose a formidable threat, and it takes a force of considerable size and a composition of assets to carry out a search to detect, localize, classify, and destroy a hostile submarine. Furthermore, Jane’s presumes that it will become even more difficult to prosecute ASW as more advanced technology enters service aboard submarines.

That is valid particularly for SSK with AIP systems which come close to SSNs in respect to some performance parameters, but SSKs are still smaller and quieter than SSNs. The ship-borne need for aerial ASW assets is crucial and practical in any navy with ASW capabilities today. These ship-borne assets are meanwhile only represented by ASW helicopters. Even on U.S. aircraft carriers aerial ASW is conducted by helicopters only. Once more, Jane’s summarizes that the greatest threat to a submarine is the helicopter, and the helicopter equipped with MAD, radar, EW, sonobuoys, and dipping sonar will force submarines to remain near the seabed, restricting to a degree their freedom of movement. In respect to the already explained necessity of teamwork between ship and helicopters in ASW missions, the strategic planning concerning the German Navy’s ASW capabilities, numbers, and composition of the different vessels and aerial assets seems not to be consistent. The fact that decreasing funding allows for the purchase of only 18 MH90s and even fewer ships complicates German naval efforts to

maintain their ASW capabilities at a level commensurate with the economic importance of sea transport and with NATO's expectations. Due to that shifting of ASW capabilities within the German Navy, the navy will most likely only be able to conduct ASW operations together with other nations or NATO ASW assets.

9. Deriving the Problem Statement and Primitive Need

Fixed-wing assets are needed to have fast and long endurance ASW aerial capabilities when conducting ASW operations, but the Falklands War in 1982 showed these fixed wing assets are not always available when they are land-based only. That problem can be caused by long distances to the area of operation (AO) or also by threats caused by SAM and hostile aircraft when the AO is very close to hostile shorelines, such as the Strait of Hormuz in the Arabian Sea to Iran. Therefore, as already determined, ship-borne ASW helicopters are crucial to any ASW mission and are a requirement for every fleet to defend submarines with the best probability. A coherent ASW capability, like ship-helicopter, will no longer be available for the German Navy. The composition and design of the ships cannot be changed easily and quickly, because it is very expensive, time consuming and would be politically unacceptable. Only a change concerning the aerial assets can fix this problem.

The *problem statement* can be summarized as follows:

The German Navy will have a capability gap concerning the availability of ASW helicopters in respect to the feasibility of embarkations on German ASW capable frigates and future corvette types to participate on ASW missions with an organic, well composed sensors and weaponry.

The *primitive need* can be determined as follows:

The German Navy needs an organic aerial ASW weapon system for their ASW capable ships, which can be embarked on all existing and future German Navy ships, and can operate complementary to other NATO ASW systems.

C. DEVELOPING A CONCEPT

1. Introduction

Defining the problem and deriving the primitive need, as already done before, helps the IPT during the CPM's Analysis Phase to realize the extent of the problem and to recognize the need in principle. Systems engineering is an iterative process, which ensures that the problem and the need will be redefined when other information sources, like stakeholder and constraints, have been analyzed before any procurement requirements will be defined and written. That process allows for an understanding of the entire problem and the refinement of the need from a primitive need to an *effective need*. There is, of course, not just one way to accomplish this. Many approaches exist and can be applied. It cannot be expected that the IPT applies systems engineering processes in the depth and quality as true systems engineers in a company would do. This process should be considered a very helpful step in discovering and realizing an accurate and comprehensive picture of the problem. As a result, it allows for an accurate derivation of need and potential solution for that problem.

Figure 18 was developed by a group of SE students. It effectively illustrates the iteration processes between the information sources and analyses, particularly within the concept development phase.

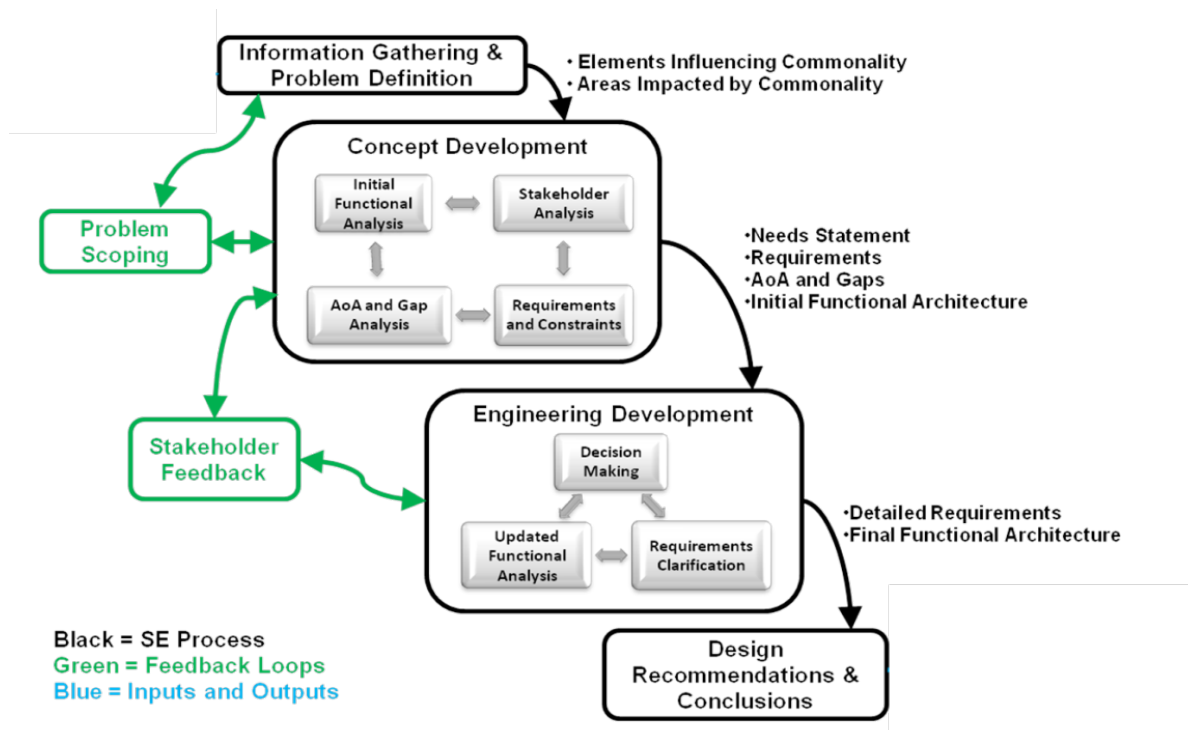


Figure 18. SE process developed and illustrated by students in NPS SE class in 2012

In their Capstone Project (MSSE Capstone Project, 2008) another group of students produced Figure 19, which illustrates the process of transforming a primitive needs statement into an effective needs statement.

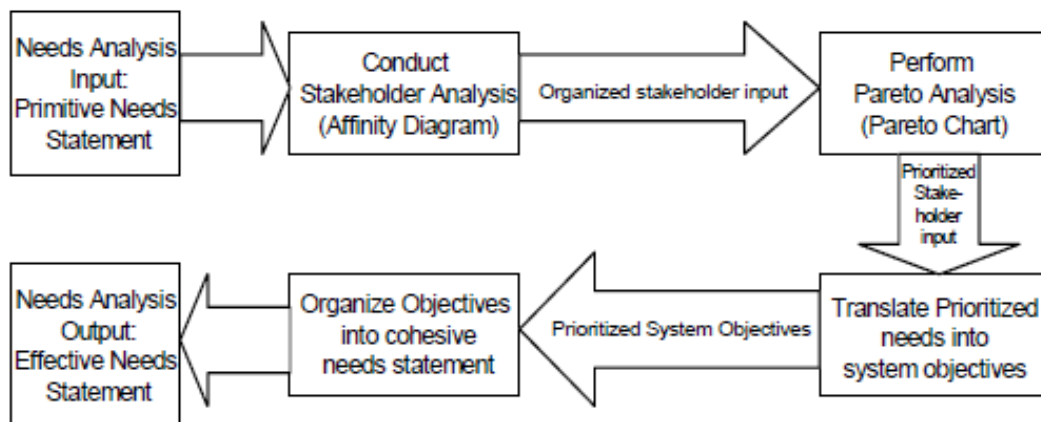


Figure 19. Needs analysis process [MSSE Capstone Project].

The next appropriate step is the identification and analysis of stakeholders concerned with the German ASW problem. Only when the stakeholders have been

analyzed can the boundaries be defined more easily, too. INCOSE (Haskins, Forsberg, Krueger, 2010) recommends identifying users and other stakeholders. To understand their needs, INCOSE also recommends gathering customers' (stakeholders') inputs on needs, wants, constraints, and critical environment. An NPS thesis technical report (Thesis report, NPS-97-06-001, 2005) concluded that by identifying the stakeholders it is easier to find the right persons to determine the requirements, scope and boundaries of the problem. Furthermore, it allows stakeholders to be involved in the entire process of definition, development, and deployment of the solution.

The stakeholder analysis has several steps that should include:

- Identifying stakeholders
- Identifying stakeholders' needs
- Conducting interviews with stakeholders
- Consolidating information

The V-model from the Tool Kit (Under Secretary of Defense (AT&L), 2009) depicts the systems engineering steps which should be conducted to determine the right knowledge and information for the FFF document.

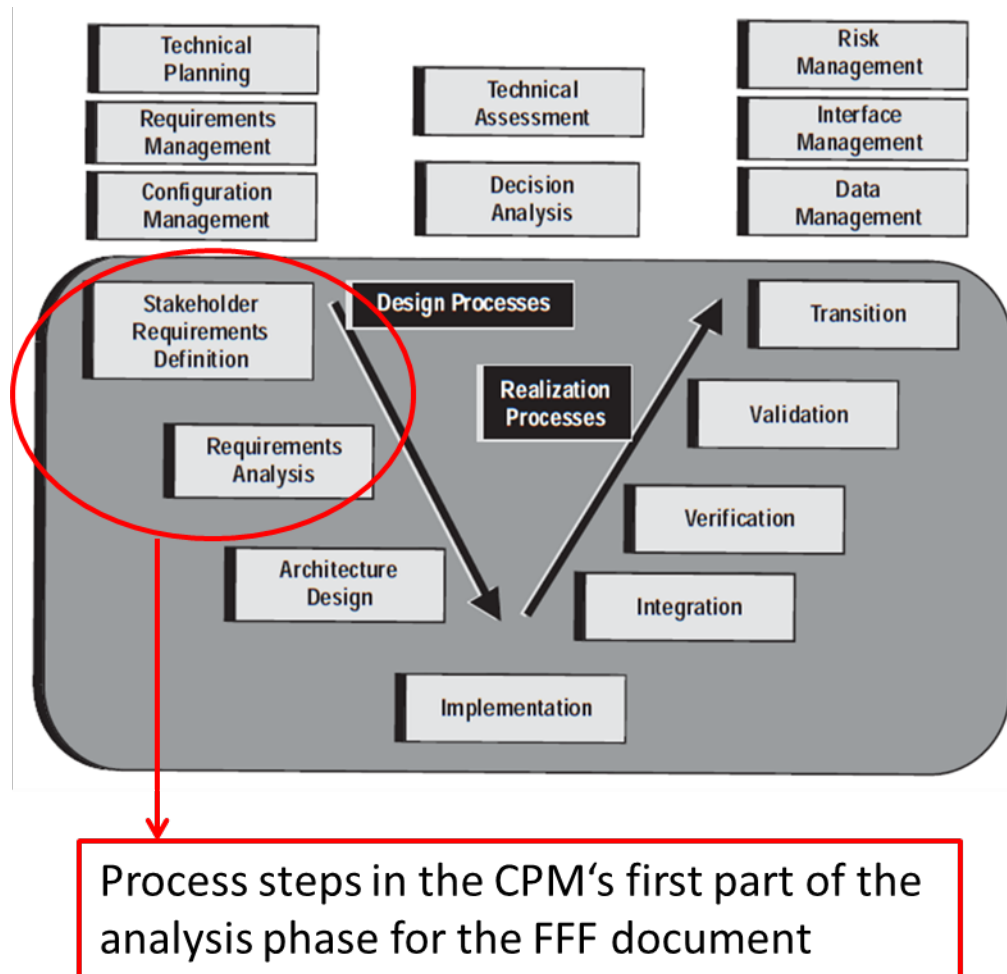


Figure 20. Systems engineering process-technical management processes in respect to first part of the analysis phase.

2. Stakeholders and Their Needs

a. Introduction

A stakeholder's analysis requires a thorough review and analysis of relevant stakeholders and their requirements and needs. The analysis should follow a careful review of the problem to identify and understand the root-source of the problem. A thorough understanding of the problem and a comprehensive *statement of the problem* would have already been presented to clarify a stakeholder's primitive needs. Combined with this statement later, conducting a stakeholder analysis makes it possible to distinguish "needs" from "wants" (Blanchard, Fabrycky, 2011).

The ISO/IEC 15288 (2008) explains the purpose for a stakeholder requirement definition process as follows:

The purpose of the Stakeholder Requirements Definition Process is to define the requirements for a system that can provide the services needed by users and other stakeholders in a defined environment. It identifies stakeholders, or stakeholder classes, involved with the system throughout its life-cycle, and their needs, expectations, and desires. It analyzes and transforms these into a common set of stakeholder requirements that express the intended interaction the system will have with its operational environment and that are the reference against which each resulting operational service is validated.

INCOSE (Haskins, Forsberg, Krueger, 2010) describes this comprehensive process as the stakeholder requirement definition process in which a stakeholder is an individual or organization with a legitimate interest in the system. Therefore, typical stakeholders include users, operators, organizations, decision makers, parties to an agreement, regulatory bodies, development, agencies, support organizations, and society-at-large. Furthermore, INCOSE states that the stakeholder requirements are an essential factor in defining or clarifying the scope of a project. During the stakeholder requirements definition process (Figure 20), it is less important to be concerned about laws, regulations, directives, standards (Controls). This can be determined in a later step during the boundaries definition process. In this case, the concern should be focused yet on “Inputs” and “Enablers” on a basic level. Some requirements of certain stakeholders are usually more important than others.

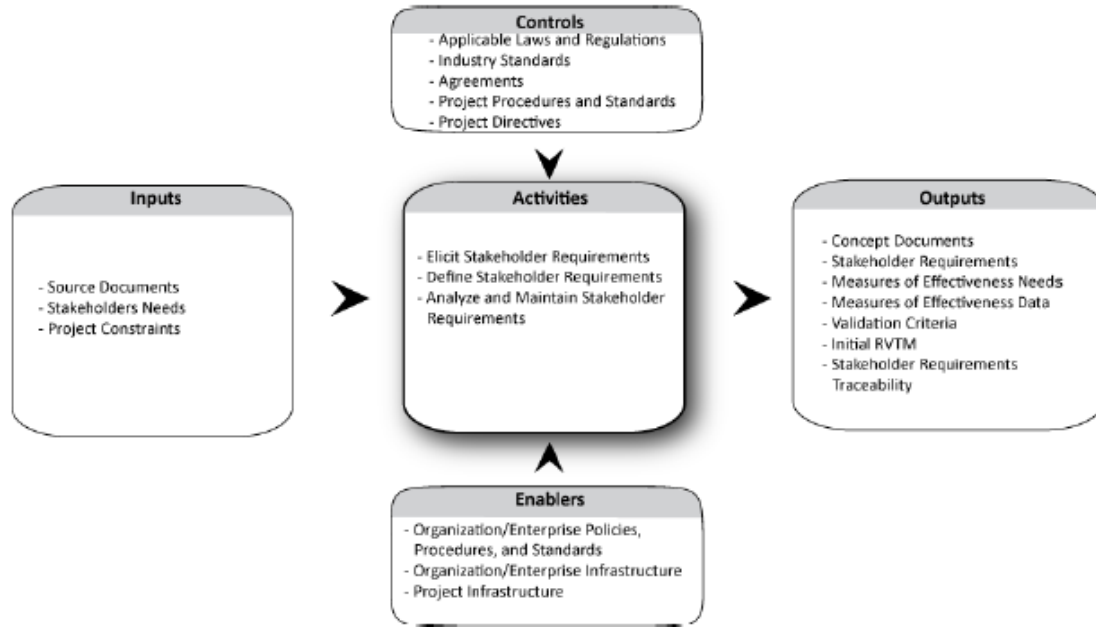


Figure 21. Context diagram of Stakeholder Requirements Definition Process. From INCOSE.

Accordingly, a stakeholder analysis should present the stakeholder with the most important requirements. Stakeholders can be categorized based on anticipated interaction with the system.

- User/Direct Contact (those stakeholders who directly interact with a system)
- Adjacent Systems (those stakeholders who operate adjacent systems or equipment that is anticipated to interact with the “needed” system)
- Requirements/decision makers (those stakeholders who possess decision making authority over a procurement program)
- Sponsors (those stakeholders who have to pay for the need)
- Acquisition/decision makers (those stakeholders who exercise decision making authority over the needed systems life-cycle)

The top-level stakeholders in a procurement process can be allocated according to categorization (Table 2). The stakeholder in each category can be broken down to lower levels to gain a more detailed stakeholder analysis, but that would exceed the scope of this thesis.

User/Direct Contact	System operators; system logistic personnel; German forces generally, foreign military forces (NATO, other allies)
Adjacent Systems Support	German armed and allied forces, ASW community (other assets, like ships helicopters and aircraft; intelligence community (sonar data); submarine community; naval forces community; aviation community, hostile forces
Requirements/Decision Maker	German government, German parliament, MoD,
Sponsor	Taxpayers
Acquisition/Decision Maker	MoD; BAAINBw, German Navy

Table 2. Stakeholder categories.

b. Stakeholder Needs Analysis

System Operators. The system operators are German military personnel who operate the ASW asset. They will be responsible for flying, detection, identification, tracking, and engaging the threat with the needed ASW system. They are the priority stakeholders since they will be positioned “at the tip of the spear” and are responsible for operating the ASW system. Operational success/failure of the system depends utmost on the system’s performance in conjunction with operator’s performance. The system operators’ needs include adequate training for operating the system, simplicity in system design to ensure it is user-friendly, availability, reliability, and the adequate performance to enable the operators to fulfill their task. The operators’ success or failure on a mission, as well as their own lives, may depend on the system’s performance.

Systems Logistics. The systems logisticians are German military system maintainers and supply personnel, civil employees, and civil contractor personnel who are responsible for life-cycle maintenance of the ASW system. Their responsibility is to ensure the weapon system is operational and available when needed by conducting routine and depot level maintenance, as well as ordering and tracking spare parts and ammunition. They are also priority stakeholders because without needed availability the

best systems have got no value to operators. Needs for these stakeholders are the level maintainability, like accessibility and reparability, adequate tools and diagnostics, supply support, appropriate training on system maintenance, technical manuals, databases, IT systems capable of tracking maintenance action and supply support.

German and Allied ASW Community. These stakeholders are personnel coming from other ASW assets, such as ASW frigates, helicopters and MPA, from the German forces, and also from NATO/allied forces. These personnel are secondary stakeholders and are also responsible for operating, flying, detecting, identifying, tracking, and engaging the threat with their existing ASW system. They are concerned that the new system can be integrated into existing systems and networks (that is, ships, aircraft, satellite command and control) in order to provide a common operational situational picture for all participants and to operate as a coherent ASW community within the theater of operation.

Intelligence Community. The intelligence community is composed of military and civilian personnel who are responsible for collecting, analyzing, and communicating existing and potential threats to Germany and its allies. In particular, information about current and future submarine developments and the impact on the threat level must be incorporated into the design and development of the new ASW system accordingly. Furthermore, sonar-data are needed to feed the system to enable the system to detect and identify submarines.

German and Allied Military Forces. The German military forces, in particular the Navy, interact with the system, and at least all German armed forces' services are primary beneficiaries of the system and, therefore, are stakeholders. The ASW system's operational goal is to protect naval vessels from submarines. Naval vessels transport forces personnel and materiel for the Navy, Army, and Air Force to the theater of operation. These vessels also protect German and allied forces on land and in the air by denying enemy forces entry into the operational theater from sea or air (ASuW and AAW operations). The ASW system stands to gain or lose strategic, operational, and even tactical advantage of German forces based on the ability of the system to deny and eliminate submarine threats on friendly forces.

The German forces primarily need an adequate ASW system that is capable of contributing significantly to an overall ASW effort. For example within a NATO fleet, it is necessary to address the performance and availability of such systems to protect German and allied naval vessels from submarine threats. These needs also include affordability and adaptability. The German forces must be able to purchase the system within current funding constraints, to tailor the system to the environment and facilities, as well as to integrate and operate the system along with other existing systems of the German armed forces and NATO forces

Allied Governments. Allied governments refer primarily to NATO members and also countries which may either purchase or use this ASW system. These stakeholders benefit from lower cost, interoperability, shared training and supply. NATO members whose governments do not purchase the system benefit from the capability improvement within NATO and save money for other assets.

Enemy forces. Hostile forces lose the advantage of their submarines operating freely and disturbing or even to denying sea forces access to their operational area. They also lose their ability to act as freely as mission and task demand. In short, hostile submarines lose their effectiveness.

Procurement Community. The acquisition community is composed of civilian and military personnel from the BAAINBw and also the members of the IPT. These stakeholders will need a viable acquisition strategy and plan that supports the entire weapon system life-cycle, an affordable system in respect to funding, and an available technology that can be incorporated into the needed ASW system according to the schedule, requirements and any other constraints. These stakeholders need funding, personnel, and information to deliver a product that fulfills the requirements in order of their importance to all stakeholders.

Taxpayers. Ultimately, these stakeholders “foot the bill” and have to pay for a new ASW system. Germany’s economy highly depends on exports and imports, so the taxpayers are interested in open and free trade of goods on the sea. German citizens and their economy primarily need an effective and efficient system at an affordable cost

that is capable of neutralizing a submarine threat to protect the economy's sea routes for a free trade of the exported goods and imported commodities.

German Parliament. These stakeholders are composed of elected officials who represent the interests of Germany's population and economy. On the one hand they have to ensure appropriate funding to establish forces to protect the country and national interests, but they must do so without exacting high taxes. The parliament also has an interest in maintaining effective and efficient forces, as well as to return some of the spent funding to German taxpayers by buying equipment in Germany.

Therefore, their needs include life-cycle affordability that protects the German population, economy, military personnel, facilities, and interests; while neutralizing threats to the German and the global economy (through free trade on sea). At the same time, they must not lose focus on the interests of the German defense industry. The power of controlling money and the influence to the MOD make the parliament and their needs, of course, a primary stakeholder.

German Defense Industry. The defense industry is composed of the various companies that will compete for a contract to manufacture a system or at least components of a system. Their needs include increasing contract incentives to maximize profit, reducing production costs, as well as reducing schedule and performance risks to gain maximum profit. These stakeholders are concerned that the system fits the German forces' needs, but also the needs of foreign forces to gain further contracts.

Table 3 summarizes these various stakeholders and their associated needs.

Stakeholder	Gain	Lose	Needs
System operators	Successful defense of submarines, protection of own forces	Successful enemy attack, loss of operation or own forces	- Availability - Effectiveness - Survivability - Interoperability - Meet performance criteria - Network capability - Training - Design simplicity
System logistics	Can “deliver” availability as requested, means successful maintenance service, save time and money	Cannot “deliver” requested availability of the system for operational use, need more personnel, higher efforts, and funding	- Maintainability (design attributes) - Logistics/supply support - Training - Integrated maintenance Database
ASW community (German & allies)	Increased overall ASW capabilities	Decrease overall ASW capabilities	- Interoperability - Network capability - Availability - Effectiveness
Intelligence community	More sonar data gathered and available		- More capability to handle sonar data - Interoperability - Network capability - Effective database management system to collect, analyze, and disseminate threat information
Own military forces (German & allies)	- Force protection - Freedom of operation - Strategic, operational, tactical advantage	- Loss of vessels - Loss of freedom of operation friendly force activity - Strategic, operational, tactical disadvantage	- Availability - Effectiveness - Efficiency - Survivability - Interoperability - Meet performance criteria - Network capability - Training - Design simplicity - Maintainability (design attributes) - Logistics/supply support - Integrated maintenance database
Allied governments	- Can fill own gaps - They do not cover the gap/need within NATO - Strategic, operational, tactical advantage - Easy availability of a new system - Share training - Share supply - Save money	- Need to fill gaps within NATO themselves - Cannot share training and supply - Need to develop a similar system	- Affordability - Can be purchased
Hostile forces	- Freedom of operation - Strategic, operational, tactical advantage	- Lose freedom of operation - Strategic, operational, tactical disadvantage	- Anti ASW capabilities - Survivability of submarines - More submarines
Procurement community	- Can deliver a successful system - Save funding - Deliver in time	- Cannot deliver a successful system - Need more funding - Cannot deliver in time	- Funding - Personnel - Political support - Information - Know-how exchange
Taxpayers	- Get an equivalent value for tax money - Protect peoples interests - Protect und support economy	- Get not an equivalent value for tax money - Cannot protect peoples interests - Cannot protect und support economy	- Effectiveness - Efficiency - Equivalent value
German Parliament	- Economic impacts - Protecting own and NATO interests - Safe and free trade - Political implications (positive in nature NATO)	- Financial obligation(s) - Political implications; potential fallout from an ineffective a system	- Affordability - Trouble free program - Overall system effectiveness - Political acceptance
German Defense Industry	- Profit - Intellectual capital - Improved reputation - Growth	- High risk could result in financial loss - Possibly divert resources from another ongoing program	- Defined requirements - Systems engineering plan - Increased contract incentives - Reduced cost, schedule, and performance risk

Table 3. Stakeholders’ analysis overview.

Table 4 shows many stakeholders exist and have divergent interests and needs, but they also share common ones concerning the project. That overview supports the next step, which is to rank the needs in respect to their importance and influence concerning the requirements of the ASW system, and then to derive the requirements from the needs.

Many programs have failed or were cancelled due to lack of support by the population and government. The taxpayer finances and the government funds a program only as long as the need for a new system is widely recognized in public and the political arena. That is true in particular for huge and expensive programs; accordingly, the needs of the taxpayer and government will be placed here as one of the most important.

The needs of the German armed forces are ranked second because it is more important that a system works effectively and efficiently within the composition of all assets. Military systems usually work together in a very complex way. Therefore, mission success depends on the overall effectiveness of all systems combined. The needed ASW system should be well balanced concerning the requirements to fit best into the existing and future weapon systems composition of the German armed forces. Embedded within the German Navy the system will perform as optimally as possible and will, whenever possible, be available. The operator's and logistical needs should be considered next. Their needs are important because they define a lot of requirements and influence the design of the system. Adjacent systems, such as other ASW systems and assets, need complete interoperability to work closely in a well-orchestrated manner with the new ASW system. The same is valid for the intelligence community. The procurement community is most likely at the bottom of the "need" food chain, but nevertheless, they are important to conduct a program successfully.

Table 4 shows the ranking and the most important common needs of the different stakeholders.

Stakeholder	Needs	Common Needs
Taxpayer, Government	• Effectiveness • Efficiency • Equivalent value • Affordability • Trouble free program • Overall system effectiveness • Political acceptance	• Effectiveness • Efficiency • Affordability • Survivability • Interoperability • Meet performance criteria • Network capability • Training • Design simplicity • Maintainability • Logistics/supply • Integrated maintenance database • Funding • Personnel • Effective database management
German armed forces	• Availability • Effectiveness • Efficiency • Survivability • Interoperability • Meet performance criteria • Network capability • Training • Design simplicity • Maintainability (design attributes) • Logistics/supply support • Integrated maintenance database	
System operator	• Availability • Effectiveness • Survivability • Interoperability • Meet performance criteria • Network capability • Training • Design simplicity	
System Logistics	• Maintainability (design attributes) • Logistics/supply support • Training • Integrated maintenance Database	
ASW community (German & allies)	• Interoperability • Network capability • Availability • Effectiveness	
Procurement community	• Funding • Personnel • Political support • Information • Know-how exchange	
Intelligence community	• More capability to handle sonar data • Interoperability • Network capability • Effective database management system to collect, analyze, and disseminate threat information	

Table 4. Stakeholder ranking and common needs.

At this point it is necessary to gain additional and detailed information about the stakeholders' needs and interests. So far, the thesis researched and covered only information from references, such as books and reports. To understand the true needs for a system the stakeholder should be asked in order to get detailed information about each stakeholder's needs. Elicitation is one good way to get answers, but good questions should be defined first. According to Miller (Class 2012, NPS), elicitation is not only a process of collection, but rather an acknowledgment that unspoken needs and considerations exist.

Elicitation is used to:

- Assess project and solution feasibility
- Identify organizational biases
- Define the user's operational environment
- Identify domain constraints limiting functionality and performance
- Create usage scenarios to facilitate thorough analysis

The clarifying questions should be:

- Who are the users and how do they intend to use the product?
- What are the reasons behind the system needed?
- Why is the system being developed?
- What are the user's expectations?
- How will the user measure the performance of the system?
- What functions will the system perform, expressed in "user's language?"
- Users can be system operators, maintainers, supplier, and also adjacent systems operators, who should be considered as well.

Naval Postgraduate School students applied the technique of elicitation in their MSSE Capstone Project (NPS-SE-08-002, 2008). After identifying the major stakeholders, the students developed a questionnaire "in order to establish a standard set of interview elements for each stakeholder." The students conducted an interview with relevant stakeholders to gather the needs, wants and desires of the stakeholders. The result of their work was presented in a table with affinity categories derived for ASW system "detection" and "doctrine" as shown in Figure 22.

Affinity Results (sample)

Affinity Category		Original Needs Elements	
Goal/Constraint	Count	Interpreted Need	Count
Detection	15	The system should provide high Pd and Low Pfa with tactical significance	11
		The system should maximize search rate	3
		The system should maximize kill rate	1
Doctrine-Constraints	19	The system should avoid force-on-force engagements	8
		The system must secure friendly maneuver area: Sea Shield/Base/Strike	4
		The system should minimize the Fog of War	1
		The system should optimize command structure to support Joint ASW execution	1
		The system needs to accommodate non-ASW tasking of assets	1
		The system should be offensive vice defensive	4

Figure 22. Affinity results (Sample) of the MSSE Capstone Project.

The students conducted a Pareto Analysis presented in a chart (Figure 22) to prioritize the stakeholders' inputs. The students explain that activity as follows.

The Pareto chart is designed to utilize the data, not perception, to separate the few critical problems or issues from a multitude of possible problems or issues by graphically arranging the data according to frequency of occurrence. The stakeholder analysis generated 207 individual stakeholder inputs – clearly a multitude of data elements. The individual inputs were subsequently categorized into 67 interpreted results and the occurrences of stakeholder inputs assigned to each interpreted result were tallied. The interpreted need results shown in Figure 9 were sorted and plotted according to which results have the highest occurrences of stakeholder inputs. The interpreted results that contain the top 20% of the total number of stakeholder inputs were identified as the critical stakeholder needs.

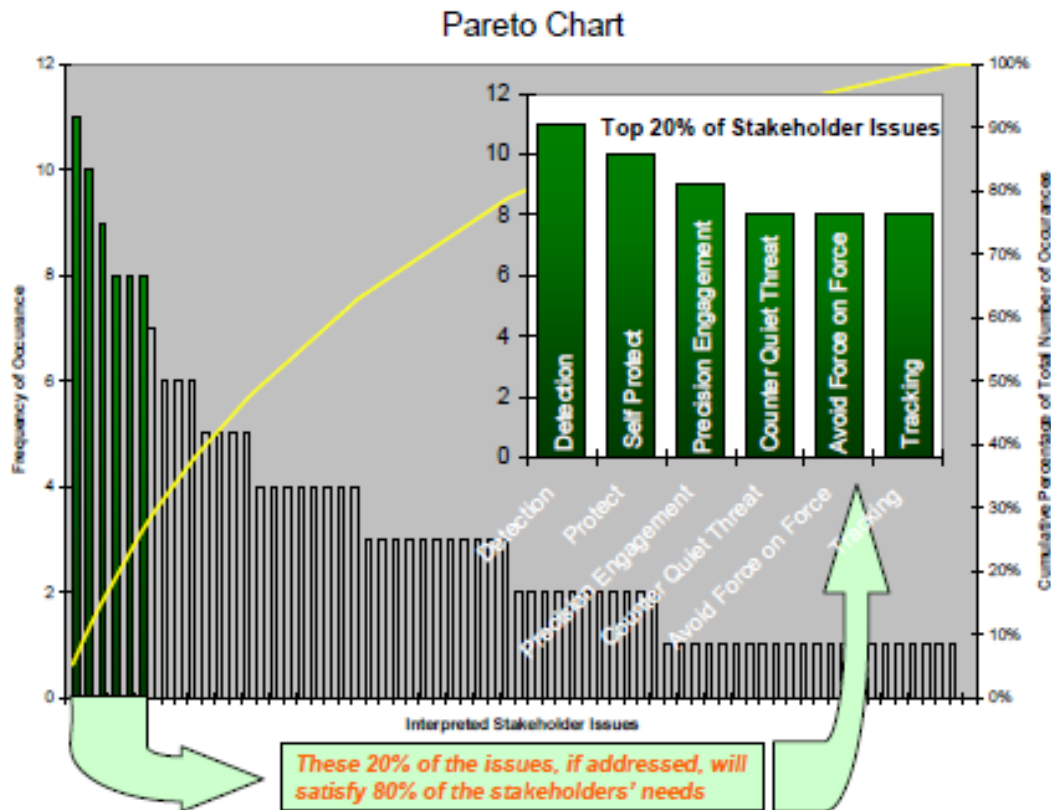


Figure 23. Pareto chart [From MSSE Capstone Project, 2008].

3. Boundaries of the Needed System

a. Introduction

Buede (2011) explains in his book that a system is a set of entities that interacts with the system via the system's external interfaces. External systems can impact the system, and the system can impact the external systems. Buede (2011) also states that a system's inputs may flow from these external systems or from the context, but all of the system's outputs flow to these external systems. On the other hand, the context of a system is a set of entities that can impact the system but cannot be impacted by the system (Figure 24).

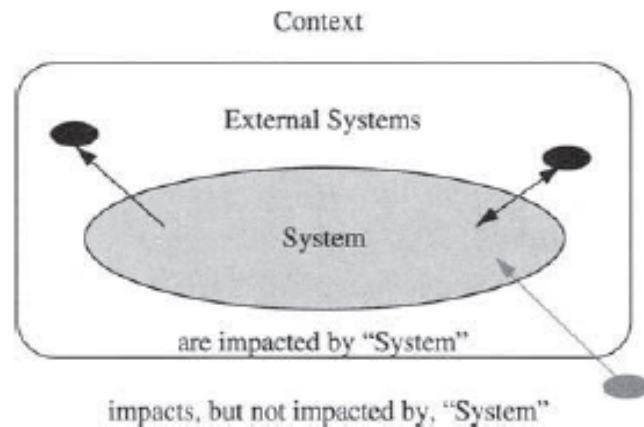


Figure 24. External and Internal System Relationship [Buede, 2011].

That principal rule means that the needed system will be influenced (impacted) from outside, and external systems themselves may be impacted by the needed system. The degree to which these external systems are impacted is determined by the system's boundaries. Even from outside the boundaries, the system can still experience inputs. These boundaries must be defined.

Buede (2011) states concerning boundaries:

The single, largest issue in defining a new system is where to draw the system's boundaries. Everything within the boundaries of the system is open to change, subject to the requirements, and nothing outside of the boundaries can be changed, leading to many of the system's constraint requirements. The external systems diagram is the model of the interaction of the system with other (external) systems in the relevant contexts, thus providing a definition of the system's boundary in terms of the system's inputs and outputs. Who is responsible for drawing these boundaries? All of the stakeholders have a say in drawing these boundaries.

It can be summarized that a system exists only within its boundaries, and therefore, the boundaries need to be defined. A first step to define the boundaries is to define the problem, which has been discussed already in the previous chapter. Another source which helps to define the boundaries is the information received from the stakeholder elicitation. Some other sources include laws, regulations, directives, standards, agreements, funding and many more. Additionally, an operational concept that defines the operational boundaries in which a system will work and an "Input-Output

Model” are appropriate tools and information sources for research on a system’s boundaries.

b. Identifying Rules and Non-Technical Constraints

Rules and constraints are an important part of any system boundary. Rules are usually laws, regulations, directives and standards. Research on these rules is also research on stakeholders, which should be added into the list of already determined stakeholders. The funding for a new system is the most important constraint. Funding for a new system requiring more than 25 million Euros must be approved by the parliament. That approval process involves many different stakeholders at the top level in the MoD, MoF, (Bundesministerium für Finanzen, Federal Ministry of Finance) and Defense Committee.

Accordingly, the key players involved in the funding issue should be identified. Germany is an important NATO member, and many agreements have been signed concerning military and procurement cooperation. The needed system has to conform to the terms of these agreements; thus, the applicable NATO or bilateral agreements must be identified. Again, that would add one more new stakeholder to the list. Laws and regulations concerning procurement and acquisition must be sifted. Additionally, responsibilities within the MoD and also within other governmental departments, such as the Bundesministerium für Finanzen (Ministry of Finance) or the Bundesamt für Sicherheit in der Informationstechnik (Federal Office for Safety in Information Technology) must be identified, and pertinent laws must be listed. A major constraint comes from the Navy ships on which the system shall be embarked. Finally, these examples show that merely identifying rules and non-technical constraints is a huge effort. The IPT must perform these tasks thoroughly to understand other stakeholders’ interests and needs in order to define the system’s boundaries.

c. Identifying Technical Constraints

According to the primitive need statement determined in Chapter I, the needed system will be an aerial system. For aerial systems, in particular, many technical rules must be taken into consideration to get an airworthiness certification. Certification

is required because these systems fly in national and international air spaces, which are controlled by civil and military air traffic controllers. Therefore, all aviation standards and regulations from national and international agencies, such as the U.S. Federal Aviation Administration (FAA) and the European Aviation Safety Agency (EASA), related to the needed system must be determined and applied. Today, laws and regulations related to environmental protection and safety are always a concern in any military and civil project, and these regulations must also be taken into consideration. A system will not get a certification for use when current minimum regulations and standards in respect to that matter are not implemented.

Another crucial technical (physical) constraint that must be defined is derived from the naval ships which will accommodate the system. As already stated, it is most unlikely that the ships will undergo a major and expensive design change. Thus the system must fit into the current physical environment (that is, the landing deck and hangar). The needed system must also interoperate with other technical equipment on these vessels. The ship with the most challenging physical scale in respect to size, weight and interoperability should be selected to define and derive these boundaries, because it is usually much easier to integrate a system in a ship when enough physical reserves are available for small adaptations.

d. Operational Concept

A major effort that helps to understand the “Need” and to define its boundaries is to develop an operational concept in respect to the problem. According to the ASW capability problem, a concept concerning ASW in the Germany Navy and NATO is advisable. The IPT will usually consist of specialists and experts with some experience in ASW. Nevertheless, the existing NATO and German Navy doctrines and also the user (ASW community) can deliver an attuned operational concept based on their experience from conducting ASW missions. Consequently, the ASW experts (users) from NATO and, in particular, the German Navy are in charge to deliver a coordinated and applicable basic operational concept to enable the IPT to understand the extension and scope of ASW operations. Researching and developing an operational concept is out of

the scope of a procurement-embedded IPT due to its limitation in knowledge and personnel strength. The IPT should be in charge to gather information and to transform these findings into a “Need” only. To enable the IPT for that task, the concerned stakeholders’ operational concept should contain viable information and descriptions (requirements) in respect to the expectations of the system’s performance and environment.

The basic operational concept should at least contain statements about:

- Mission definition
- Performance and physical parameters
- Operational deployment or distribution
- Effectiveness factors
- Operational life-cycle
- Utilization requirements
- Environmental factors
- Peer systems

e. Input-Output Model and External System Diagram

The Input-output Model is a valuable tool to help determine the scope of the problem and the boundaries of the “need.” A system consists of many different components. A system’s boundary determines whether a component or subsystem belongs to a system. Systems are always connected to their environment, and this environment separates the system from it. The connection to the environment outside the boundaries is established through the inputs and outputs to and from the system. Therefore, an Input and Output Model helps to define the boundaries and to analyze the inputs and outputs. In their MSSE Capstone Project (NPS-SE-08-002, 2008] the students illustrated the controlled and uncontrolled input into a needed ASW system (Figure 25). The parallelism of the capstone project in 2008 and the “Need” in this thesis are close enough that this model is applicable in the German case, too.

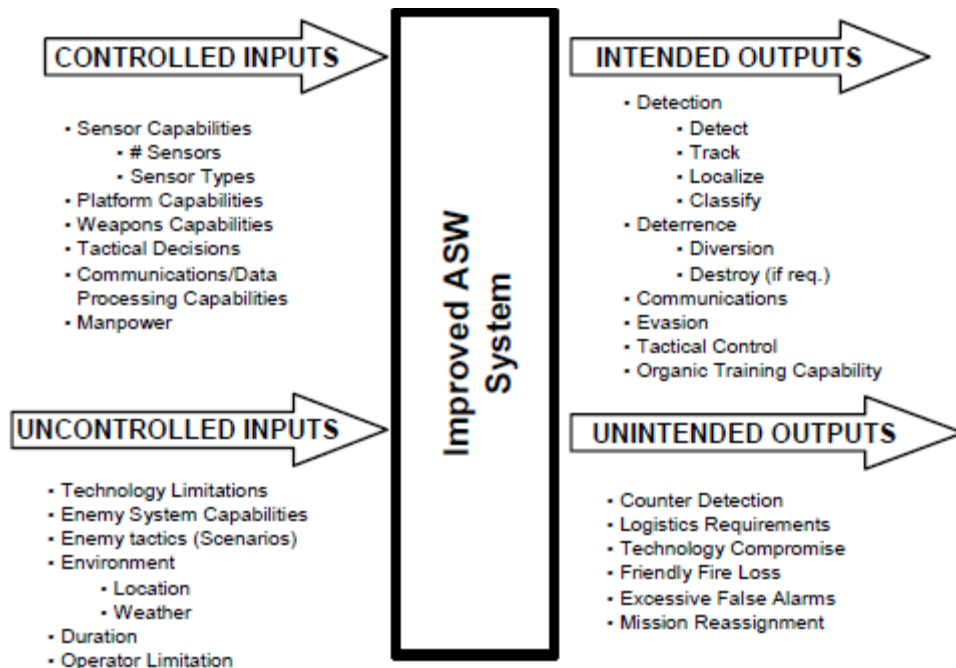


Figure 25. Input-Output Model.

An external system diagram delivers at least the same results, but helps with interfaces and more defined boundaries to illustrate the relationships of systems collaborating with the needed system. Figure 26 shows a generic model of an external system diagram that puts the system into its environment and depicts the needed system's relationship with other systems.

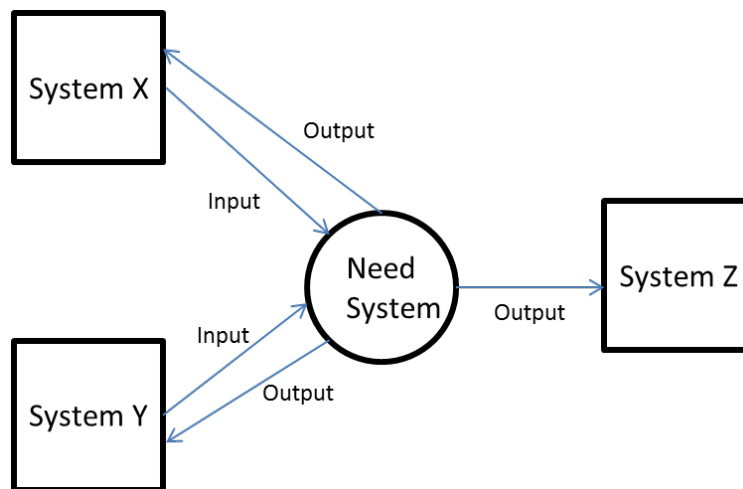


Figure 26. Generic context model.

The already collected and known information from background analysis, stakeholder needs and the operational concept should make it possible to explain the relationship of collaborating systems outside the boundaries as illustrated Figure 27.

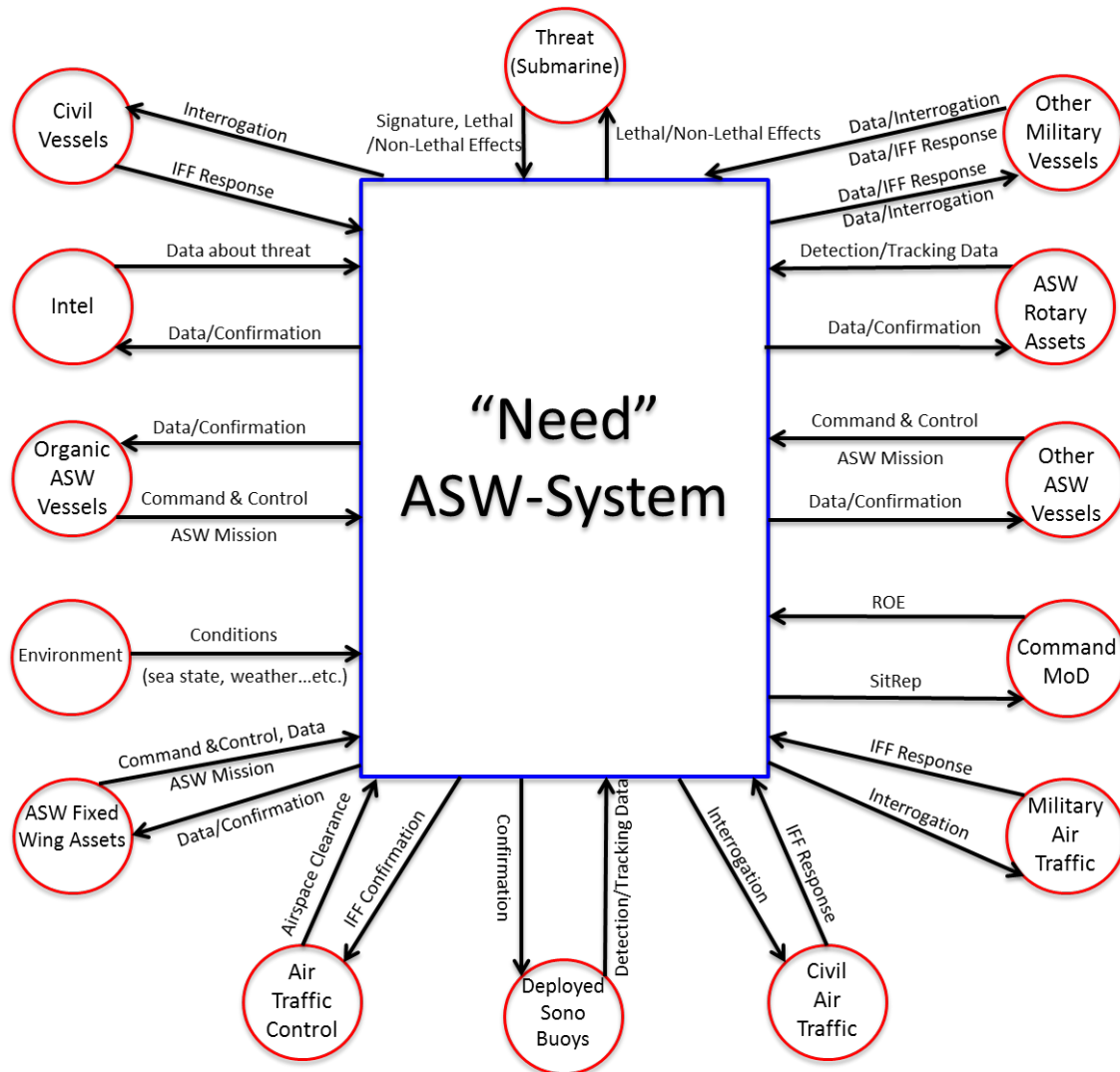


Figure 27. "Need" ASW system context diagram.

The context diagram helps us to understand and classify inputs, outputs, and relationships of the system and helps to define its boundaries, but the diagram also helps us to detect failures in thinking and incorrect assumptions made during the previous steps.

So far, it has been assumed and stated that the primitive need is about an organic aerial ASW weapon system for ASW-capable ships. This system can be embarked on all existing and future German Navy ships and must interoperate with other NATO ASW systems. That might imply that the system is an independent system which works only closely with other ASW units, as the current ASW helicopters do. The illustration of the context diagram (Figure 28) incorporates some other valuable information already available, as well as some ideas about the relationships between the ASW units and, in particular, with the related carrying vessel. The diagram allows for the assessment of the relationships and boundaries as a “system of systems.” In particular, the network between today’s assets and the already described absolute need that ASW work as “one unit” to be successful emphasizes this thought. The following context diagram depicts these new thoughts and relationships between the ASW units and sets the boundaries differently.

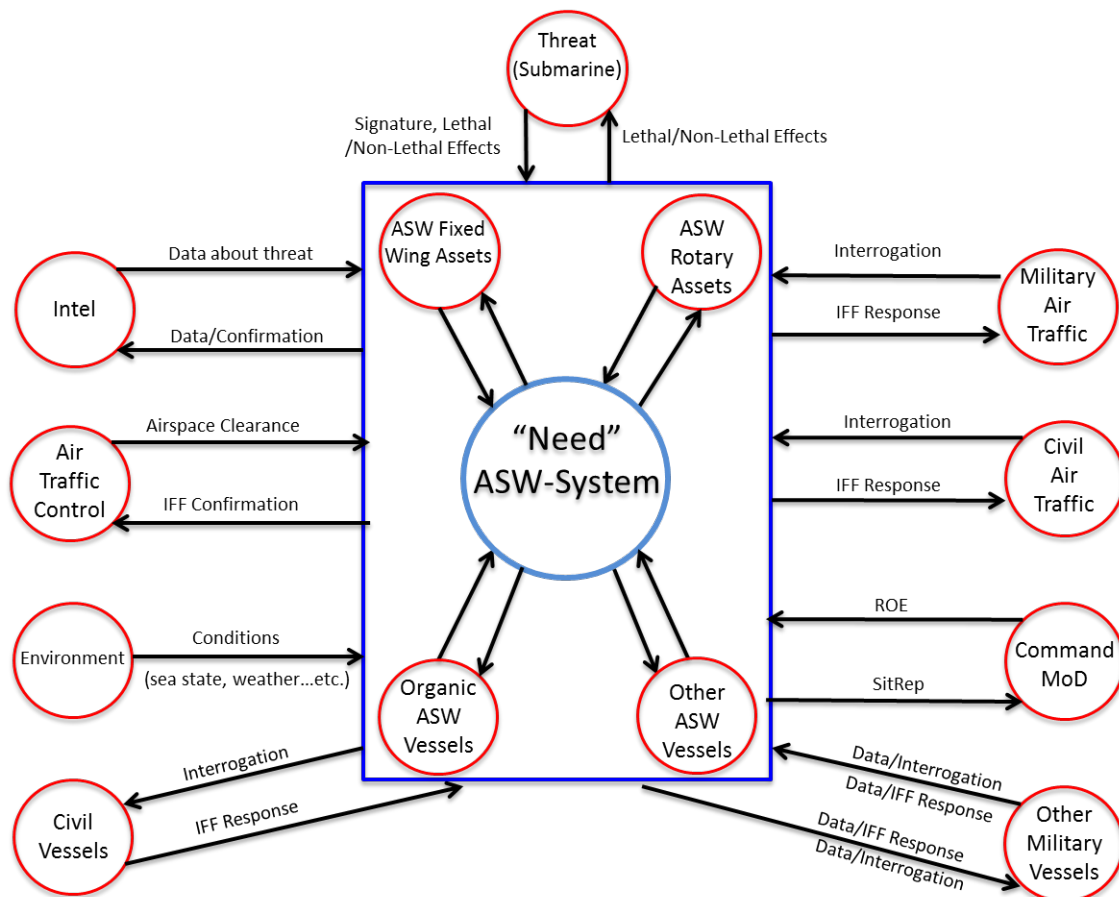


Figure 28. Redefined “Need” ASW system context diagram.

4. Functional Analysis

a. Introduction

The purpose of a Functional Analysis is to determine at a high level what the system must do to fill a gap in defense. That process happens through presenting the analysis in an organized, articulate, and meaningful way.

Blanchard and Fabrycky (2011) describe this process as follows:

An essential activity in early conceptual and preliminary design is the development of a functional description of the system to serve as a basis for identification of the resources necessary for the system to accomplish its mission. A function refers to a specific or discrete action (or series of actions) that is necessary to achieve a given objective, that is, an operation that the system must perform, or a maintenance action that is necessary to restore a faulty system to operational use. Such actions may ultimately be accomplished through the use of equipment, software, people, facilities, data, or various combinations thereof. However, at this point in the life cycle, the objective is to specify the whats and not the hows; that is what needs to be accomplished versus how it is to be done.

Functional decomposition is a fundamental tool in systems engineering. It identifies most broad functions, uses verbs and verb phrases, decomposes functions into sub-functions, and it is about thinking functions, not components or solutions. The functional decomposition, in conjunction with different diagrams and charts provided here, help to round out our understanding of the principal functions of the systems and to redefine the Need statement to an effective need. Furthermore, functional decomposition is also very useful for defining the requirements for the system in the next step of the systems engineering process.

b. Hierarchical Structure and Components

The hierarchical structure helps to identify the stakeholders involved within the boundaries, to define the systems involved concerning the “System of Systems,” and also to identify involved stakeholders outside the boundaries of a system on a high level. Additionally, this diagram depicts the components involved within the hierarchical structure. Only systems in current use have been taken into consideration. Future developments might extend the structure. The hierarchical structure shown in

Figure 29 is related to the command structure of military operations. Technically, the single components are often capable of communicating and transferring data between each other, but the different warfare operations and their “System of Systems,” for example, ASW, AAW, and ASuW, need a hierarchical command structure to orchestrate the units within the warfare operation to achieve the mission goal. Therefore, communication and data exchange between different warfare scenarios must be conducted according to the hierarchy level as illustrated in Figure 29.

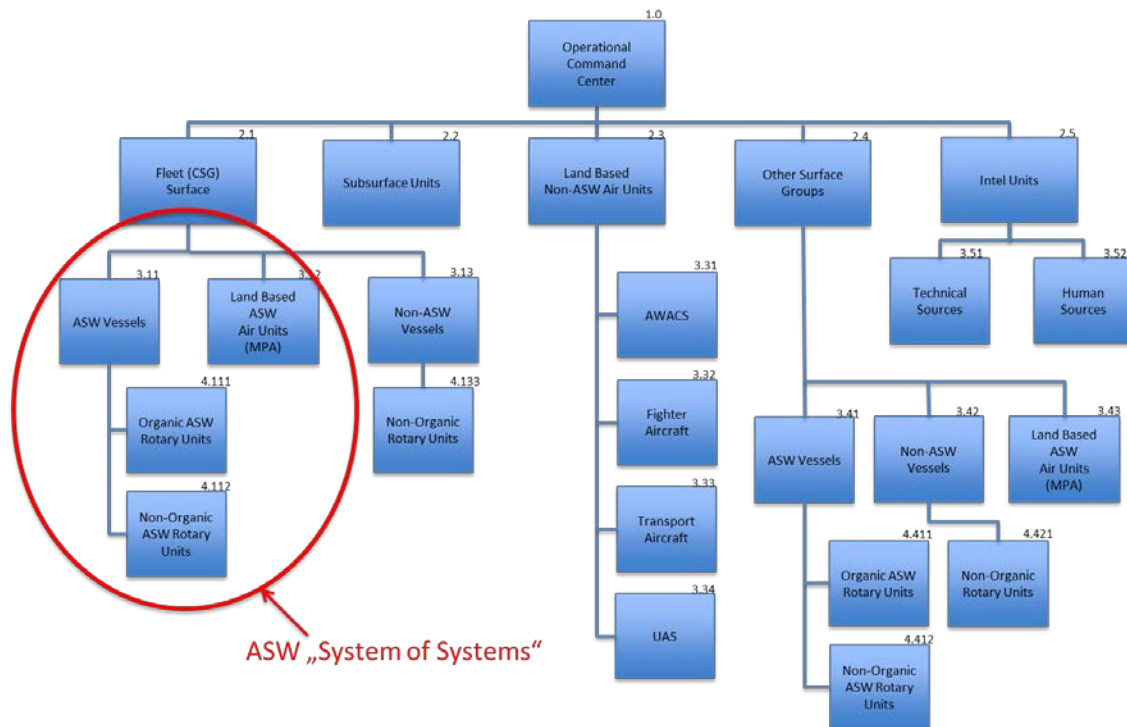


Figure 29. Hierarchical structure and components, including “System of Systems.”

c. Component Breakdown

The component breakdown (Figure 30) illustrates the basic equipment of ASW vessels and aircraft regarding their sensors and weapons. In respect to the German Navy, the surface components are the F123, F124, and MZK 180, and the air components are the P-3C and the MK 88A and MH90 helicopters. The ASW component breakdown applies also for other NATO surface and air units.

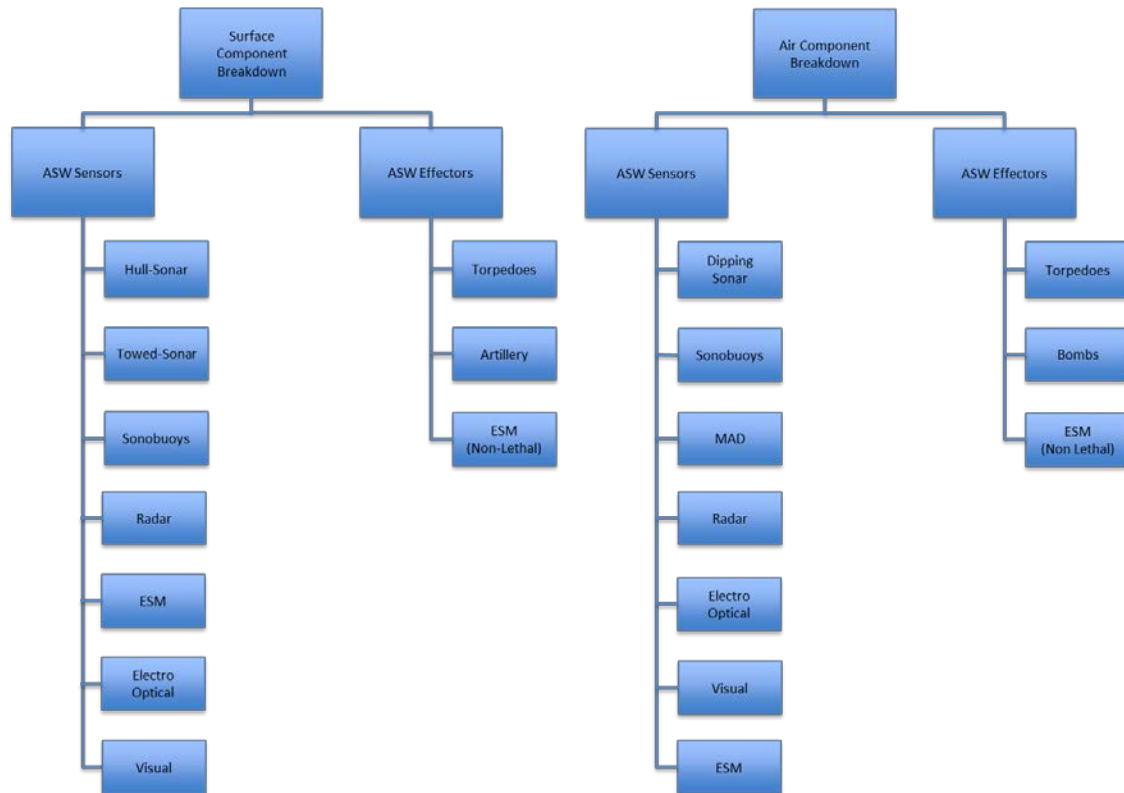


Figure 30. ASW component breakdown.

d. Functional Flow Block Diagram

Figures 31, 32, and 33 depict the functions of an ASW system using a high level approach, and they also apply to the Need.

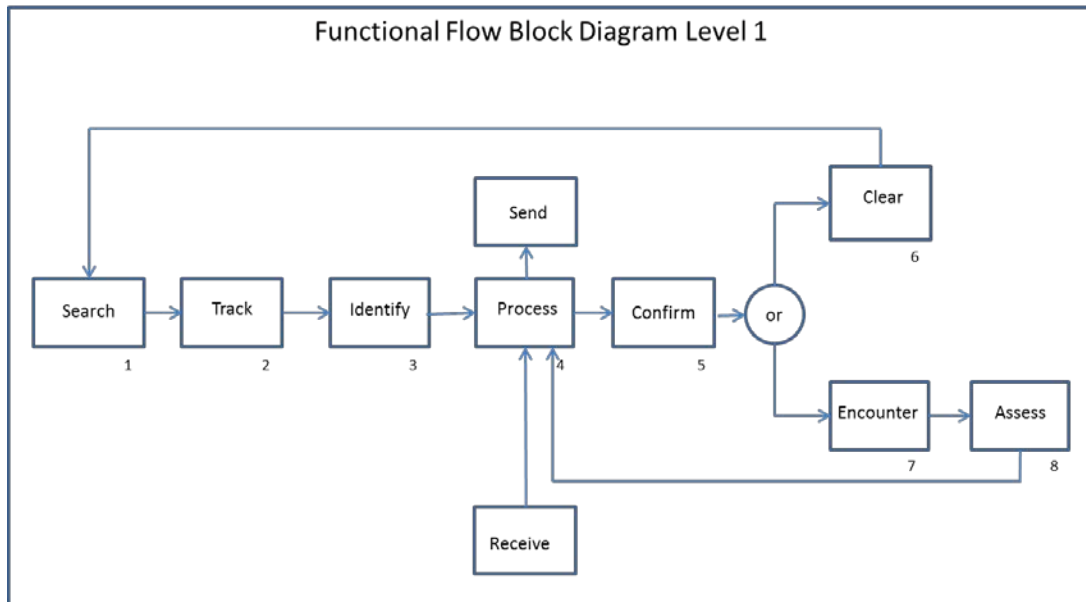


Figure 31. “Need” ASW system functional flow block diagram Level 1.

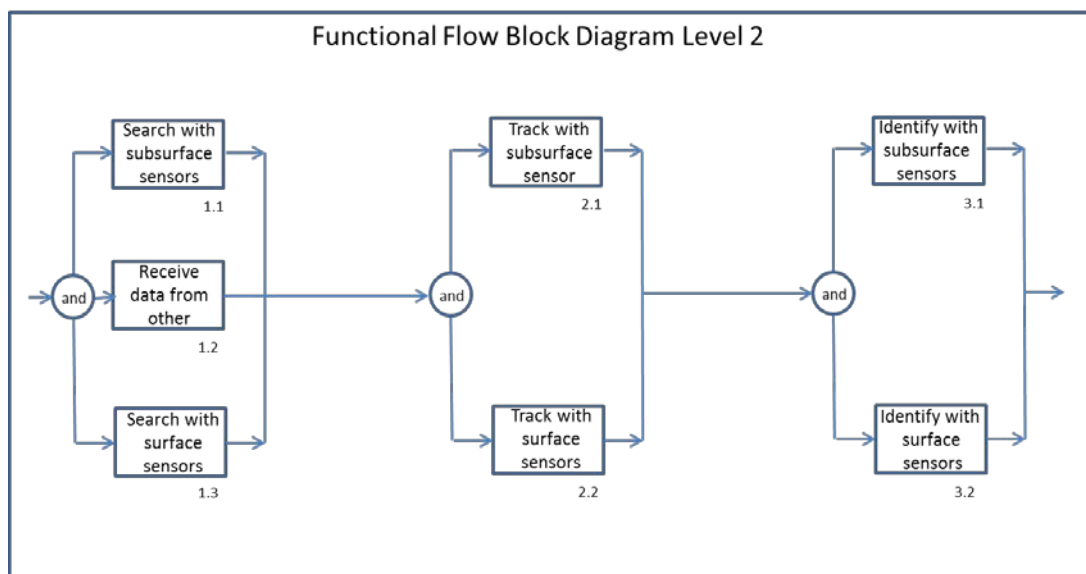


Figure 32. “Need” ASW system functional flow block diagram Level 2.

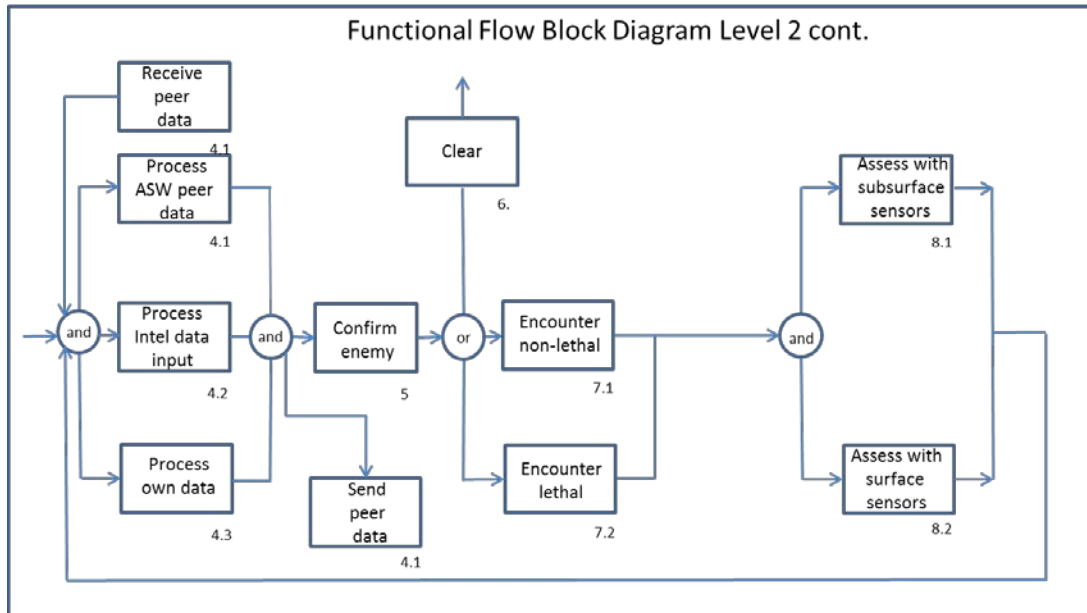


Figure 33. “Need” ASW system functional flow block diagram Level 2 (cont.).

5. Redefining the Need

The stakeholder analysis, boundaries definition, and functional analysis gather the information and knowledge to understand all the issues and concerns related to the ASW more fully. The IPT should now be in a position to reanalyze the problem and redefine the Need for the German Navy.

The early problem statement in Chapter II states that:

The German Navy will have a capability gap concerning the availability of ASW helicopters in respect to the feasibility of embarkations on German ASW-capable frigates and future corvette types to participate on ASW missions with organic, well composed sensors and weaponry.

The primitive need in Chapter II states that:

The German Navy needs an organic aerial ASW weapon system for their ASW-capable ships, which can be embarked on all existing and future German Navy ships and which can operate complementarily to other NATO ASW systems.

The problem statement redefined according to the information and knowledge from Chapter III is as follows:

The German Navy's ASW-capable vessels will have a capability gap in respect to an organic and quickly deployable ASW sensor-system (sonar) to search and engage submarines within distance of its own surface units.

The redefined primitive need, (effective need), which is as follows:

The German Navy's ASW-capable vessels need an organic, quickly deployable, interoperable, and endurable ASW system to conduct ASW at some distance from its own surface units using the vessel's flight deck and hangar for deployment and long-term embarkations.

6. Preliminary Design Analysis

a. Introduction

Blanchard & Fabrycky (2011) state that having justified the need for a new system, as was done in the previous chapters of this thesis, it is necessary to conduct some steps to find the right design for the solution:

- Identify various design approaches or alternatives that could be pursued in response to the need.
- Evaluate the feasible approaches to find the most desirable.
- Recommend a preferred course of action.

It is recommended (Blanchard, Fabrycky, 2011) that such a design research must address limiting factors like environmental ones, as well as the projected capability of each alternative to meet life-cycle cost objectives.

b. Basic Preliminary Design Analysis of the ASW Need

The recommendation mentioned earlier applies also for constraints set by the customer, in this case the German Navy. In particular the constraint that the need must mainly be adapted to the ships, and not vice versa, means that expensive and time-consuming design alterations on the ships is outside the financial and policy boundaries. The Need shall be interoperable with the vessel's flight-deck and hangar. Additionally, the system shall be an easily deployable system. Those conditions limit the possible alternatives regarding the preliminary design. Underwater system solutions or even surface system solutions would need huge efforts to adapt the system to the ship and

would also cause a tremendous redesign of the ship. The need for a quickly deployed system emphasizes an exclusion of subsurface and surface systems as solutions, too. Therefore, the IPT should consider aerial solutions regarding the principal systems design only, but it should not focus on one aerial solution only. Many different solutions for an aerial system can be taken into consideration, such as conventional ASW helicopters of different types or various types of unmanned solutions.

7. Requirements Management

a. Introduction

Allen N. (2008) states that requirements management shall be conducted throughout a project's life-cycle. He explains that systems engineering accomplishes activities and processes to decompose the approved need into a progressively defined system as well as a component requirement which results in a system design that can be tested, produced, and fielded to satisfy the need. The concept development phase enables us to determine the most appropriate solution, and this phase often entails parallel study efforts, which includes various alternatives. These basic requirements are typically stated in general terms and do not provide a sufficient level of detail to enable a system design. Accordingly, the development of operational requirements closely follows the systems design process to provide the needed capability, but different solutions for the same need might also have different operational requirements systems. Allen (2008) underlines this statement with an example of a deep-attack need which could be addressed by a deep-attack aircraft or a surface-to-surface missile. Both examples may have the same requirements but some other ones would differ dramatically. Therefore, the operational concept and requirements must be redefined later in accordance with the identified basic design solutions to contribute to the design process and to determine operational requirements in terms of thresholds and objectives. The most important and critical operational requirements are the key performance parameters (KPP). The operational requirements thresholds and objectives, and in particular the KPPs, are needed later in the decision-making process to measure and evaluate the overall performance of the various solutions regarding the level of fulfillment to cover the capability gap.

b. Basic Requirements of the Need

The requirements of the Need can be separated into the two sub-requirements: function and performance. According to Allen (2008) a functional requirement identifies what the system must accomplish, and a performance requirement identifies how well the system must perform in the environment in which it operates. Furthermore, the nature of a good requirement concerns the user who benefits from the requirement and the state the user wishes to reach in respect to details and performance metric. and In addition, it must be feasible to determine how the requirement can be evaluated.(Miller, 2012). Good requirements should fulfill following criteria:

- Must be verifiable.
- Can be evaluated and tested.
- Should not be defined by words such as “excessive,” “sufficient,” “resistant,” etc.
- Must be unambiguous.
- Must be complete.
- Should be consistent with other requirements.
- Must contain all mission profiles, operational and maintenance concepts, utilization environments, and constraints.

Defining requirements is not a “one man show.” As already noted in the preceding process steps, the effort requires the entire IPT to work as a team and particularly as the user.

The Functional Flow Block Diagram delivers most of the information from which to derive basic functional requirements. Additionally, a good way to derive requirements is to think about basic scenarios in respect to a specific task the system shall perform. Basic scenarios can be developed from the stakeholder elicitation results and knowledge of an ASW basic operational concept. The information illustrated in the Functional Flow Block Diagram (Figure 32) and the Component Breakdown (Figure 31) support the definition of requirements very effectively also. The intended user (the ASW community) should also be involved to support the IPT in developing the requirements.

c. *Basic Functional Requirements in Respect to the CPM's FFF-Document*

As already explained in the background of this thesis, the FFF describes the capability gap and the functional requirements. The FFF document shall include information about the following areas:

- Designation of the required capability (Need)
- Extrapolation of the capability from reference documents and a description of the capability gap
- Description of the functional requirements and project elements

It can be summarized that the first two bullet points have been delivered in the preceding chapters. The next step concerning the CPM is the necessary description of the functional requirements without having a certain solution in mind. The Preliminary Design Analysis has already indicated that due to some constraints only aerial solutions should be taken into consideration.

The effective need in addition to information and constraints determined through the Stakeholder Analysis and Boundaries Definition enables us to derive basic functional requirements for an aerial ASW system. Unfortunately the FFF document demands only a description of functional requirements; it does not demand non-functional requirements. A system has, of course, both kinds of requirements and cannot be comprehensively defined by only functional ones. Therefore, this thesis will consider functional and non-functional requirements.

The basic functional and non-functional requirements for an organic and aerial ASW system:

- The user shall be able to accommodate, to embark, and to use the system as organic an ASW system on board the F123, F124, F125 and MKZ 180.
- The user shall be able to maintain the system on board the ship during the time of embarkation.
- The user shall be able to deploy the system quickly to the designated ASW mission area.
- The user shall be able to search, track, and identify submerged submarines by using a dipping sonar.
- The user shall be able to process sonar data to the system's ASW data processing device.

- The user shall get displayed and already processed search and track dipping sonar data of the possible threat.
- The user shall be able to send sonar data to other ASW units in HF and VHF/UHF frequency (Network capability).
- The user shall be able to receive sonar data from other ASW units in HF and VHF/UHF frequency (Network capability).
- The user shall be able to search, track, and identify submerged submarines by using sonobuoys.
- The user shall be able to process sonar data to the system's ASW data processing device.
- The user shall get displayed and already processed search and track sonobuoy data of the possible threat.
- The user shall be able to send sonar data to other ASW units in HF and VHF/UHF frequency (Network capability).
- The user shall be able to receive sonar data from other ASW units in HF and VHF/UHF frequency (Network capability).
- The user shall be able to deploy dipping sonar and sonobuoys simultaneously.
- The user shall be able to search, track, and identify snorkeling and surfaced submarines by using electro-optical devices.
- The user shall be able to process electro-optical data to the system's ASW data processing device.
- The user shall be able to send electro-optical data to other ASW units in HF and VHF/UHF frequency (Network capability).
- The user shall be able to receive electro-optical and infrared data from other ASW units in HF and VHF/UHF frequency (Network capability).
- The user shall be able to search, track, and identify snorkeling and surfaced submarines by using Radar.
- The user shall be able to process Radar data to the system's ASW data processing device.
- The user shall be able to send Radar data to other ASW units in HF and VHF/UHF frequency (Network capability).
- The user shall be able to receive Radar data from other ASW units in HF and VHF/UHF frequency (Network capability).
- The user shall be able to search, track, and identify transmitting submarines by using electronic warfare system (EWS).
- The user shall be able to process EWS data to the system's ASW data processing device.
- The user shall be able to send EWS data to other ASW units in HF and VHF/UHF frequency (Network capability).
- The user shall be able to receive ESM data from other ASW units in HF and VHF/UHF frequency (Network capability).

- The user shall be able to receive and send information and data from other assets (outside the boundaries of the “System of Systems”) in HF, VHF/UHF frequency, and satellite (Network capability).
- The user shall be able to engage submerged and surfaced hostile submarines successfully by using lethal or non-lethal weapons.

d. Basic Performance Requirements

The performance requirements concern the performance in respect to sensors, weapons, and the performance of the system itself in terms of speed, flight-level, endurance, environment, communication, etc. They are related to functional requirements and describe the performance of some functions. The performance requirement should, of course, be delivered by the stakeholders, particularly from the users of the ASW system. In particular, future system operators, maintainers, logisticians, and also peer system users are requested to present and explain the performance requirement figures and numbers. Because these are not available for this thesis, an “x” is used as a placeholder for real ones. The basic performance requirements for a ship-borne aerial ASW system include the following:

- The user shall be able to handle and move the system on board from hangar to flight deck, and vice versa with the ships handling devices up to sea-state level “x”.
- The user shall be able to maintain for all routine level maintenance the system in the hangar in level 1 and 2 during the time of embarkation.
- The user shall be able to maintain the aerial system with lesser maintenance hours as needed for the MH90.
- The user shall be able to maintain a higher average operational availability for the aerial system than the MH90 does have.
- The user shall be able to supply the system with an embarked spare-part stock with a safety level of “x” %.
- The user shall be able to prepare the aerial system for take-off and to conduct take-off the aerial system up to sea-state level “x” within “x” minutes.
- The aerial system shall be able to reach the designated ASW mission area with a minimum speed of “x” kts (IAS).
- The aerial system shall be able conduct an automatic flight transition from forward flight to hover for deploying dipping sonar to the selected position within “x” minutes.

- The aerial system shall be able to hover steadily for several minutes in position even in severe weather.
- The user shall be able to search, track precisely, and identify reliable and certain, submerged submarines with a dipping sonar with a performance that is at least equivalent to the MH90.
- The user shall be able to lower the transducer of the dipping sonar to selected a depth within “x” minutes.
- The aerial system shall be able to retract the transducer of the dipping sonar within “x” minutes.
- The aerial system shall be able to reach the next dipping position from hover to hover within “x” minutes.
- The user shall be able to conduct a sustained dipping-sonar mission with a minimum of “x” sonar dips at least up to “x” hours at a distance of at least “x” miles.
- The system shall be able to deploy up to “x” sonobuoys during a mission cycle.
- The system shall be able to deploy up to “x” sonobuoys at determined positions within “x” minutes.
- The user shall be able to search, track precisely, and identify, reliable and certain, submerged submarines with sonobuoys with a performance that is at least equivalent to the MH90.
- The user shall be able to search, track, and identify, reliable and certain, surfaced submarines with a radar with a performance that is at least equivalent to the MH90.
- The user shall be able to search, track precisely, and identify, reliable and certain, surfaced submarines with electro-optical and infrared with a performance that is at least equivalent to the MH90.
- The user shall be able to search, track precisely, and identify, reliable and certain, transmitting submarines with an EWS with a performance that is at least equivalent to the MH90.
- The aerial system shall be able to send and receive encrypted data of all its sensors to other ASW units in HF and VHF/UHF frequency without delay.
- The system (within the System of Systems) shall be able to send data of all its sensors to other friendly units in HF and VHF/UHF frequency and satellite without delay.
- The user shall be able to survive hostile attacks with a probability of “x” %
- The system shall be able to operate in extreme environments.
- The system shall not be inhibited by icy weather conditions.
- The system shall not be inhibited by stormy and rainy weather conditions.

It is important that functional requirements are not combined with operational requirements at this point. That will happen at a later step in the process when functional requirements, design, and operational requirements will be formulated to certain system performance specifications. The presented functional and performance requirements will not meet all previously identified attributes of good requirements at that process stage. Requirements are insufficient for designing a solution and must be translated into specifications that can be tested or verified. The requirements presented earlier are the minimum necessary to allow the design process to find alternative solutions based on functional requirements. Accordingly the basic functional and performance requirements must be redefined later during the next design processes when a proposed design and possible alternative solutions have been established. Then, the redefined and improved functional, performance, and operational requirements will be translated and fused into system specifications which should then conform to the previously identified attributes of good requirements.

8. Expected Future Life-Cycle and Life-Cycle Costs for the FFF-Document

a. Introduction

The US Defense Acquisition Guidebook (Under Secretary of Defense (AT&L), 2011) defines that Life-Cycle Cost (LCC) in general terms:

Life-cycle cost consists of research and development costs, investment costs, operating and support costs, and disposal costs over the entire life cycle. These costs include not only the direct costs of the acquisition program, but also include indirect costs that would be logically attributed to the program. In this way, all costs that are logically attributed to the program are included, regardless of funding source or management control. Program cost estimates that are supporting the defense acquisition system normally are focused on life-cycle cost or elements of life-cycle cost.

The German's CPM Analysis Phase, which is the concern of Chapter III, is a pre-acquisition phase. No funding has been approved, and no program has been initiated in that phase. The FFF document is to some extent comparable to the U.S.-ICD (Initial Capability Document). At that early stage no certain solution and design has been

selected; accordingly no detailed calculations concerning life-cycle costs can be done. Only broad considerations and estimations could be delivered by the IPT for the FFF document.

The U.S. Defense Acquisition Guidebook (2011) explains this cost issue at this phase:

However, for programs in Pre-Systems Acquisition or the Engineering and Manufacturing Development Phase, cost estimates that are used within the program office to support system trade-off analyses—such as evaluations of design changes, or assessments of energy efficiency, reliability, maintainability, and other supportability considerations—may need to be broader in scope than traditional life-cycle cost estimates to support the purpose of the analyses being conducted. Moreover, for mature programs (in transition from production and deployment to sustainment), cost estimates in many cases may need to be expanded in scope to embrace total ownership cost concepts in order to support broad logistics or management studies.

Furthermore, the Guidebook explains that:

“Life-cycle cost can be defined as the sum of four major cost categories, where each category is associated with sequential but overlapping phases of the program life cycle. Life-cycle cost consists of:

1. research and development costs associated with the Materiel Solution Analysis phase, the Technology Development phase, and the Engineering and Manufacturing Development phase,
2. investment costs associated with the Production and Deployment phase,
3. operating and support costs associated with the sustainment phase, and
4. disposal costs occurring after initiation of system phase out or retirement, possibly including demilitarization, detoxification, or long-term waste storage.”

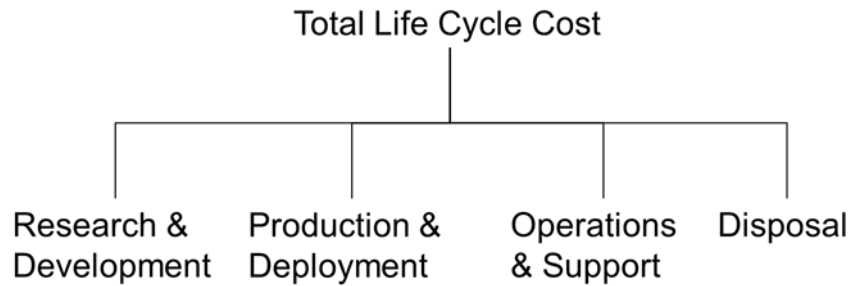


Figure 34. Composition of total life-cycle costs.

The nature of many programs is that the cost over time increases at each step of a program. Every program shows different amounts of cost corresponding to each of its phases. Because of the complexity of programs, their associated costs other than those associated with acquisition are not readily apparent (Figure 35).. Often, only research and investment costs are taken into consideration by decision makers when they go for an alternative, because these two phases are usually separately funded from Operations and Support (O&S) and disposal. That practice applies for German Armed Forces as well.

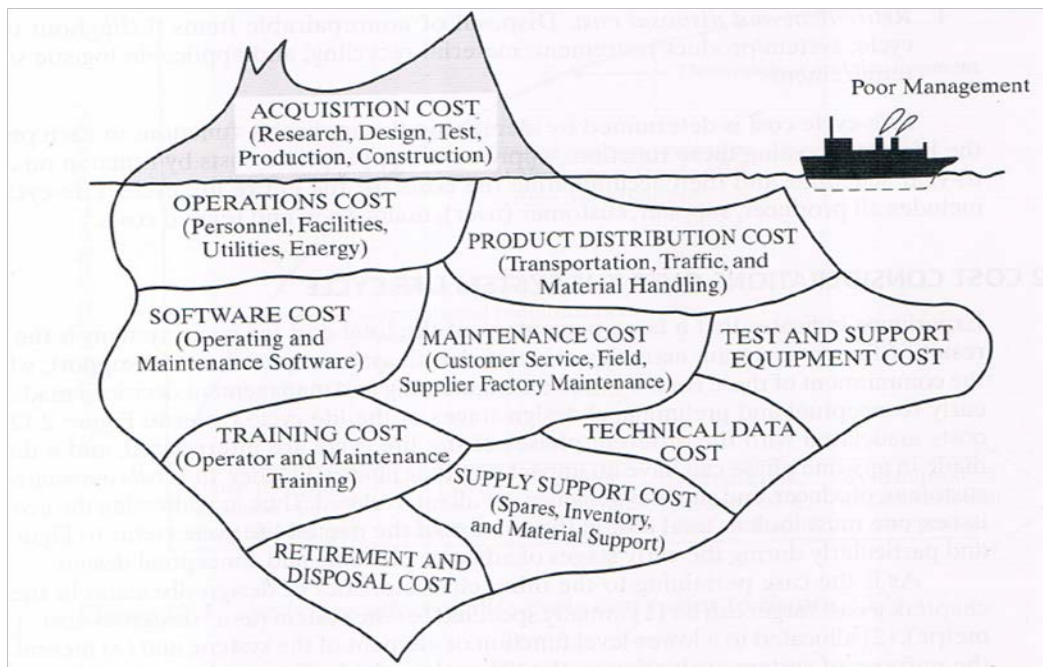


Figure 35. Visibility of LCC-Elements (Blanchard, Fabrycky 2011).

In an early stage of the Research and Development (R & D) phase the O&S cost are vague due to the lack of detailed information for calculations. This is particularly true if it concerns programs with a new technology (Figure 36). These programs are often involved in high cost overruns in respect to early life-cycle costs estimations, and that happens already during the R&D and Investment phases.

The F-35 is currently a good example for that problem. The F 35 cost problems may aggravate when the program enters the O&S phase, where the partition of the entire life-cycle costs is even higher than R&D and Investment together.

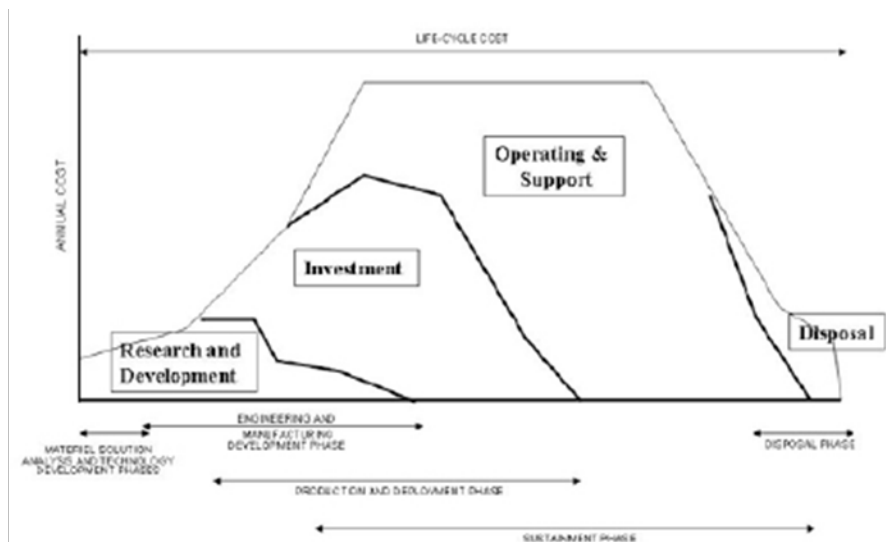


Figure 36. Life-cycle cost according to Defense Acquisition Guidebook (Under Secretary of Defense (AT&L), 2011).

If the future program is a System of Systems, then life-cycle costs calculations may not be sufficient or comprehensive enough to determine the real cost for a Need. That is because the program concerns more than a single system, as may be the ASW case. A possible future solution to cover the gap could involve some more stakeholders (other aerial systems, vessels, etc.) in respect to the costs, which are not part of the traditional life-cycle cost calculation. It may be advisable to take costs in respect to the total ownership into consideration instead life-cycle costs only.

Once more, the guidebook describes this consideration:

Total ownership cost includes the elements of a program's life-cycle cost, as well as other related infrastructure or business processes costs not necessarily attributed to the program in the context of the defense acquisition system. Infrastructure is used here in the broadest possible sense, and consists of all military department and defense agency activities that sustain the military forces assigned to the combatant and component commanders.

In general, traditional life-cycle cost estimates are often adequate in scope to support the review and oversight of cost estimates made as part of the acquisition system. However, in special cases, depending on the issue at hand, the broader perspective of total ownership cost may be more appropriate than the life-cycle cost perspective, which may be too narrow to deal with the particular context. As discussed previously, for a defense acquisition program, life-cycle costs include not only the direct costs of the program, but also certain indirect costs that would be logically attributed to the program. In a typical life-cycle cost estimate, however, the estimated indirect costs would include only the costs of infrastructure support specific to the program's military manpower (primarily medical support and system-specific training) and the program's associated installations or facilities (primarily base operating support and facilities sustainment, restoration, and modernization).

b. Life-Cycle Cost for the ASW Need

The FFF document requests some numbers concerning the time-frame of intended usage and life-cycle costs. The first part of the CPM's Analysis phase explicitly does not ask for a certain solution; rather it asks for a neutral description of the Need. Accordingly, the already applied systems engineering processes helped us to understand the stakeholder needs and boundaries and to define the Need definition. The constraints and boundaries enabled us to limit the basic design to an aerial one and maybe to identify it as a System of Systems. That means many different alternatives could still be developed, and only one will be the solution. That fact makes it difficult to estimate any life-cycle costs on a sound basis. It is understood that decision makers need some numbers to approve and fund further research. However, it is not legitimate to expect

sharply calculated life-cycle numbers and costs for a Need from the IPT. Instead, the IPT should deliver life-cycle cost estimations which cover the possible range (max-min) of the costs.

The Program Manager's Tool Kit (Under Secretary of Defense (AT&L). 2009) takes that problem into consideration and describes four different ways to estimate costs (Figure 37):

Estimate Methods	Comments
Analogy	Comparison to <i>one</i> similar existing system; based on judgments. Little or no data available; relatively quick, easy, flexible. Used in early phases (e.g., Material Solution Analysis and Tech. Dev.)
Parametric	Comparison to <i>many</i> similar existing systems; based on statistical analysis. Determine primary cost drivers and establish Cost Estimating Relationships (CERs). Used in early to mid-phases (e.g., Material Solution Analysis, Tech. Dev., and Engr. and Manufacturing Dev.)
Engineering or "Bottoms-Up"	Summation of "all" individual items in the system. Uses Work Breakdown Structure (WBS) for estimating purposes. Used in mid-phases (e.g., Engineering and Manufacturing Development)
Extrapolation	Comparison to historical cost of <i>same</i> system. Based on extrapolation from actuals. Uses Learning Curve Theory. Used in late phases (e.g., Production and Operations/Support)

Figure 37. Costs estimate methods according to DAU Program Manager's Tool Kit.

Regarding the German ASW capability Need and due to the early phase of the CPM, only the Analogy Method seems to be applicable. This method is also advised by the Tool Kit for early phases.

The MK 88A "Sea Lynx" has been in use for decades and is the predecessor-system of the Need; thus the Navy should have the real life-cycle costs for that weapon system. By requesting these figures and updating these numbers in terms of current/future Euro the IPT can set the "Sea Lynx" costs as minimum expected life-cycle costs. Some people may disagree with this method. However, even when these numbers do not precisely correlate to the new system (Need), they are still real, reasonable, and preferable to random estimation. Additionally, figures from the current procurement and operation of the NH90 (Army variant) are available and can be used as maximum expected life-cycle costs. If some similar research, efforts, and programs in NATO or

Allies exist, then data and program information should be requested from these sources and subsequently adapted for our own cost estimations. By the way, the request of the FFF document concerning the expected future user has been already determined by the Stakeholder Analysis.

9. Summary and Conclusion

The Systems Engineering processes are applicable in the FFF Analysis phase and help to illuminate the ASW capability Need thoroughly. The processes enable us to identify and understand the “wants and needs” of the stakeholder, and also to identify and to select the most important needs. Additionally, the determination of the boundaries and top-level functions allowed for a redefinition of the problem statement. Finally, an effective need could be developed from the early primitive Need that enables the IPT to understand the true nature of the need. Accordingly, with all that information, the design alternatives can be limited to an aerial system, and its basic functional requirements can be derived. Estimating life-cycle cost is the last step in a comprehensive and complex process of presenting a sound FFF document. If the FFF document is approved, the BAAINBw and its IPT can continue with the second part of the CPM’s Analysis phase.

V. SYSTEMS ENGINEERING AND THE CPM'S ANALYSIS PHASE: PART 2

A. ANALYSIS PHASE PART 2: DESIGN AND ANALYSIS OF ALTERNATIVE SOLUTIONS

The second part of the analysis phase concerns the physical component analysis and shall identify technical and design solutions (alternatives) to meet the requirements. The alternative solutions can be differentiated into categories of employment of already available products and use of existing services, improvement of “in service” systems, and development of new products. The IPT has to provide at least one solution that meets all the functional requirements and other solutions that meet at least the time and cost frame of the FFF. A proposal of all alternative solutions has to be presented to Chief of Federal Armed Forces Staff (CoS) by the MoD Directorate of Equipment, Information Technology, and In-Service Support. The solutions can be categorized into:

- Procurement of available products
- Improvement (adaption) of in-service materiel
- Realization of new products

The IPT has to follow the CPM document-given tasks when developing the solutions. These tasks include the following:

- Sighting and assessing of available products
- Assessing the improvement (adaption) potential of in-service materiel
- Assessing the realization of new products
- Assessing possible national and international cooperation
- Considering obsolescence
- Determining demand (amount)
- Planning and scheduling of the life-cycle
- Determining resources for Testing
- Estimating the logistic footprint
- Illustrating risk in respect to realization and operation
- Determining life-cycle costs
- Estimating time period and funding for the realization and operation phase
- Assessing the degree of fulfillment in respect to the requirements stated in the FFF-document

Possible solutions need to be analyzed and assessed with respect to performance, time, costs, and risk against the background of research and technology to be used. The

BAAINBw can contract companies to support research on feasible solutions by conducting modeling, simulation, and prototyping to evaluate the technical feasibility of the possible product. To reduce risk an incremental procurement process, which leads to the fulfillment of the requirements according to the FFF-document, can be taken into consideration, if appropriate.

The CoS decides which solution will be selected and continued as a procurement program. Accordingly, for each proposed solution a design needs to be researched and developed by the IPT and presented to the decision makers. This thesis will cover some of the above mentioned tasks which can be determined using systems engineering processes.

B. APPLYING SYSTEMS ENGINEERING

1. System Design and Synthesis

a. Introduction

Allen (2008) explains that synthesis defines a design solution which will satisfy the requirements of the verified functional architecture and translate the functional architecture into a physical architecture of system elements. This describes a system design that emerges from the functional requirements. He states that this synthesis involves selecting a preferred design solution from a set of alternatives. The V-model depicted in the DAU PM Tool Kit (Under Secretary of Defense (AT&L), 2009) illustrates once more the next step within the design processes (Figure 38).

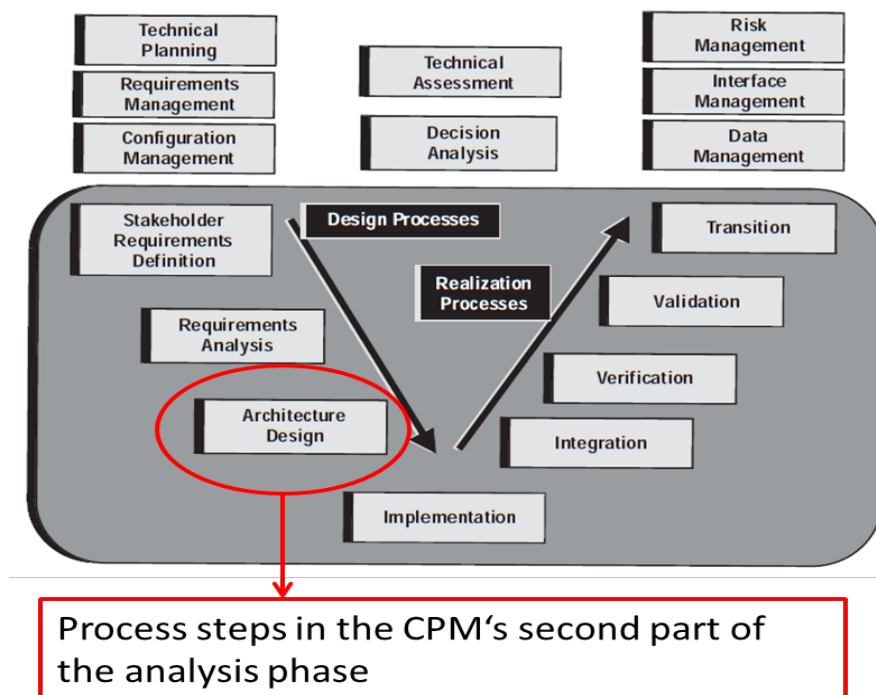


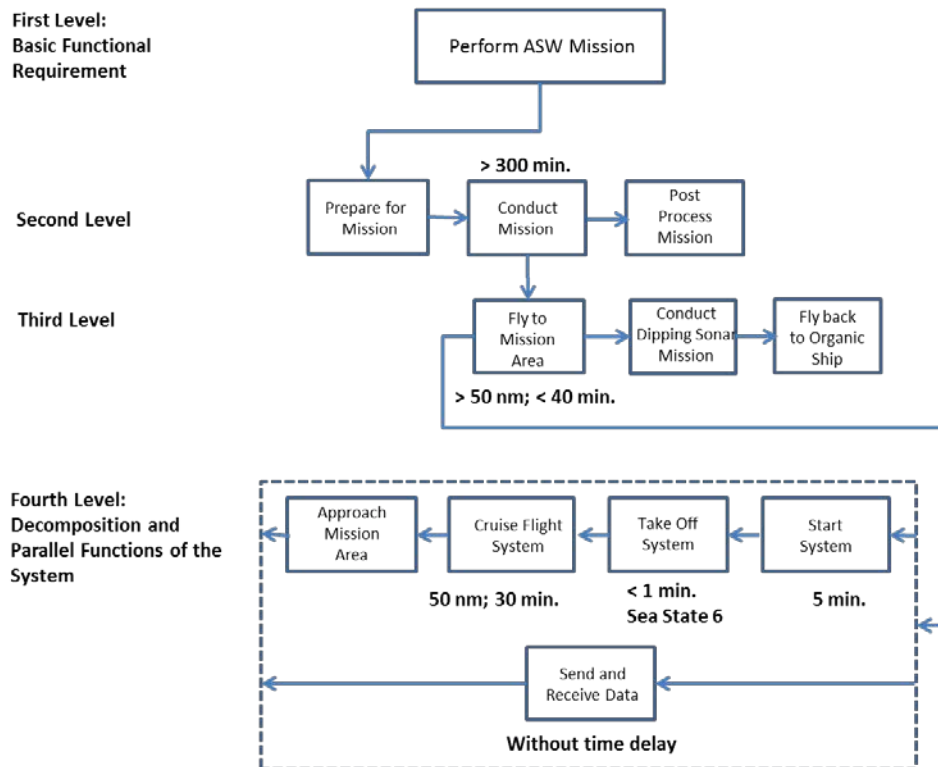
Figure 38. SEP and technical management processes in respect to second part of the analysis phase.

Finding the right design is the last step before decision makers have to decide which one will be developed. The IPT shall present some thoroughly derived physical designs which can be assessed by an analysis of alternative (AoA) processes. The process of “Systems design and synthesis” will support the IPT to develop some designs (solutions) derived from the functions and requirements to physical subjects and designs.

b. Functional Analysis of the Need

The functional analysis is a process that allows for the combination of basic requirements and functions into a functional architecture. It defines the functions necessary to accomplish the requirements. It decomposes functional requirements (what must be done) and performance requirements (how well must it be done) into lower-level functions (Allen 2008). That process enables us in principle to decompose top-level functions into single maintenance works and system usage. Each level’s functions can be compared with some real-life scenarios and what must be performed within these partial

scenarios to fulfill a certain mission within the “big picture” scenario. A comprehensive application for the development of an actual functional architecture is not within the scope of the thesis. The following figure (Figure 40) is an example of how that functional architecture illustrates the decomposition of functional requirements and performance requirements, derived from the example presented by Allen (2008). The illustrated example concerns a dipping sonar mission on level three and four. The numbers in Figure 40 are assumed performance requirements. Although these numbers do not come from research, they do approximate real ones and can be used for explanation. To understand the systems functions comprehensively, the IPT should develop for each second-level function further lower-level functional architecture diagrams, such as pre and post-flight activities, maintenance, sonobuoys, mission, etc., to analyze and understand each function for all actions conducted with the system.



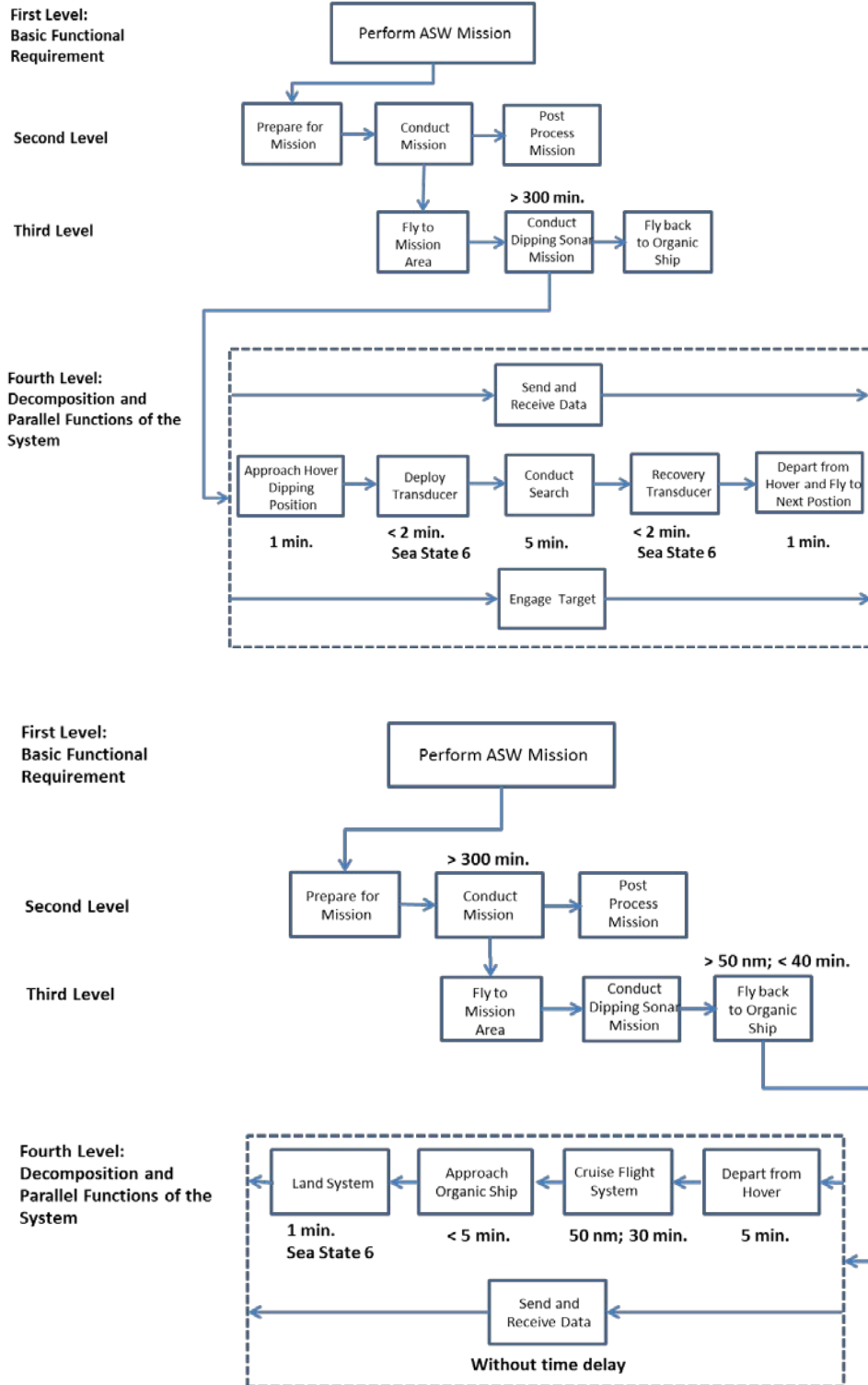


Figure 39. Functional architecture levels 1-4.

c. Physical Architecture through Functional Allocation

By allocating functional architecture to a physical architecture, physical components can be identified and allocated to each function. That process determines the function and the physical component that is required to develop a physical design for the need. Allen (2008) describes that process as a synthesis of requirements and functions for defining a design by translating functional architecture in a physical one. This step also involves the selection of the basic preferred design. As already stated, the preferred design is an aerial one within the context of a System of Systems which involves ships and other aerial assets.

The allocation of functions to basic physical components and a description of functions and requirements is shown in Figure 40.

Function	Physical Component	Description of Meeting Function and Requirement
1. Fly to Mission Area/to Ship	Airframe	Airframe must be capable to fly to mission area within 40 minutes.
1.1 Start from Organic Ship	Airframe	Airframe must be capable to start from board their organic ship at Sea State 6 within 1 minute.
1.2 Land on Organic Ship	Airframe	Airframe must be capable to land board their organic ship at Sea State 6 within 1 minute.

2. Search, Track, Identify		
2.1 Dipping Sonar Search		
2.1.1 Hover over dipping position	Airframe	Airframe must be capable for steady vertical flight and hover for dipping sonar in severe weather conditions for 10 minutes.
2.1.2 Deploy/recover transducer	Dipping sonar system	Dipping sonar system is required to lower/recover a sonar transducer within 2 minutes.
2.1.3 Search	Dipping sonar system	Dipping sonar system is required to send and receive sonar signals.
2.1.4 Track	Dipping sonar system	Dipping sonar system is required to track sonar signals.
2.1.5 Identify	Dipping sonar system	Dipping sonar system is required to identify sonar signals.

2.2. Surface Sensor and Sonobuoy Search		
2.2.1 Cruise flight over search area	Airframe	Airframe must be able for flight in different heights in severe weather.
2.2.2 Search with radar	Radar system	Radar must be capable to detect surfaced submarines and submerged submarines with deployed snorkel.
2.2.3 Track with radar	Radar system	Radar must be capable to track surfaced submarines and submerged submarines with deployed snorkel.
2.2.4 Identify with radar	Radar system	Radar must be capable to identify surfaced submarines .
2.2.5 Search with EO/IR	EO/IR system	EO/IR system must be capable to detect surfaced submarines and submerged submarines with deployed snorkel.
2.2.6 Track with EO/IR	EO/IR system	EO/IR system must be capable to track surfaced submarines and submerged submarines with deployed snorkel.
2.2.7 Identify with EO/IR	EO/IR system	EO/IR system be capable to identify surfaced submarines.

2.2.8 Search with EWS	EWS system	EWS system must be capable to detect transmitting submarines.
2.2.9 Track with EWS	EWS system	EO/IR system must be capable to track transmitting submarines.
2.2.10 Identify with EWS	EWS system	EO/IR system be capable to identify transmitting submarines.
2.1.11 Deploy sonobuoys	Sonobuoy system	Sonobuoy system is required to deploy sonobuoys at position.
2.1.12 Search	Sonobuoy system	Sonobuoy system is required to send and receive sonar signals.
2.1.13 Track	Sonobuoy system	Sonobuoy system is required to track sonar signals.
2.1.14 Identify	Sonobuoy system	Sonobuoy system is required to identify sonar signals.
3. Process all Sensor Data and Confirm	Mission data processing and management system	The systems mission data processing system must be capable to compute and process all sensor's and received data.
4. Send and Receive	HF-radio; UHF/VHF-radio, LINK 11, LINK 16, and LINK 22, en/decrypting system, antennas	The systems radios, data link, decrypting system, and antennas are required to communicate and send/receive data to/from organic ship and other peer systems.
5. Encounter Threat	Torpedoes, bombs, missiles,	The systems anti-submarine weapons are required to deny, disable or to destroy tracked hostile submarines in the mission-area.

Figure 40. Function to physical architecture for the ASW need system.

d. Refining Requirements and Key Performance Parameters

Systems engineering inherently iterates, reconsiders and repeats methodologies implemented using feedback loops to improve and correct the outcomes. As already stated in Chapter IV, requirements management shall be conducted throughout a project's life cycle. Therefore, the already defined operational concept, including a maintenance and supply concept, should be refined and adapted in respect to knowledge about alternatives. The derived requirements should also be refined in accordance with the three identified alternative solutions to contribute to the design process. The users now have a better understanding of the possible solutions and can refine and state more precisely their operational requirements. This is particularly necessary because the design architecture alternative have been extended by a possible solution that shifts some basic physical components to the ships. Accordingly, the operational concept and requirements in that case are different as these solutions are for aerial systems only. The given example of a deep-attack need which could be a deep-attack aircraft or a surface-to-surface missile may have some of the same requirements, but others would differ dramatically. The same is true for the alternative solutions with respect to the capability shift to ships. Thus, operational requirements would then involve the organic ships differently from the early requirements and would need a redefinition by the users.

Furthermore, KPP should be derived from the most critical operational requirements. The KPPs contain operational requirements thresholds and objectives. They should be directly traceable to the most critical attributes stated in the FFF document. Additionally, the KPPs should accomplish the following:

- Address the most critical operational requirements.
- Express requirements in terms of thresholds and objectives
- Remain few in number (eight or fewer).
- Address interoperability.
- Address Net-readiness.
- Consider materiel availability
- Be validated by users and decision makers.

Some important and useful KPPs for the ASW need might be following ones:

- The system must be embarked, maintained, and operated on board of the F123 and F124 frigates without adapting the hull structure of the ships.
 - The system must be capable of conducting “x” sonar dips per hour for “x” hours in a distance of “x” nautical miles.
 - The system must be capable of conducting an ASW patrol flight for “x” hours and covering a patrol area of “x” nautical square miles
 - The system must be capable of conducting ASW mission up to sea state 6, wind up to 60kts, at temperatures between -30°Celsius and +50°Celsius, at all kind of precipitation.
 - The system must be capable of operating in current and future naval networks and shall use ship’s sonar data processing capabilities.
 - The system must be mission ready for 12 hours continuously per day, five days a week, for three month with an availability of 85%.
- e. Analyzing the Physical Components, their Functions, and Requirements with respect to System of Systems***

ASW systems work successfully only in a team with other peer ASW systems. Accordingly, in an ASW mission, ships and aerial assets form a close team, and therefore, a high level of interoperability is required. The interoperability usually concerns software compatibility (data exchange), rather than physical interoperability. Within the Germany Navy a comprehensive interoperability between ASW assets is given and expected. For example, all helicopters can be serviced on all ships with flight decks and only one type of torpedo is used on ship, helicopter, and aircraft. The “need” system must also have full interoperability features. In a system of systems, multiple functions and components are often available. The relationship between ship and helicopter has often been termed as organic, because that relationship is vital for mission success. This vital relationship can be considered as a system of systems, including a ship and an aerial asset, since each ship or aerial asset could operate independently as a systems in its own right, but through design we desire them to operate as a single interoperable system of systems. Therefore, the “need” ASW system should be considered as a system of systems, meaning an ASW ship and an aerial ASW asset. Accordingly, the physical architecture should take both systems into consideration to find a design and a solution for the need. By their nature ASW ships and aerial assets are

tasked with different missions in different search areas within an ASW operation, but multiple requirements and functions should be identified and analyzed if these assets can be used in a complementary fashion. When going through the list of physical components shown in Figure 40, mission data processing and management, EWS, and the ASW weapons are the only components which are not unique to an aerial system and which exist on other ASW platforms. All other components are closely related to an aerial asset and cannot be substituted by ships.

Following components are related to aerial ASW systems only.

- **Airframe:** Today only one principle design of aircraft is used for deploying dipping sonar; that is the helicopter. Only helicopters are enabled to combine steady hover performance with acceptable forward-flight and endurance performance. These design features made the helicopter the only design yet for ship-borne ASW missions regarding dipping sonar. Currently only conventional manned designs are in development or in service worldwide, but unmanned and unconventional designs are feasible due to the availability of technology.
- **Dipping sonar:** The major acoustic detection device for helicopters is the dipping sonar. ASW aerial assets should today be integrated in the framework of network centric ASW. That demands modern dipping sonar systems which have centric frequency and bandwidth and are compatible with surface ships and with sonobuoys. Helicopters, equipped with dipping sonar, are considered as the greatest threat to submarines, especially in littoral regions. (Watts, 2005). The sonar data will be processed by an ASW processing computer which is part of the helicopter's dipping sonar system. That means many ASW helicopters are able to process and manage the sonar data with its computers and crew. Nevertheless, according to Jane's the SH-60's LAMPS MK III ASW system is not a fully independent operating system; rather it relies on other ASW vessels which provide computing power and personnel to process and evaluate sonar data. Accordingly, dipping sonar data could be processed and managed by ASW ships only, too.
- **Sonobuoys:** These buoys are used by vessels and helicopters and are considered as a primary airborne detection system. They are expendable, relatively cheap, and reliable and are in use as passive and active variants, directional and non-directional, large and small size. Sonobuoys transmit their sonar data to the aircraft for processing (Watts, 2005). Accordingly, the sonar data could also

be solely transmitted from the aircraft to ships for further processing, analyzing, and management.

The following components are in use by ASW vessels and ASW aerial systems. Analyzing the multiple components used should enable us to assess which of these can be used together and which are not mandatory for a single aerial ASW system within a system of systems.

- **Mission data processing and management systems:** In today's weapon systems many different sensors are used, and the information and data collected need computerized processing to identify and filter important data, to organize them in order of importance, and to distribute them between the different users automatically (management). That is especially true for aerial ASW assets which have the most sensor density on board. To bring these data from all sensors together and to manage these by crews requires intensive computer hardware performance, complex software, and well-trained personnel at the consoles. The latest ASW helicopter developments, such as the MH90, suffer in particular from delays caused by problems with the complex mission processing hardware and software. Their mission computer and software are designed so that these ASW helicopters and their crews can use and operate the sensors independent from other assets. Only completely processed data will be exchanged between different ASW assets. An exception to this model is the U. S. Navy's SH-60. ASW ships have many more resources available in respect to hardware and human capital to process, analyze, and manage sensor data than any helicopter could due to size and weight limitations. A conclusion is to consider the processing capabilities of the aerial ASW system that could be reduced and simplified, and those that could be managed by the organic ship through the exchange of collected basic data rather than relying on independent processing performance.
- **Electronic warfare suite (EWS):** EWS detects electronic emissions, measures their amplitude, and analyzes the parameters so that the transmissions can be identified against a stored library of emitters. However, within a littoral area where a submarine operates, it is most unlikely that any hostile submarine would emit any transmissions. Therefore, EWS is not a primary or even secondary sensor for ASW. The EWS of ships is more powerful and sensitive than those of most aerial ones; nevertheless, due to the closer distance to the threat and altitude advantage of aerial systems, EW receivers are needed at least for aerial ASW assets when conducting ASW missions. Additionally, EWS is required for aerial systems' safe operation to detect other surface and aerial

transmitters, and to avoid other hostile threats. EW raw data can be processed by the helicopter crew, but it could also be transmitted to peer-systems for further processing, analyzing, and management.

- **Electro-optical and infrared sensor (EO/IR):** EO/IR is a system with several cameras which operate in different ranges of the spectrum of light. That enables the crew to see the objects, like submerged submarines or snorkels, through magnification during the day and night. Additionally, the IR spectrum allows for the detection of heat signatures, such as the hot air exhausted by submarines when diesel engines are recharging batteries, during day, night, and severe weather. The EO/IR sensors are often connected to the radar, which enables them to transfer radar track data to the EO/IR system and lock on a radar track. Today's EO/IR systems use computer software to process the picture before displaying it to the crew. Once more, due to the closer distance of the threat and the altitude advantage of aerial systems, a EO/IR sensor is required for aerial ASW assets when conducting ASW missions. When helicopters hover to dip the sonar transducer, their hover altitude exposes them to the threat of collisions with ships; thus, an EO/IR sensor is also useful (although not required) for aerial systems to detect other surface vessels and avoid collisions during the night or severe weather conditions. Although EO/IR raw data can be processed by the helicopter crew, it could also be transmitted to peer-systems for further processing, analyzing, and management.
- **Radios, data link, and de/encryption devices:** The transmitting systems used are commonly radios capable of using civil and military frequencies in the HF, VHF, and UHF bandwidth. De/encryption devices are also commonly used by allies and NATO for radio, voice, or data-only secured transmission. Link systems allow for two-way transmission of data via radio automatically as well as to feed the mission system. Thus, aerial and sea vessels need these systems to interoperate with other systems. A satellite-radio capability is usually not required for ASW missions, because helicopters operate within radio distance of ships.
- **Radar:** Radar is one of the most important sensors for on-sea operation of aerial assets because no air traffic control exists at sea, and the aircraft need radar for collision avoidance. A radar system is not required for an aerial ASW system only when peer systems provide radar control. However, the system cannot leave the radar control area. That may cause problems when the system is radar-controlled by ships and when the system is at low altitude (hover); The earth's curvature limits the radar distance for ships at low altitude. On the other hand, the radar-distance extension provided

by aerial systems is also vital today for naval ships. To conduct an ASW mission successfully, radar is very important to detect surfaced and snorkeling submarines at some distance. Thus, a radar system is in principle a vital system of any naval vessel and aerial asset.

- **ASW weapons:** The primary ASW weapon is today the torpedo in many variants. They can be separated into heavyweight and lightweight torpedoes, which rely on different kinds of energy sources for their propulsion. Due to weight and size constraints, ASW aircraft use only lightweight torpedoes. These variety is also often used by ASW capable ships, too. Other ASW weapons are guided ASW weapons (torpedo carrying missiles) ASW rockets (including rocket boosted torpedoes-ASROC), bombs, and depth charges. Only those missiles that can be deployed by surface vessels missiles are deployed by both kinds of assets. Even so, a submarine will never operate surfaced within a theater of war, except when it is in serious trouble. Thus, the probability of engaging a surfaced submarine is very unlikely. Therefore, primarily torpedoes and secondarily bombs are the weapons of choice for ASW conducting aircraft. But lightweight torpedoes weigh up to 300 kg, and ASW helicopters' flight performance (particularly their hover performance) is very limited by weight. Especially small helicopters, like the "Sea Lynx," are not capable of carrying all the sensors and ASW weapons simultaneously. Against this background the German Navy used to operate two "Sea Lynx" helicopters in parallel; while one of them carried the torpedoes only, the other conducted the search with the dipping sonar. Another problem is that unused torpedoes that are deployed on helicopters must be brought back to the ship. These torpedoes have a limited life before they require maintenance (MTBM). A torpedo requested by the helicopter and deployed from ship with a range that covers the mission area of the helicopter would enable us to use the ASW helicopter without the disadvantage of carrying torpedoes. That would increase their flight endurance.

It can be summarized that all the physical components discussed in this section are required within an ASW system of systems, but not all physical components are required for a single ASW system. With respect to the aerial system only, it can be concluded that an airframe, dipping sonar, sonobuoys, and an EO/IR sensor comprise the minimum elements of what a physical design should contain to fulfill requirements and functions within an ASW system of systems. On the other hand, the aerial system's need for physical components related to mission data processing capacity, radar, and anti-

submarine weapons depends on the users, the operational concept, and how deep it will be embedded in an ASW system of systems.

2. System Architecture and Basic Design Solutions

The knowledge gained from the functional to physical architecture and the completed analysis enables us to develop alternative designs. The first could focus on the design of a single ASW system, which means it is a conventional manned ASW helicopter that fits onto the various ASW ships with respect to its physical parameters. That solution contains all or at least the most of the physical components, and most likely it fulfills the required functions. However, it will not fulfill the requirement for endurance performance. That solution could be a market available product. Another approach could be a design of a manned helicopter, but its mission equipment is strictly tailored to be a system of systems solution. That means, it does not fulfill all required functions. Therefore, it must cooperate closely with its organic ASW ship, or at least with other ASW peer systems, to conduct an ASW mission successfully. This approach could generate more endurance because the helicopter has to carry fewer components and can carry more fuel. This solution is not market available, but the components (including the airframe) are available individually. Additionally, this design approach would involve other ASW peer systems; in particular, it involves the organic ship into the solution. When this solution is broken down, the functions and physical components for ASW will be distributed across several aerial systems, as is already practiced by the German Navy by separating sensors on weapons and two “Sea Lynx” helicopters.

To achieve increased endurance and performance specially tailored designs and system solutions are necessary. Today unmanned aerial systems (UAS) must be taken into consideration. That kind of aerial vehicle allows for specialization with respect to the design that more strictly adheres to the requirements and functions. Unmanned aerial systems cannot operate independently because they have no crew on board, and more significantly in the ASW context, the UAS is a system of systems. This possible approach makes ASW peer systems and the organic ASW ships part of the solution. Once more,

such a solution can be broken down even further when the functions and physical components for ASW are separated and distributed on several aerial systems.

According to the previously analyzed information, the alternative solutions will propose three different basic design approaches to cover the CPM's need for different solutions, including the use of available products, improvement of in-service materiel, and realization of new products, and the need to fill the capability gap. The performance requirements concerning the sensor performance of dipping sonar, sonobuoys, radar and EO/IR shall be at least the same as those of the MH90. In this ASW case it is assumed that the latter requirement is set by the stakeholders and decision makers as a common sensor solution to simplify the process and keep the costs and risks down. Therefore, all alternatives will be equipped with the same sensors and weapons or at least with sensors with the equivalent performance. In this ASW case that limitation and preselection of certain sensors and weapons simplifies the acquisition process. The alternative's sensors and weapons will include the following:

- Thales Flash dipping sonar
- Selex Seaspray 7000E Radar
- Standard helicopter sonobuoy dispenser
- Wescam MX15 EO/IR turret,
- Link 11, 16, and 22 system
- Eurotorp MU90 impact torpedo

a. Available Product Solution

The first possible alternative solution could be an AW 159 “Wild Cat” “off the shelf” solution (Agusta Westland, 2013).



Figure 41. AW 159 “Wild Cat” arts image.

Airframe	Sensors	Mission data processing and management	Radio, Link, en/decryption-device	ASW weapons
• Max. speed: 160 kts • Range: 420 nmi • MTOW - Endurance: 2,55 hrs • Crew: 3 persons	• Radar: Seaspray 7000E, • EO/IR: MX-15Di, • Dipping sonar: Thales Compact Flash • ECM (Radar /IR)	• Tactical Processor, console • Sonar processing system	• I-Band Transponder • Military Identification Friend or Foe • Tactical Data link (Link 11/22) • VHF/UHF SATURN and HF radios (Secure voice)	• Torpedo: Stingray or MU90 • Depth charges

Figure 42. List of physical components and performance of the AW 159 “Wild Cat” “off the shelf.”

The company Agusta Westland developed the AW 159 “Wild Cat” in an Army and Navy version based on a contract with the British forces. It is a reengineered and improved evolutionary design and still bases on the “Sea Lynx” helicopter, which is still in service on board of the ASW capable frigates. The physical size and shape of the AW 159 is like the old “Sea Lynx.” Thus, the interoperability and embarkment of the AW 159 on the F123 and F124 is given and should not be a concern. The helicopter is

available on the market, and no developments or adaptations are required. It is an independent ASW design that carries all sensors and components, except sonobuoys. It also carries a crew to process and manage ASW data, and to deploy its torpedoes or depth charges. Accordingly, this solution needs no ASW peer systems to conduct an ASW mission, but it can also operate within an ASW of systems due to its radios and tactical data link capability.

b. Improvement of In-Service Materiel

A second possible alternative design could be to modernize and improve the Mk 88A “Sea Lynx” that is still in service. The airframe still has enough remaining flight hours left before the life-cycle ends. Furthermore, it could be tailored to system-of-systems ASW operations which would involve adding the organic ship or second aerial system into the solution:



Figure 43. German Navy Mk 88A “Sea Lynx.”

This possible alternative could be modernizing and refurbishing the Mk 88A “Sea Lynx” airframe, electric, and engines to extend the life cycle, and it could be equipped with new sensors similar to those of the MH90. Additionally, it could be taken into consideration that the mission processing system and the third crew member and his console could be removed from the helicopter. Weight and space saving should enable us to equip this alternative with additional internal fuel cells. Accordingly, the endurance could be increased to a level close to that of the MH90. To enable this alternative design

to conduct ASW missions, the sonar data must be transmitted, processed, and managed by crew members on board the organic ASW ship. That means that this alternative system is truly a system of systems in respect to the organic ship. The pilots only fly the helicopter according to dipping positions advised by ship's crew.

c. Realization of a New Product

The third solution would include an unmanned aerial system. Currently no market-available UAS exists that can conduct dipping sonar missions. The United States Army and Navy have already some promising helicopter drone systems in use, or in development, but they do not yet fulfill the requirements of the ASW need. These are the K-Max (Lockheed Martin, 2013), UAS, A160 Hummingbird (Northrop Grumman, 2013a), and the MQ-8C Fire-X (Northrop Grumman, 2013b).



Figure 44. Lockheed Martin K-max UAS.



Figure 45. Northrop Grumman MQ-8C Fire-X.



Figure 46. Boeing A 160 Humming Bird.

K-Max and Fire Scout are already deployment proven systems and have logged several thousand operating hours. The Fire-X will start at a low rate of production and initial operational with the U.S. Navy in 2014. Except for the A 160 Hummingbird, the UAS are derived from manned helicopters which are intended for decades in service. These systems' operational purpose and design is mainly tailored to transport/replenishment purposes and intelligence, surveillance, and reconnaissance (ISR) missions. All three systems are smaller in size and weight than the "Sea Lynx" and would

fit onto the German ASW frigates. All these systems are capable of conducting flights of between at least 5 and up to 12+ hours with some payload. Concerning the requirement to deploy a dipping sonar, only the K-Max and MQ-8C Fire-X are capable of carrying the payload of a dipping sonar (approx. 300 kg), but they are not designed to accommodate it internally; so they would need a major redesign. No serious data are available concerning their mission endurance when conducting a typical dipping sonar mission, of course, because this unique flight profile with many and long hovers has not been flown by any UAS yet. The current endurance of the Fire-X of 11 hours with a payload of 600 lbs (max. internal 1000 lbs) promises dipping sonar flight-profile performances which are superior to every current available and manned ASW helicopter, but it combines this performance with a lot smaller size and weight footprint. However, even when none of these UAS is really usable for dipping sonar missions, these UAS demonstrate the tremendous endurance increase in contrast to manned ASW helicopters combined. Therefore, they represent the basic technical feasibility of naval ship-borne helicopter drones and the expected endurance increase for a sonar dipping system.

d. Complementary Possible Solution for all Alternatives

An additional solution is to free the helicopter from its torpedoes; torpedo engagement would be done by the ships themselves. Usually ships are out of range to deploy torpedoes on the tracked threat, but developments such as “MILAS” can increase their range up to 32nm. “MILAS” is a surface launched ASW-torpedo carrying missile system and uses an MU 90 torpedo which is also in service of the German Navy.



Figure 47. “MILAS” missile.



Figure 48. “MILAS” system components.

e. Summarizing and Assessing the Alternative’s Features

The first alternative represents a typical multi-role helicopter which covers several more requirements than just an ASW. The disadvantage of this design is that it lacks the fuel capacity to fulfill demanding endurance requirements like those of the MH90 with four hours ASW endurance. It is not known if the AW 159 can perform the maximum endurance with full ASW equipment and torpedoes, but due to the high power performance increase over its predecessor, we can assume so. Furthermore, it seems that this solution is not capable of using sonobuoys and dipping sonar in parallel, because the available room in cabin is not sufficient to accommodate both sensors at once. The IPT has to release a request for information (RFI) from the producer to get more detailed information regarding performance, functionalities, technical design features, and basic costs. This solution approach would satisfy the CPM’s request for identifying and assessing of available products. This solution also promises an immediately available product and a low risk related to schedule and funding because there is no need for any development. Even less integration is required if ordered “off the shelf,” but this solution may not meet all requirements. It depends on the KPPs and the decision makers whether this alternative can stay in the selection process, or if it must be eliminated due to missing the minimum requirements to fill the capability gap.

The second alternative solution would include the organic ASW ship in the development and procurement process for ASW weaponry and sonar data processing

and management systems. However, in contrast to the first alternative, it could increase mission endurance significantly. This approach would satisfy CPM's need for assessing in-service materiel. The IPT must also release RFIs to all concerned producers of the helicopter, missile, and the ships to gain information and data for further assessment processes. Furthermore, this solution approach needs research and technology (R&T) that also involves modeling, simulation, and prototyping to evaluate technical feasibility in respect to helicopter modification. That solution promises a medium-term available product.

The third alternative represents a solution which concerns a new product and realization regarding the aerial vehicle and the systems on board the organic ships. This solution requires the most intensive R&T process including modeling, simulation, and, in particular, prototyping of the aerial system and the ground system on board the ships. Depending on the technical feasibility a UAS could fulfill or even exceed the endurance requirements, and most likely it can carry all needed ASW sensors and weapons at once. This third solution would also heavily involve the organic ship in the system development and design process, because the UAS has to be accommodated, maintained, controlled, and operated on board the ship by its crew. Most likely many other hardware and software changes need to be done also to establish line of sight (LOS) connectivity for VHF/UHF radios in order to integrate this solution successfully into the existing ASW ships. Therefore, in terms of time requirements and R&T funding concerns this is the most challenging of the three basic solutions. On the other hand, it promises the best performance potential and maybe the greatest cost savings over the life cycle, as the K-Max UAS has already impressively proved in Afghanistan (Price, 2013). The third solution has only long-term availability and has most likely the highest level of high risk concerning technical feasibility, schedule, and funding because of the need for complete development and full integration of the drone with ground control and operation management on the different ships. Even so, it promises the highest grade of fulfillment concerning the requirements and perhaps the lowest life-cycle cost as well.

All three alternatives promise a possible solution. Every one, of course, promises a different cost, schedule, and performance, which are called *triple constraints*

in military program management and reflect the program manager's basic goals. Further steps of the process of preparation for decision making will help to measure and evaluate each alternative with respect to the triple constraints.

An additional solution, which supports all three aerial solutions, is the “MILAS” system that would at least benefit all three solutions. It is independent from the aerial system and allows us to free the helicopters from the torpedoes (weight) when operating within a 30 nm radius of the ship. The 30 nm radius screen is a typical ASW scenario (Figure 49) to protect carrier strike groups (CSG) with ASW helicopters (NPS capstone project, NPS-SE-08-002, 2008). The same is perhaps true with respect to shifting the mission data processing and management components and crews from the helicopter to the ships. In particular when the aerial ASW systems operate within line of sight (UHF/VHF) to the organic ship, which is what happens usually when conducting ASW escort missions. In this situation, data transmission is not a technical and security issue, and it has already been applied this way by NATO navies for decades using the naval Link 11 and Link 22 components on ships and aircraft.

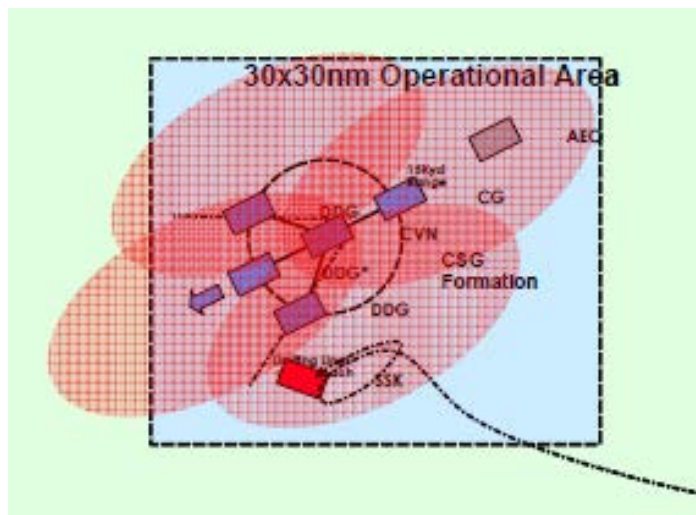


Figure 49. Helicopter coverage area according to NPS capstone project [NPS-SE-08-002, 2008].

The systems engineering design process applied so far has enabled us to identify the functions and physical components and their allocation within an ASW system of systems. It is true that an aerial ASW system does not need all functions and

physical components combined into one system as is currently the case with ASW helicopters like the MH90 and SH-60R. The ASW system can also consist of several systems which operate in a system of systems. The IPT should take the newly gained knowledge into consideration and should separate, regarding the CPM's analyzing process, the "MILAS" and the mission data processing and management system from the original ASW need process. Both systems are ships systems and should be researched and analyzed by another "ship"-IPT that should work parallel to the original ASW-IPT. However, the ASW-IPT should proceed with all three possible aerial solutions.

3. Detailed Design of the Alternative Solutions

a. Introduction

Refining the requirements, basic work breakdown structures (WBS), specifications, and measures of performance need to be determined to enable the IPT to develop further the alternative solutions and to understand their functions and physical architecture. Subsequently, it will enable the IPT to task contractors to conduct studies, research, modeling, and simulation on the possible solutions to get more information about the technical feasibility and technology readiness level (TRL) of each alternative. It is required to provide the contractor with a comprehensive and sound request consisting of accurate and well-written specifications, as well as limited scenarios and test cases to support the contractor's understanding about their task if useful results are expected. The first alternative is already available "off the shelf," and therefore, it will not be discussed further in this thesis. The same is valid for the second alternative. Therefore, the remainder of this thesis will focus on the third alternative to proceed with the application of systems engineering methodologies and tools.

b. Work Breakdown Structure

The WBS illustrates all basic physical components on all levels to produce a system and how to integrate the components on each WBS-level of the system. Because a WBS captures the work necessary to develop and produce a system, according to Allen (2008), it is an excellent tool to support most activities within project work. The MIL-HDBK-881A (Under Secretary of Defense (AT&L), 2005) delivers an already allocated

WBS for different weapon systems. The following WBS depicts the structure for a UAS from level one down to four (Figure 50). For practical reasons only the UA vehicle and communication are broken down even further. The WBS should be done, of course, for all components on all levels, and as deep as necessary for the work.

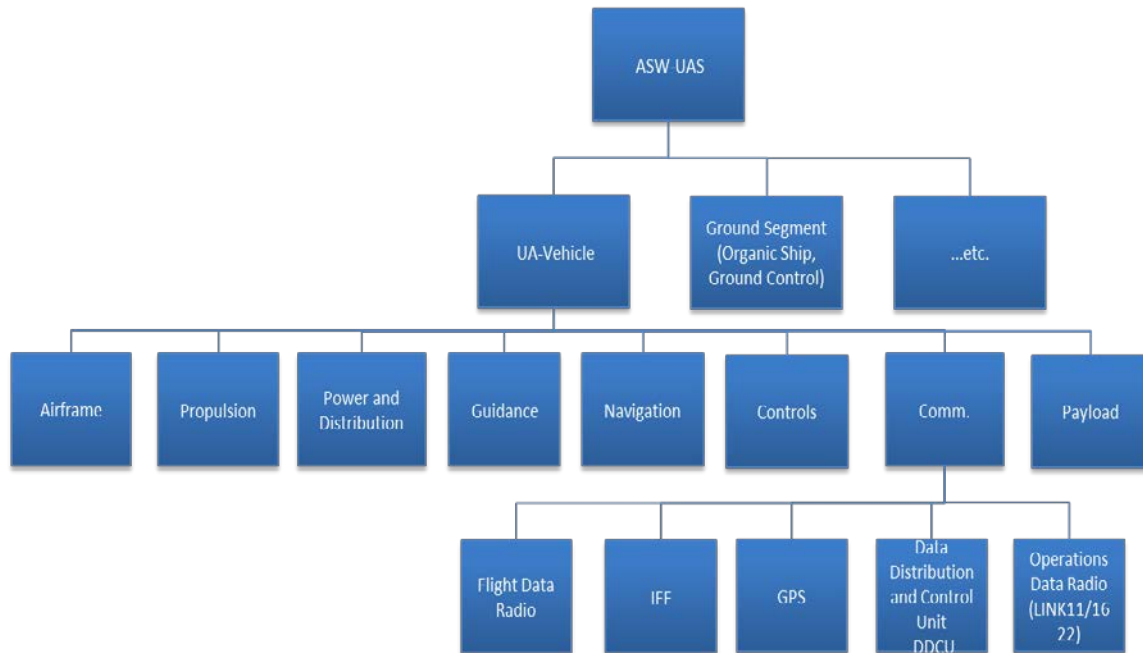


Figure 50. Work Breakdown structure for a UAS according to MIL-HDBK-881A [Under Secretary of Defense (AT&L), 2005].

c. Developing Systems Specifications and Test Cases

Requirements are insufficient for designing a solution to the problem, and must be translated into specifications that can be tested or verified. It is difficult to get sound requirements definitions and specifications. The reasons for this are lack of specification language, incorrect interpretation of user needs, partial knowledge of questions that need to be answered, failure to recognize the critical importance of requirements analysis, and unwillingness to spend the time and funding to get requirements correct at the first time.

Two kinds of specifications are commonly used in military acquisition. A performance specification defines the functional requirements for the system and it shall

state the requirements in terms of the required verifiable results, but without stating methods for achieving the required results. Performance specifications should be preferred if feasible because they state specifics only to the extent necessary for interface, interoperability, and environment in which the system or its component must operate. Performance specifications usually reduce acquisition costs, take advantage of new technology, reduce lead time, and place design responsibility on the contractor.

By contrast, a detailed specification gives design solutions, such as how a requirement is to be achieved or how an item is to be fabricated or constructed. Therefore, detailed specifications specify physical characteristics and should only be used if necessary, for example, to define certain interfaces between components or systems.

To develop sound specifications no single person has all the information needed to lay out the system. It is again a team effort of the IPT and the users of the system to specify the requirements. The Software Engineering Institute (SEI) of the Carnegie Mellon University in Pittsburgh (USA) developed the Architectural Tradeoff Analysis Methodology (ATAM) for software projects (Software Engineering Institute (2013). However, it is also applicable on non-software systems and an effective way to develop specifications based on scenarios concerning function and component. The following figure (Figure 51) retrieved from Prof. Naegle's software acquisition class at the Naval Postgraduate School (NPS) shows the basic relationships involved and the methods used to develop from the need scenarios for use case, growth and exploratory scenarios, and finally to develop test cases to measure and evaluate the specified scenario. (In Figure 51, MUIRS stands for maintainability, upgradeability, interoperability, reliability, and security/safety, and FMECA stands for failure mode, effects and criticality analysis.)

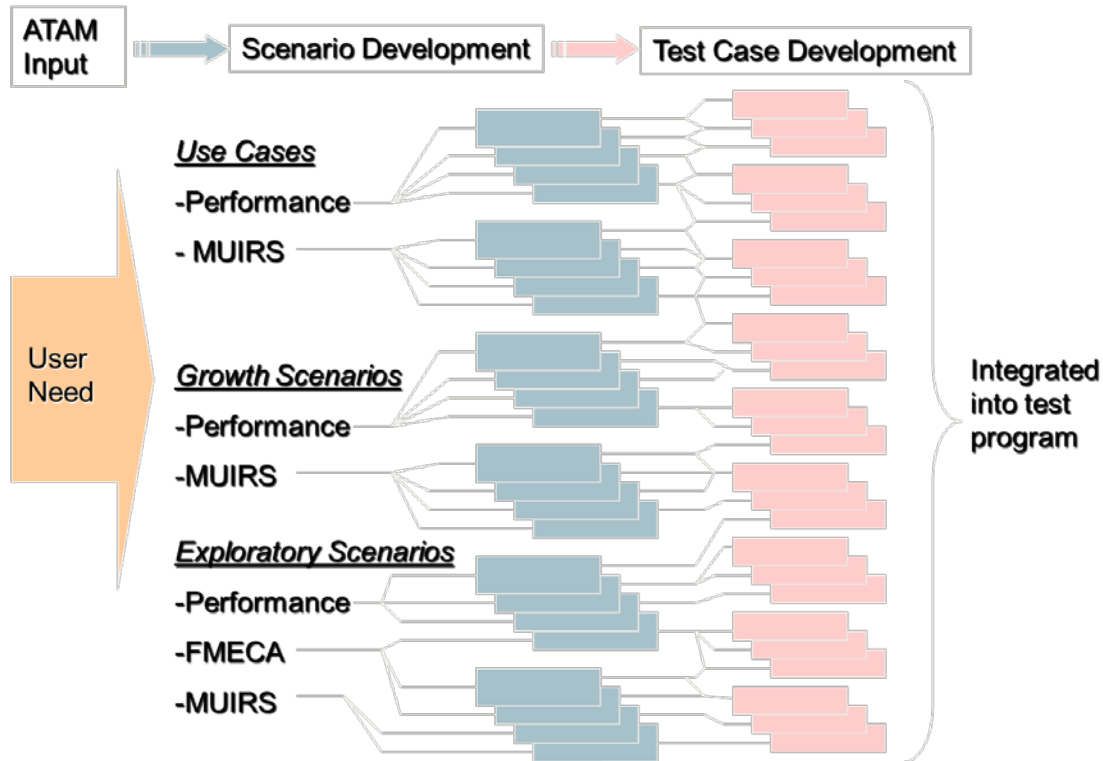
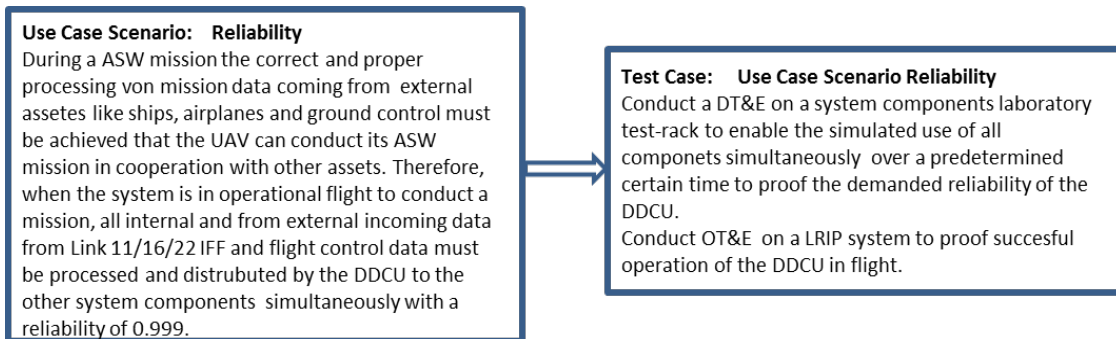


Figure 51. Example of basic application of SEI-ATAM according to Naegle (2013).

Figure 52 illustrates how the requirement of interoperability with regard to the DDCU on WBS level four can be developed into a performance specification related to scenarios and, subsequently, into test cases. This step should be applied for the whole WBS and be broken down as far as necessary to cover all requirements and functions in respect to the components and their specifications and test cases.



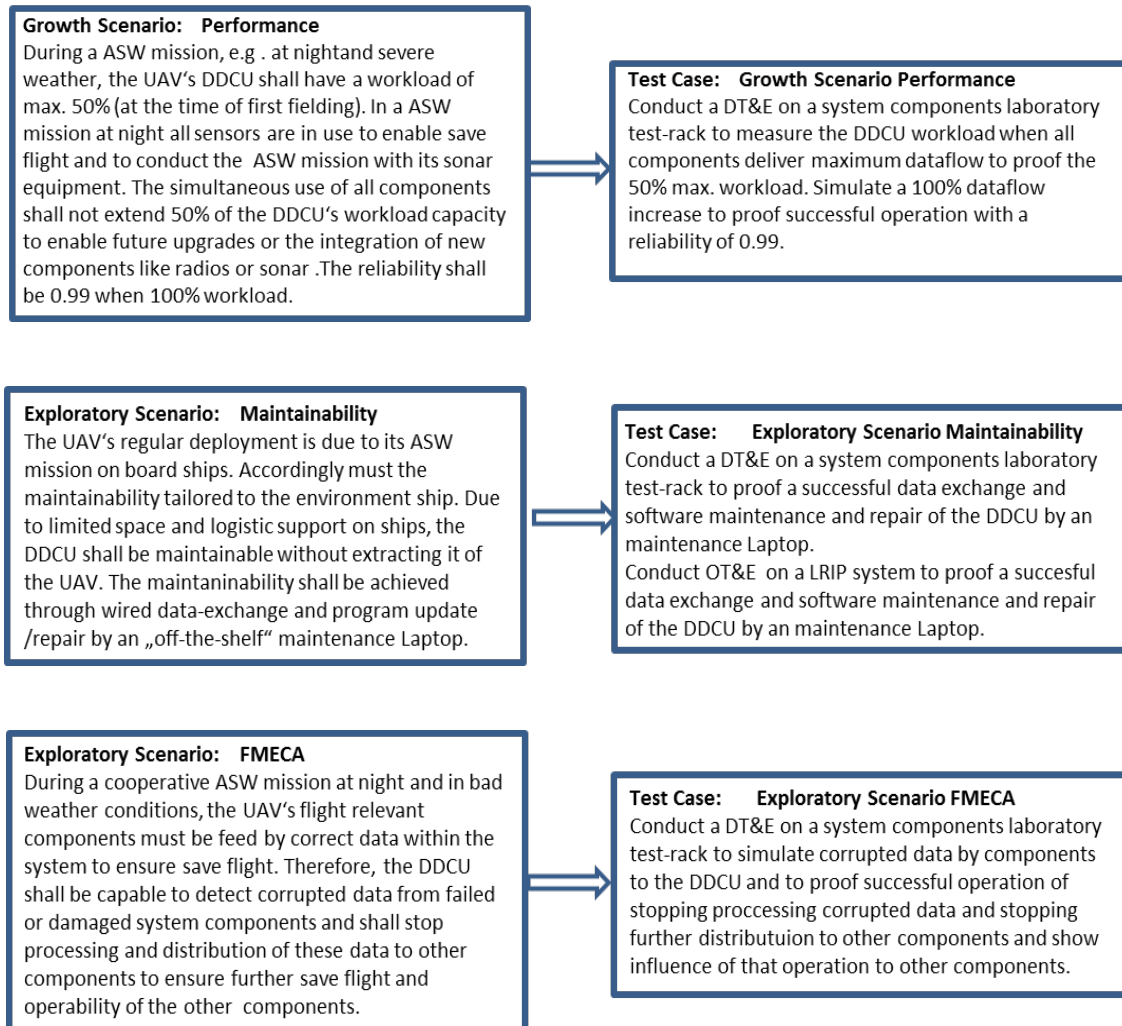


Figure 52. Application of ATAM concerning the ASW UAS.

Many other ways of developing sound specifications and test cases exist. The method examined here is just one way, but a very effective one because the specifications and test cases are derived from case scenarios. As such, they help us to understand the specifications, and therefore, they are easily replicated.

4. Analysis of Alternatives (AoA)

a. Introduction

The *U.S. Defense Acquisition Guidebook* (Under Secretary of Defense (AT&L), 2011) states the analysis of alternatives is an important element of defense and

procurement processes which play a key role in support of the materiel solution analysis phase. It is described as an analytical comparison of the operational effectiveness, suitability, and life-cycle cost (or total ownership cost) of alternatives that satisfy reasoned capability needs, as shown in Figure 53.

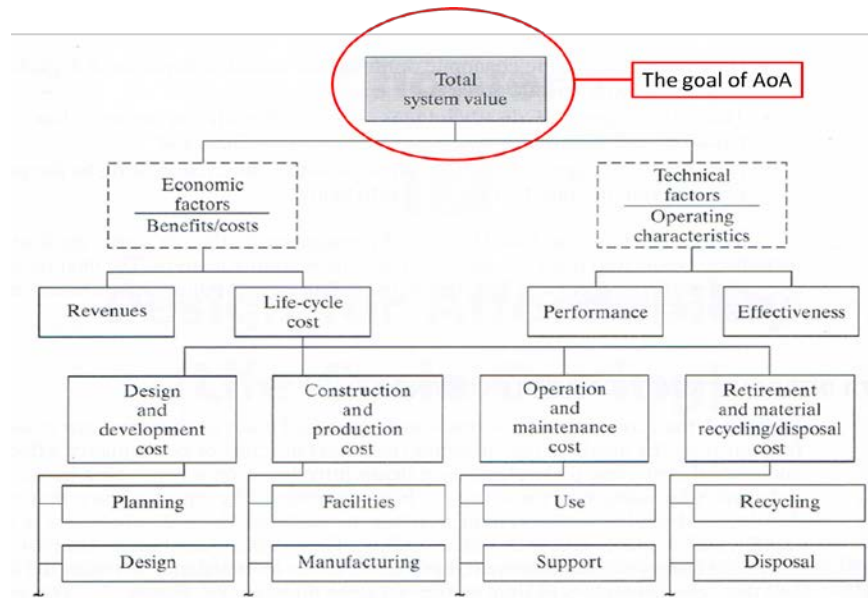


Figure 53. Determination factors of a system's total value [Blanchard, Fabrycky, 2011].

The goal of AoA is to examine potential materiel solutions and in a second step to identify the most promising option. To identify the most promising option, as stated in the guidebook, does not mean to identify only the best and most effective solution, rather it means to identify the most promising solution in respect to many factors, like political and economic, and cost and strategic constraints as illustrated in Figure 54. Therefore, it is very important to understand that even the same solutions would be assessed differently if different nations do the AoA process, due to their different constraints. Once more, an AoA process is not the only way to conducting this analysis. Thus, the AoA processes vary somewhat for weapon and other tactical systems and need to be adapted to each program. In respect to systems engineering, risk management, effectiveness measure, effectiveness analysis, cost analysis, cost effectiveness comparison and presenting and assessment of the results are the steps which

need to be done to be able to present a final report. This true for the CPM's second part of analysis phase, too.

The *U.S. Defense Acquisition Guidebook* (2011) explains the role of the AoA as follows:

The AoA is used to identify the most promising end-state materiel solution, but the AoA also can play a supporting role in crafting a cost-effective and balanced evolutionary acquisition strategy. The alternatives considered in the AoA may include alternative evolutionary paths, each path consisting of intermediate nodes leading to the proposed end-state solution. In this way, the Materiel Solution Analysis can help determine the best path to the end-state solution, based on a balanced assessment of technology maturity and risk, and cost, performance, and schedule considerations—. The rationale for the proposed evolutionary acquisition strategy would be documented as part of the Technology Development Strategy.

Materiel Solution Analysis and Technology Development Strategy

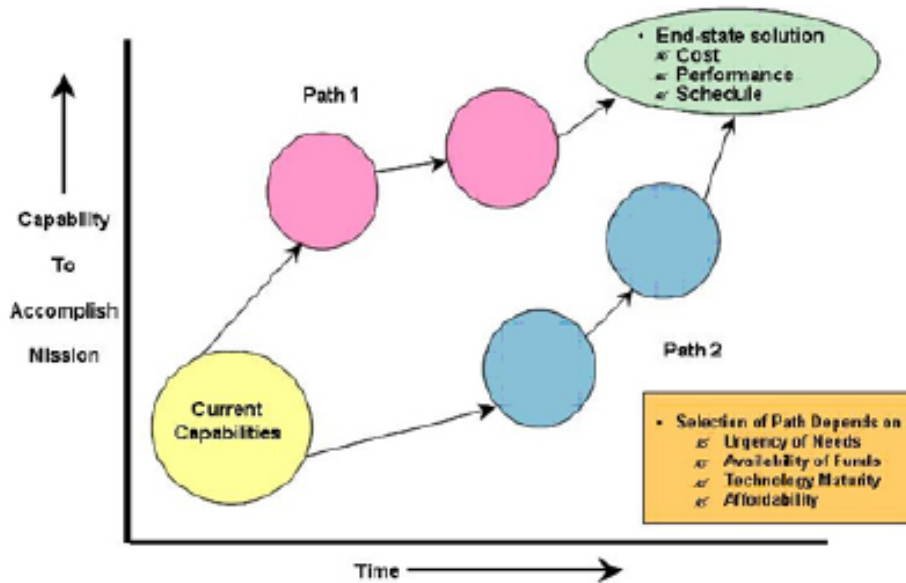


Figure 54. Establishment of an evolutionary acquisition strategy according to the guidebook.

b. Evaluation Measure

Evaluation measures are a necessary step before requirements will be defined. With regard to military acquisition processes, especially during the early FFF-phase, it may not seem very applicable. Therefore, evaluations measures can also be used to verify and improve or even correct the early requirements because they contain performance and quality definitions.

In AoA, evaluation measures help to verify and validate the studies, research efforts, delivered detailed information, and data with respect to the most important KPPs. Evaluation measurement is accomplished using a quantifiable form with a clear definition of the measure and the units associated with it, and should focus on what is important objectively (Figure 55). Later, during the analysis of alternatives process, they are used to measure the level of success of alternatives with respect to the requirements and cost.

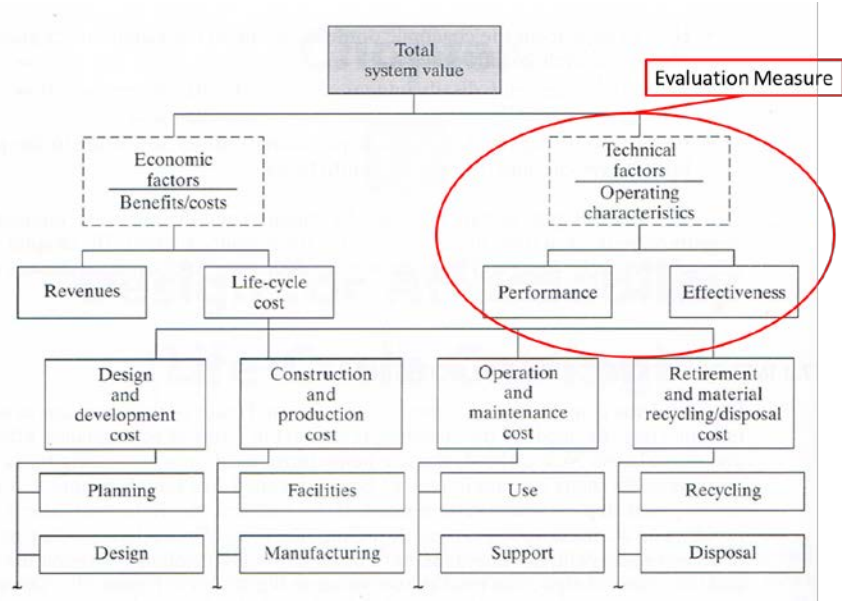


Figure 55. Determination factors of a system's total value [Blanchard, Fabrycky, 2011].

Measures of performance must be related to the requirements stated earlier and to KPPs. The ATAM process enables us to develop traceable measures of performance for each alternative component. Testing enables us to deliver results of performance measurement for validation and verification, and it should be conducted throughout an acquisition process. The performance measurements can later be used for the measure of effectiveness.

Figure 56 illustrates the path from requirement, which is converted to a physical component according to the WBS, down to the sub-component and to its specification and test cases which delivers the measured performance.

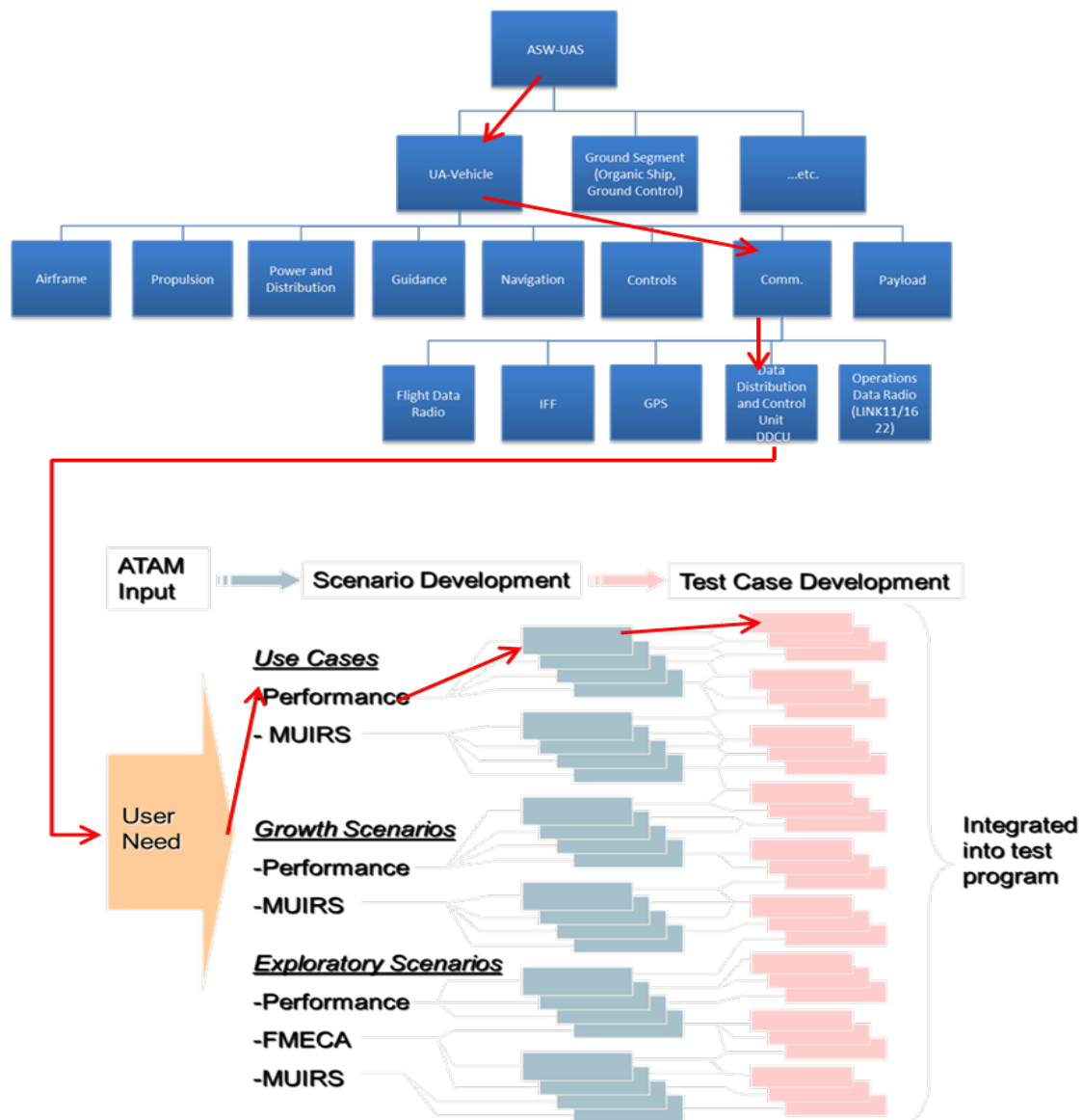


Figure 56. The path from requirement and physical component to performance.

An attribute of evaluation measures should be traceability from technical performance measure (TPM), to measure of performance (MOP), and finally to the measure of effectiveness (MOE) of the alternatives. Figure 57 (which originated in Prof. Miller's Systems Engineering class at NPS) shows the path from technical performance measurement up to measure of performance and at least to the measure of effectiveness (MOE).

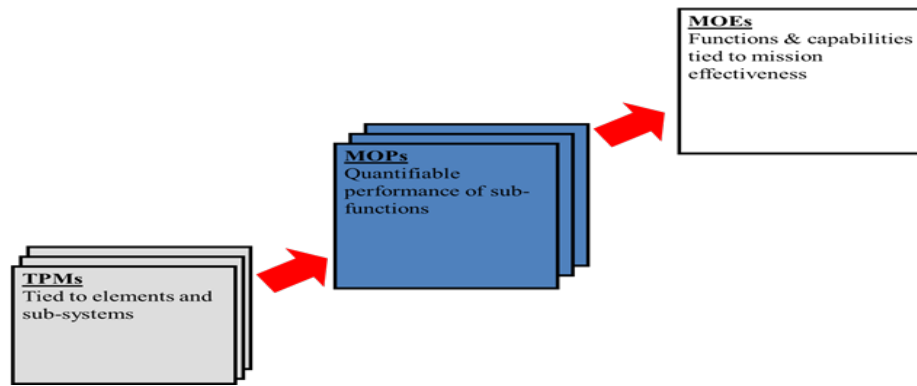


Figure 57. Evaluation measures and traceability according to Miller (2012).

Evaluation measurement quantifies the performance for each capability of the components and the system as a whole, and the value functions define the value of each evaluation measurement row data's score. The way to measure the effectiveness is to get raw data from the measure of performance and to transform them into values. It depends on the decision makers how the values will be weighted. According to the preferences of the decision makers the value functions can be linear, convex, or concave as is shown in Figure 58.

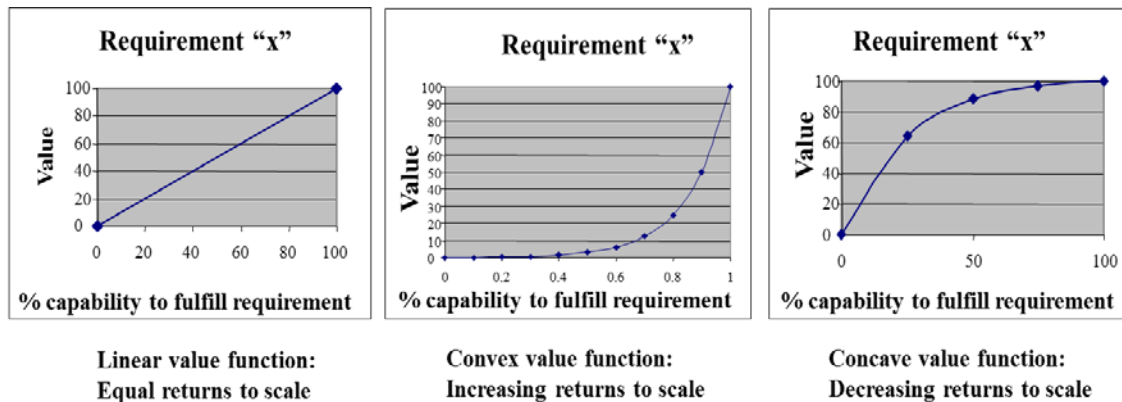


Figure 58. Different kinds of value functions.

The values of each evaluation measure need to be put into a table and weighted with the decision maker's weights in respect to the importance of each

evaluation measure. Each alternative's total value score is calculated by multiplying the values with the weight and adding them. The following numbers shown in Table 5 are random numbers used for explanation and might apply to the proposed alternatives.

Evaluation Measure	Global Weight	Alternative 1	Alternative 2	Alternative 3
Maintenance	0,15	65	58	85
Embarkation capability	0,2	92	92	80
Endurance dipping sonar	0,25	30	50	90
Endurance patrol	0,05	30	60	100
Environment capability	0,15	100	100	70
Network capability	0,2	65	85	90
Total Value Score	1,00	65.15	74.6	84.75

Table 5. Basic performance total value score matrix.

The third alternative solution shows the highest score with respect to the measures and weights. The score reflects the effectiveness related to the measures. Effectiveness is defined by the inputs of the operational scenarios, requirements, the alternative system's attributes, like performance, and the preference inputs of the decision makers as depicted in Figure 59. The measures used in the result or decision matrix covers truly not all relevant issues concerning the ASW need. It just give the level of performance to some requirements. Many more requirements and even more operational ASW scenarios exist.

Another, much more comprehensive and sophisticated way to get results and determine a system's effectiveness is by conducting operations research (OR) methods originated during World War II as a response to tactical problems relating to the efficient operation of weapon systems, and to operational problems. Today, mission effectiveness can be best determined through conducting OR methods because it ties functions and capabilities together with mission effectiveness.

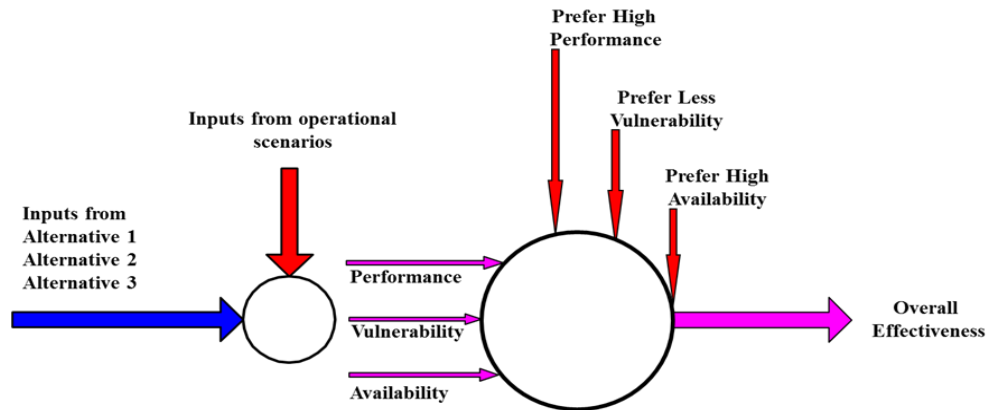


Figure 59. Input flow diagram concerning effectiveness according to Hansen (2012).

According to Hansen (in Cost Benefit Analysis class at NPS, 2012) OR has evolved since then to a full-scale scientific discipline that is practiced widely by analysts in industry, government and the military. OR is a development and application of mathematical models, statistical analyses, simulations, analytical reasoning and common sense to the understanding and improvement of real-world operations. Improvement can be measured by the minimization of cost, maximization of efficiency, or optimization of other relevant measures of effectiveness.

The military uses OR at the strategic, operational and tactical levels. OR improves decision making and facilitates insights into the phenomena of combat. OR applications cover military activities including: national policy analysis, resource allocation, force composition and modernization, logistics, human resources, battle planning, flight operations scheduling, intelligence, command and control, weapon selection (weapon system effectiveness, cost, compatibility and operability), engagement tactics, maintenance and replenishment, and search and rescue (NPS, Department of Operations Research, 2013).

With respect to the ASW need, OR can research the alternative's performances against certain scenarios by using mathematical modeling and in a later step by programming software and conducting simulations. Accordingly, OR requires all parameters concerning the operational concept and some specific operational scenarios.

Furthermore, performance parameters of the different airframes, sensors, and weapons are required to develop and program models of each alternative. The needed data for operational scenarios should be available, because they already developed und delivered by the users during earlier process steps.

The data concerning alternative one and two can be requested from the producer, but alternative three has not yet any producer. Logistic data, like availability, concerning alternative two are available because it is service and data can be requested from the Materiel Command. Concerning alternative three data from related projects, other UAS, studies, and technical research should the IPT enable to deliver some value data for an operational research. The alternative's sensors are all the same because they are set by stakeholders and decision makers as common sensor solution. Therefore, the operational research has to focus on the mission effectiveness in respect to the performance like endurance, numbers of possible dipping cycles, availability, and deployment of weapons. It must be acknowledged, that conducting a comprehensive operational research is not what an IPT can perform rather, it must be ordered to an specialized military department or civil contractor must be tasked. OR contains methodologies, which requires special skills and knowledge which can be only properly applied by OR-educated, specialized and trained personnel. Accordingly, an operational study on the ASW-need could easily extend to a thesis itself and can, therefore, not be covered in this thesis.

c. Life-Cycle Costs for the Alternatives

The fundamentals of life-cycle cost (LCC) are already described in Chapter IV with respect to the basic ASW-need system for the FFF-document. The LCC analysis in the FFF-document is based mainly on conceptual design with little actual data available. The analysts use past experience and intuition to make rough estimates to support a top-level design decision. By contrast, the determination of the life-cycle costs related to the three proposed alternatives cannot be based on estimations only. To get a cost related performance comparison for the AoA process by applying a cost-benefit analysis (CBA), the costs of each alternative solution with respect to its life-cycle must

be conducted in advance. Life-cycle cost is composed of many different factors. These factors are illustrated in Figure 60. The number of factors shown enables us to estimate the vast pile of work “just” to determine a system’s total cost. Therefore, this task is more a study on it its own which could be covered by a single thesis or capstone project. Thus, this thesis will not conduct LCC research and calculations because no real data are available, and it would be out of the intended scope. However, a basic discussion regarding LCC will be presented.

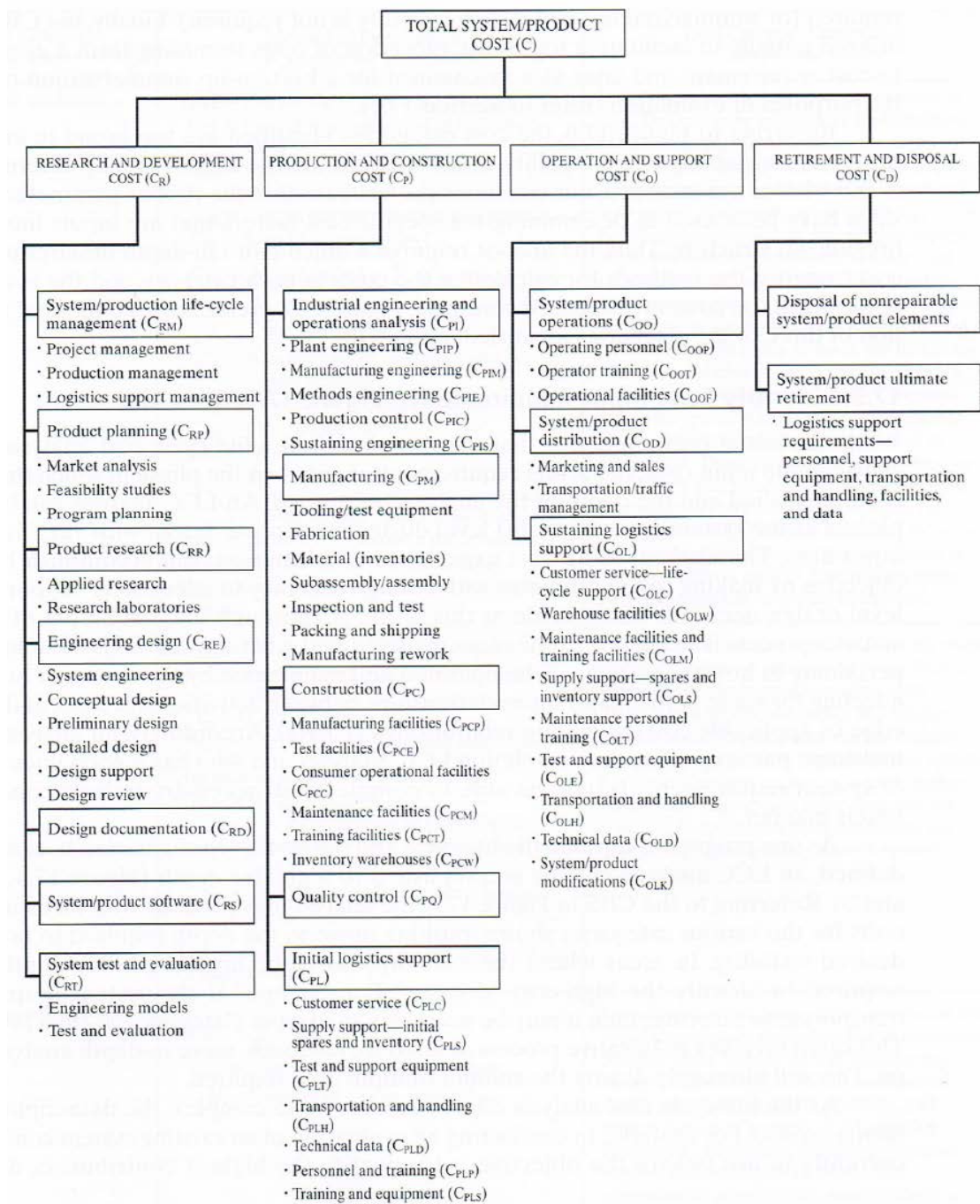


Figure 60. A general cost breakdown structure (CBS) [Blanchard, Fabrycky, 2011].

Blanchard and Fabrycky (2011) explain that LCC analysis needs an analyst with a thorough understanding of the LCC process and who has some knowledge

of how the system will be operated and maintained by the user, and also an understanding of the major interrelationships between activities and costs. As the program progresses and a more specific definition of the system emerges, then LCC analysis can be accomplished in greater depth. Even so, the LCC analysis relies heavily on estimation which is based on the experience of the analyst. Furthermore, they state that due to increasing data-input requirements the LCC analysis becomes more complex. That may apply especially for our first two alternative solutions because of their already existing system configurations in use. It may be appropriate to solicit LCC data from diverse sources from the producer and other involved companies, for example, for maintenance, and from different departments within the German Armed Forces which have cost data related to the system. Analyzing production cost is usually a task that should be done by the producer. However, the LCC analyst of the IPT should be able to understand, validate, and assess these numbers to implement them correctly in the LCC analysis.

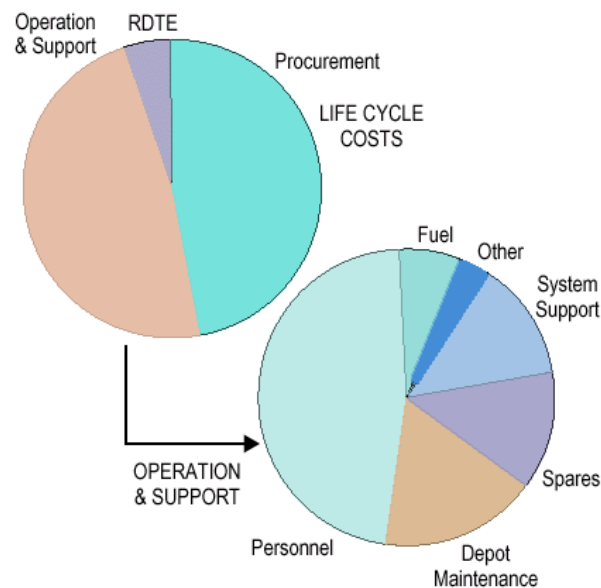


Figure 61. Example of shares of cost factors regarding total system costs [tms.org, 2013].

Up to 50% of the total life-cycle cost can be caused due to research, development, test and evaluation of a new system as shown in Figure 61, but meanwhile the share of operation and support (O&S) cost of new weapon systems will increase more

and more in relation to the total costs. The JSF program is an example of increasing O&S costs. Figure 62 shows the increase of estimated O&S costs over the last decade in comparison to the acquisition costs.

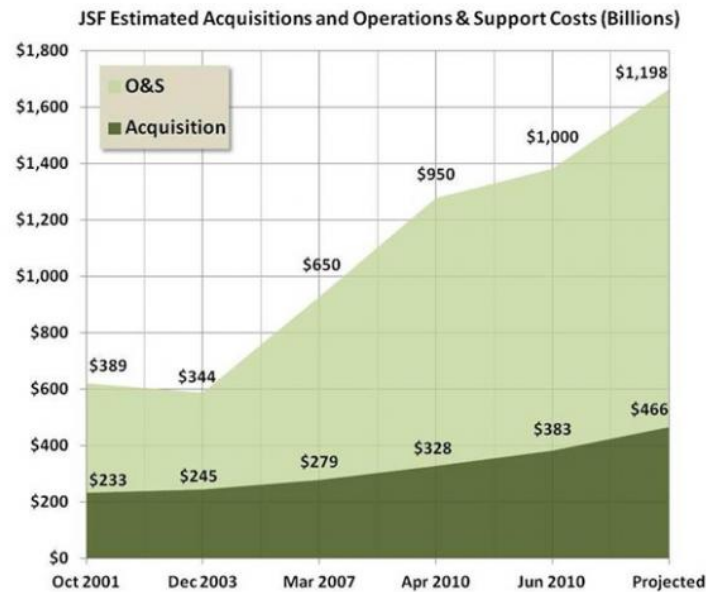


Figure 62. Estimates of acquisition and O&S cost of the JSF program from 2010 [mca-marines.org, 2013].

The LCC analysts of the IPT should seriously care about the O&S costs. In the beginning of a program these costs are often highly underestimated, as Figure 62 shows. A reason to underestimate O&S costs may be the high involvement of software related components in a new system. Such an example is the F-22 Raptor for which approximately 85% of all functionality is software driven (Naegle, 2013). Therefore, a major driver of increased O&S costs today is the complex software of the weapon systems, which can account for up to 40% of the overall O&S costs depending on the complexity of the weapon system. The cost to maintain software today is typically between 60% and 80% of the software component total life-cycle cost because software maintenance is personnel intensive (Naegle, 2013). Many old weapon systems do not have this software complexity and cost intensive maintenance. Accordingly, their cost-

data does not reflect much data concerning software. That might be one of the reasons that experienced LCC analysts currently underestimate O&S costs.

Another major driver of O&S costs is the required availability of the system. Operational availability (Ao) is defined as follows:

$$Ao = \frac{\text{uptime}}{\text{uptime} + \text{downtime}} = \frac{\text{MTBM}}{\text{MTBM} + \text{MDT}}$$

- MTBM (Mean Time between Maintenance)
- MDT (Maintenance Down Time)

Ao is a commonly used readiness measure for weapon systems, and this value represents the percentage of weapon systems in mission capable (MC) status.

$$Ao = \frac{\text{number of MC systems}}{\text{total number of systems}}$$

According to the formulas, Ao is only alterable by changing the MTBM and MDT that addresses the reliability of the system before it breaks and in terms of the maintenance effort, which is the time needed for maintenance (MDT). Maintenance itself must be distinguished in terms of scheduled and unscheduled maintenance. Scheduled maintenance includes the maintenance activities that are determined by the producer of the system to keep a system safe and available. Therefore, the data about scheduled maintenance are sensitive to the LCC analysis and are valuable. They enable us to analyze one of the most important drivers related to availability and cost. Unscheduled maintenance is a reliability issue of a system. Concerning our second proposed alternative, the reliability data can be filtered from the maintenance log files. Our first alternative uses many major components and parts from the second alternative solution, including the gearboxes, rotor-head, rotor-blades, landing-gear, etc. Thus, reliability data can be derived from the maintenance log files and analyzed for this solution also. The

reliability of our third proposed solution must be calculated based on the reliability data of parts and components with respect to its functional and physical architecture.

Maintainability is a basic need requirement and is indirectly specified within the operational availability of 85%. Actually, that specification does not specify the reliability and maintainability itself. Maintainability is dependent on the level of supply, which is indirectly specified through the availability rate and requirement that a certain level of the supply must be stored on the organic ship.

To cover all these hardware and software maintenance issues, a logistic concept is required to analyze costs when the system is embarked and also when land based. The logistic concept should be part of an operational concept which must be refined and adapted for each alternative solution from the basic operational concept already developed during the FFF-phase. The logistic concept determines many of the O&S cost drivers, like the way of maintenance and supply, determines the required personnel, facilities, spare-part level, training, and some more concerns.

It can be summarized that experienced LCC analysis personnel are required to understand the complex interactions and connections of the life-cycle theory and its construct to conduct a comprehensive and useful LCC analysis. That requires the effort and support from producers, military and civil departments of the German armed forces to generate and deliver these data. Additionally, only when a logistic concept exists, then, according to that concept, the LCC analyst is able to determine the composition and proportion of each of the logistic cost drivers and to present correct and valuable life-cycle cost calculations for each alternative to enable the IPT to compare the costs of the alternative systems to their effectiveness.

d. Risk Management

Risk management in defense acquisition and procurement plays an even more critical role than it does in commercial projects according to Allen (2008). Risk is defined as an uncertain event or condition that, if it occurs, has had positive or negative effect on the projects objectives. Furthermore he notes that the U.S. DoD defines risk as a measure of future uncertainties in achieving performance, schedule and cost goals.

Military weapons systems are one of the most complex and sophisticated products which require large sums of tax payer money. Risk management is conducted through the programs life-cycle, and one of the PM's major concerns is to achieve that the program within cost, schedule, and performance. As Blanchard and Fabrycky (2011) note, risk management consists of four basic categories. These are technical risk, cost risk, schedule risk and programmatic risk. Furthermore, they explain that the potential risk becomes increasingly greater as complexity and new technologies are introduced in the design of systems, and as the number of program suppliers increases through outsourcing. That is especially true for many major weapon systems programs due to the political requirement to involve many national companies. Figure 63 depicts the relationship between the four basic risk categories according to the INCOSE handbook (Haskins, Forsberg, Krueger, 2010).

Risk involves three elements. Allen (2008) explains that these are a future event, the probability of that the future event occurring, and the consequence of that future event occurrence on the program's cost, schedule, and performance objectives.

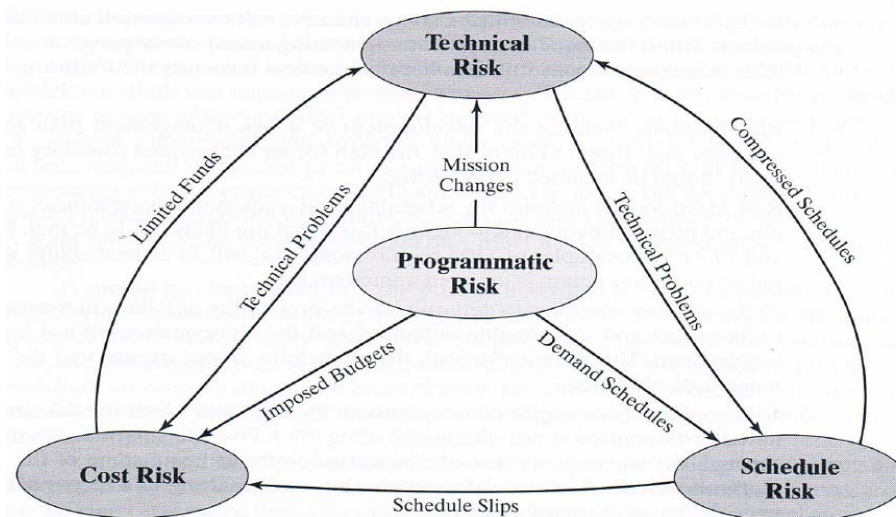


Figure 63. Relationship between risk categories.

Furthermore, Allen (2008) states that in the context of program management the level of risk is the highest in the beginning of the program and decrease

as it progresses to completion (Figure 64). Therefore, an early risk management is vital in a military program.

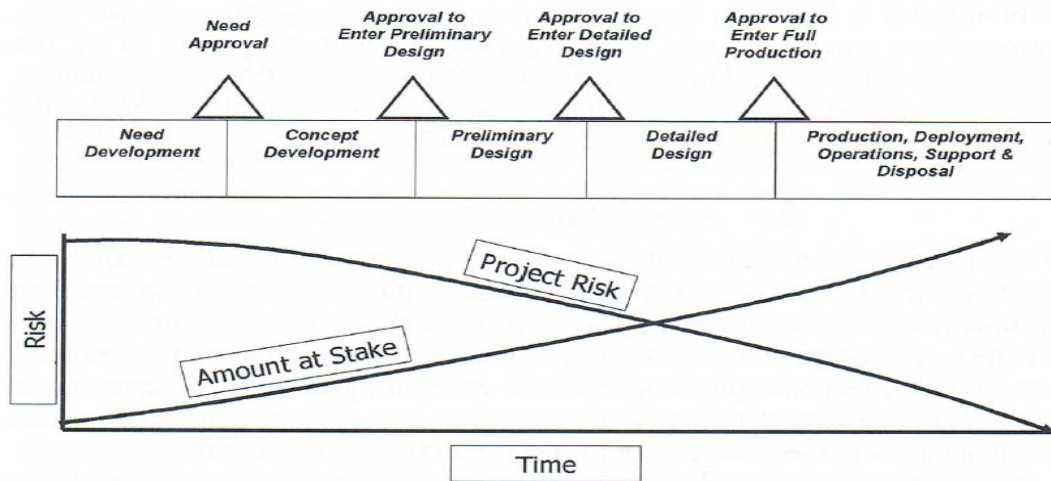


Figure 64. Risk and program life-cycle relationship according to Allen (2008).

Risk management contains five basic steps and is considered an iterative process:

- Risk identification
- Risk analysis
- Risk mitigation planning
- Risk mitigation implementation
- Risk tracking

The following risk management process model (Figure 65) according to US DoD PM Tool Kit illustrates this iterative process (Under Secretary of Defense (AT&L), 2009).

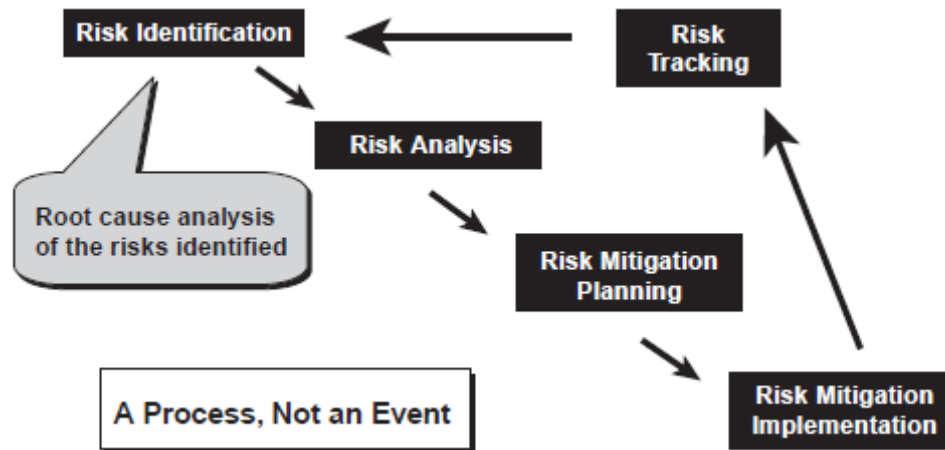


Figure 65. US DoD Risk management process model.

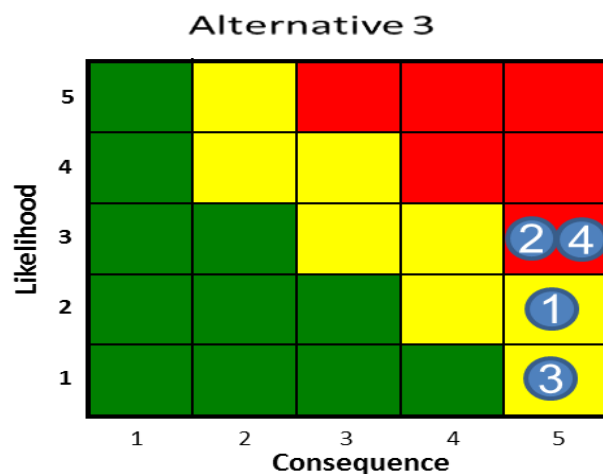
Risk planning includes the development of a risk management plan, which should be part of the systems engineering master plan. Risk identification includes the screening of the all requirements and those which are not likely to be met. Risk assessment concerns the determination of the probability not to meet a specified requirement, and risk analysis determines the way in which the risk can be eliminated or minimized. At least, risk handling includes all activities associated to change or modify the process and later the system (Blanchard, Fabrycky, 2011).

With respect to the ASW need and the current stage of the process phase, the problem of all the so far gained data about costs and performance of the alternative systems is the level of uncertainty. Many of these data are based on estimations, results from modeling and simulation, or just promises from the producer. Some of the data might be precise, others might be off by up to 50%, and some are completely wrong. That problem must be addressed by the IPT through reflecting risk. The risk areas of the alternative solutions should be identified. In particular the technology readiness levels (TRL) of the proposed solutions should be identified, assessed, and analyzed as a major matter of consideration of the selection process of an alternative solution. Information and data delivered from the contractors and studies should enable the IPT to conduct these steps. Figure 66 is an example of TRL assessment conducted on the ASW need related to some of the KPPs.

KPP / product	embarkation , maintenance, operation (TRL)	environmental conditions (weather) (TRL)	using peer sonar data processing and management capabilities	current naval networks capability	"x" sonar dips per hour for "x" hours in a distance of "x" nm
Alternative 1	8	8	3	9	-
Alternative 2 as SoS	9	9	3	8	3
Alternative 3 as SoS	3	5	5	5	5

Figure 66. TRL in respect to some of the KPPs of the ASW need.

Figure 67 includes a risk matrix and explains the risk event, likelihood of the event, and consequence level. This way of conducting and illustrating is proposed by the U.S. DoD risk management guide for acquisitions (Under Secretary of Defense (AT&L), 2006). The likelihood and consequence levels are already determined by the risk management guide. The users of this tool need to compare the identified risk areas with the definitions. A conducted risk assessment with respect to some possible risk areas of our third alternative solution is shown in Figure 68. It must be applied, of course, for all three alternatives to get comprehensive understanding of their risk areas and the likelihood and consequences.



#	Risk Event (Future Root Cause)	Likelihood Level*	Consequence Level*	Cons Type	Risk Rating	Planned Mitigation (what, when, who, funding)
1	Aerial system will not meet requirement for take-off/landing up to sea state	2) Low likely because US Navy UAS have already proven technical feasibility	(5) Cannot meet KPP, has impact on performance, schedule and cost due to more development efforts	Perf., cost, schedule	Mod	Assume Risk; plan for consequence, focus on design and interoperability with organic ship, reduce KPP from sea state 6 to 5
2	Failure to establish sonar data transfer and processing from ship to aerial system and vice versa (using ships sonar data processing and management capability).	(3) Likely due to involvement of two systems in hard and software development	(5) Will jeopardize program, project cancellation	Perf.	Sev	Control Risk; Make hard and software development a high priority to ensure earlier development, add more senior programmers and frequent reviews
3	Aerial system will not meet endurance performance	(1) Not likely because similar UAS have already proven much better endurance than KPP	(5) Cannot meet KPP, has impact on performance, schedule and cost due to more development efforts	Perf., cost, schedule	Mod	Mitigate Risk; ensure thorough data collection to identify and correct sources of problems TD
4	Aerial system cannot perform sonar dipping KPP	(3) Likely due to integration of an automated dipping sonar and unknown autonomous hover performance	(5) Will jeopardize program, project cancellation	Perf.	Sev	Control Risk; Make hard and software development a high priority to ensure earlier development, add more senior programmers and frequent reviews

Figure 67. Risk assessment applied matrix according to risk management guide.

Consequence Levels/Types

Level	Technical Performance	Schedule	Cost
1	Minimal or no impact	Minimal or no impact	Minimal or no impact
2	Minor reduction; little or no impact on program	Able to meet key dates	Budget or unit production cost increase of < 1%
3	Moderate reduction; limited impact on program objectives	Minor Schedule slip; able to meet key MS / no float	Budget or unit production cost increase of < 5%
4	Significant degradation; may jeopardize program success	Program critical path affected; MS slip < 6 months	Budget or unit production cost increase of < 10%
5	Severe degradation; cannot meet KPP; will jeopardize program	Cannot meet key program MS; MS slip > 6 months	Exceeds APB threshold of >10%

Likelihood Levels

Level	Likelihood	Probability of Occurrence
1	Not Likely	~ 10%
2	Low Likelihood	~ 30%
3	Likely	~ 50%
4	Highly Likely	~ 70%
5	Near Certainty	~ 90%

Figure 68. Consequence and likelihood levels according to risk management guide for DoD acquisition (Under Secretary of Defense (AT&L), 2006).

Another, additional way to address the uncertainty and the robustness of the information is to conduct a sensitivity analysis. There is almost no true and correct data without testing. The data and information are used in the AoA process are the most plausible estimates to cover the uncertainties in the knowledge. The purpose of the sensitive analysis is to acknowledge the underlying uncertainty, and it should convey how sensitive predicted benefits of the alternatives are to change in assumptions (Boardman, 2011). Generally, three basic approaches exist to doing sensitivity analysis. These are the partial sensitivity analysis, the worst- and best-case analysis, and the Monte Carlo sensitivity analysis. With respect to the IPT's capabilities and knowledge, only the worst-best-case analysis is applicable. In particular the Monte Carlo simulation and analysis requires specialist which are not usually available in an acquisition program office or even in the department. Therefore, analysis on the level of Monte Carlo analysis should be contracted to specialized researchers. In contrast, the worst-best-case analysis is within the spectrum of an IPT and is a tool which can and should be applied to understand the uncertainties and the possible negative or positive impact on the different solutions.

e. Cost Benefit Analysis

Cost benefit analysis can be distinguished in two major types, that are the "ex ante CBA" and the "ex post CBA". "Ex ante CBA" is the commonly used CBA. It is conducted during a stage of a project is under consideration and assist in the decision about whether resources should be allocated or not (Boardman, 2011). CBA is a framework for measuring efficiency therefore all costs must be identified and allocated. According to, Boardman, Greenberg, Vining, and Weimar (2011) the process of conducting CBA can be supported by breaking that process down in nine basic steps.

1. Specify the set of alternatives.
2. Decide whose benefits and costs count.
3. Identify the impact categories, catalogue them, and select measurement indicators
4. Predict the impacts quantitatively over the life-cycle.
5. Monetize (attach a currency to) all impacts
6. Discount benefits and costs to obtain present values.
7. Compute the net present value of each alternative.
8. Perform a sensitivity analysis.
9. Make a recommendation.

The AoA process of the ASW need meets the “ex ante CBS” definition and is also true for most likely all governmental projects. However, CBA is only useful for military projects similar to many civil projects where efficiency is in focus, like support contracts for typical homeland services (cleaning barracks, food...etc.). Nevertheless, the nine steps shown here are basically valid and useful for conducting acquisition processes concerning weapon systems. Steps one to seven have already been conducted in this thesis. So, the basic CBA theory emphasizes the methods used thus far to perform the processes to select a system for the need.

f. Cost Effectiveness Analysis

In military acquisition processes related to weapon systems the cost-effectiveness analysis (CEA) is the generally used method because often not all impact areas of a project can be monetized, like the life of a soldier or the success of a military operation. Cost effectiveness (CE) compares alternatives in terms of the ratio of their costs and an effectiveness measure (Figure 69). The costs of the three alternative ASW systems should have already been determined as explained before, and also the measure of the performances, effectiveness, and weights of each system are known. CE is a composite measure of cost (input) to effectiveness (output).

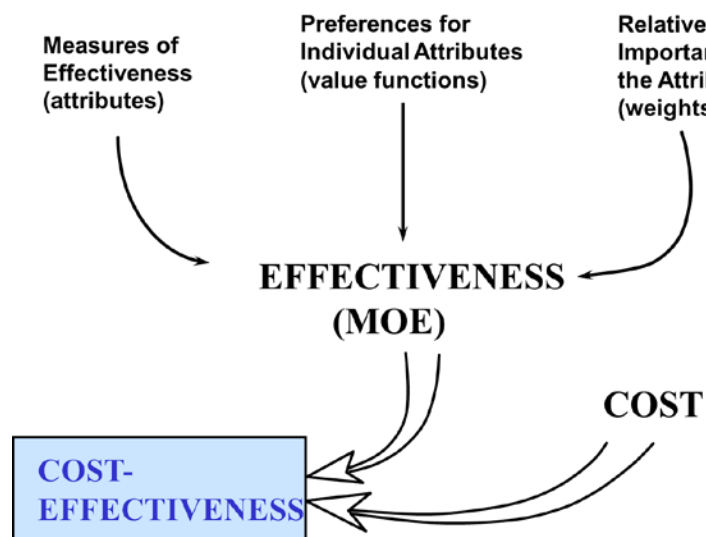


Figure 69. Cost effectiveness model according to Hansen (2012).

Military acquisition is about an alternative that combines maximized effectiveness at minimized cost. Cost-effectiveness is an indicator of how well the alternative does in these two attributes. It's useful to think about CE in two axis space of dominance and effectiveness and to depict it accordingly in graph.

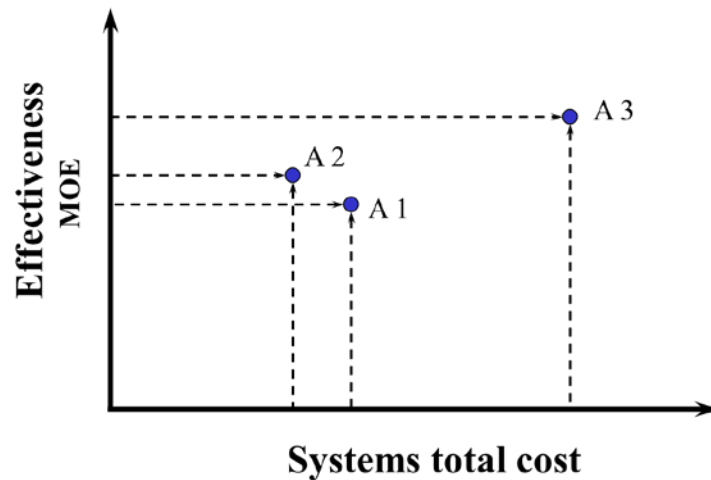


Figure 70. Cost effectiveness graph.

A sample graph of cost and effectiveness of the three alternatives is shown in Figure 70. Our second alternative would be a superior and efficient solution in contrast to our first alternative, but our third alternative shows the highest effectiveness and highest cost. In their final report, the IPT should present all pros and cons of all alternatives and also what is the optimal solution, in particular when the funding is a serious constraint. An optimal solution is a solution that is efficient in respect to its costs and has nevertheless an acceptable effectiveness. According to the graph in Figure 71, that solution would be our second alternative. Defining optimal solutions means also conducting a trade-off analysis with respect to the performance or weights. If money is no constraint because all alternative systems are within the possible program funding, then our third alternative should be presented as primary solution. At least the IPT presents only the alternatives related to performance, risks, costs, and trade-offs because the decision maker selects the alternative system that will become the future ASW system to fill the Navy's gap.

5. Summary and Conclusion

The CPM requests a study and proposal of alternative solutions which will consist of a market available one, a possible improvement of in-service systems, and also of a newly developed system. The chapter presented systems engineering methodologies and tools that enable us to refine the previously established information and knowledge of the need, and to support the identification of a physical solution in accordance to the CPM. Through conducting a system-design synthesis with a system-architecture some alternative solutions could be found and analyzed. Even when the alternatives and their data are not fully researched and designed, the illustrated alternatives could fit basically into the ASW-need requirements. The following process of analyzing alternatives is an analytical comparison of the operational effectiveness, suitability, and life-cycle cost (or total ownership cost) that shall satisfy the reasoned capability needs and fill the gap. The goal of AoA is to examine potential materiel solutions and in a second step to identify the most promising option and to present the information in the final report for the decision makers. The IPT needs to develop the evaluation measures to determine the performance of components and the effectiveness of the system, and they need to conduct a comprehensive life-cycle cost analysis. That enables to conduct an effectiveness to cost analysis that supports the decision makers to find the right system.

VI. CONCLUSION, RECOMMENDATIONS AND AREAS FOR FURTHER RESEARCH

The objective of this thesis was to examine the German basic acquisition guidelines and to examine and apply systems engineering methodologies and tools to the CPM. Our objective was to show where and how the methodologies and tools fit into the CPM's list of deliverables. Furthermore, a basic systems engineering process was conducted with respect to a possible next-generation, ship-borne ASW-system for the German Navy. The purpose of this application was to demonstrate the methodologies and tools on a realistic case common in military acquisition on a basic level. Also this thesis sought to clarify the basic problem of a possible need of a next-generation, ship-borne ASW system for the German Navy's ASW ships.

The current German Defense Guidelines define the role of the German Armed Forces in accordance with current and likely future threats. Similarly, their capabilities will be adapted with respect to the new missions and tasks. The variation and number of needed capabilities underlie the likelihood of risk, threat, and funding. ASW missions currently are no longer considered a primary capability of the German Navy. The unique configuration and flight features to operate from small ships and to deploy a dipping sonar makes an ASW helicopter the only weapon system worldwide which can deliver this kind of anti-submarine capability as a very important defense contribution to a fleet. The new military situation requires multi-role helicopters for all kinds of missions. These state-of-the-art multi-mission helicopters are meanwhile too large to be embarked and operated from older and smaller ASW capable ships, like the F123. The ASW ships in service cannot accommodate the future ASW helicopter (MH90) due to their limited hangar space. This limitation will cause the loss of the ship's important aerial ASW sensor and weapon.

The most important current guideline, the CPM, regulates the principal steps within an acquisition program, the responsibilities between departments as well as between the forces and the BAaINBw. The CPM is a MoD internal guideline concerning the need-investigation, need-cover, and utilization/in-service support processes of any

weapon systems in the German Armed Forces. As soon as a materiel solution is determined by the PlgABw and approved by the MoD for cases with high priority, the PlgABw tasks an IPT to conduct the FFF process and to present an FFF-document that explains the capability gap and determines a need. After the FFF is approved by the Chief of Federal Armed Forces Staff, the leadership of a program changes from PlgABw to the BAAlNBw, which has to develop at least three alternative solutions according to the FFF functional requirements. This is the second part of the analysis process that presents the actual initiation of a procurement program

The ASW is a good example that allows us to go through all necessary and recommended steps of the CPM and to apply systems engineering methodologies and tools. This example, as examined in this thesis, is useful for the tasked IPT to research the problem and to deliver the required CPM's phase documents. Many of the CPM's deliverables such as formulating needs, writing requirements, and conducting analyses comes from the IPT, which consists of military personnel to support the acquisition processes within the civil procurement agency at all levels. The typical German service member is usually unfamiliar with the well-known methodologies and tools applicable in project and program management. Additionally, no U.S. DoD 5000 comparable series exists that could support the work of the acquisition work force with respect to feasible methodologies and tools for military acquisition. As a result many important past acquisition programs have not been successful.

The existing tools in program management are not simply derived from one or two research disciplines; rather these tools come from a wide range of research areas of business and engineering. Modeling, supply-chain management, engineering, decision making, cost benefit analysis, test and evaluation, life-cycle cost, quality management and management soft-skill disciplines are just some of the contributing disciplines. This indispensable knowledge about the methodologies and tools makes program management in military acquisition a comprehensive and complex responsibility. Systems engineering is already a proven and widely-used method for handling projects in industry. Therefore, systems engineering should be a crucial area of knowledge for all personnel in military acquisition programs.

For this thesis, the accepted steps for working through a project were adapted to the guidelines and deliverables of the CPM. The system engineering processes in Chapter IV were shown to be an applicable method in the FFF Analysis Phase and helped to illuminate the ASW capability need thoroughly. The processes enabled us to identify and understand the “wants and needs” of the stakeholders, and also to identify and to select the most important needs. Additionally, the determination of boundaries and top-level functions allowed us to redefine the problem statement. Finally, an effective need could be developed from the early primitive need that enables the IPT to understand the true nature of the need. With all this information, the design alternatives could be limited to an aerial system, and its basic functional requirements could be derived. The life-cycle cost estimation was the last step examined that should enable an IPT to present a sound FFF document.

The applied systems engineering process in Chapter V supported the identification of the functions and physical components and their allocation. It also supports this view within a system of systems. The ASW need system can also consist of several systems which are de-located and operated by several systems in a “system of systems.” By conducting a system-design and system-architecture synthesis some alternative solutions could be found and analyzed. The systems engineering process presented led to three possible solutions in accordance with the CPM requirements. An additional solution which could support the system of systems approach was also proposed that could increase the endurance performance of the three aerial alternative solutions. Although the alternatives and their data have not been researched and designed, they appear to meet the stated ASW-need requirements. The process of analyzing alternatives presented here is an analytical comparison of the operational effectiveness, suitability, and life-cycle cost (or total ownership cost) that will satisfy the reasoned capability needs and fill the gap. The main objective of conducting an AoA process is to examine potential materiel solutions, and in a secondary objective is to identify the most promising option. The process that was partially applied in this thesis should support the IPT in producing and presenting the previously gathered information in a final report in accordance with the requirements of the CPM.

No military program is entirely equivalent to another. Therefore, military acquisition needs to be flexible. It must adapt methodologies and tools to determine solutions for problems, such as capability gaps. Methodologies and tools of systems engineering allow for establishing a flexible analysis process for military acquisition programs that is in compliance with the new German Armed Forces acquisition and procurement guidelines. This enables the involved personnel, like the IPTs, to adapt the methods and tools to the different demands and conditions of a program, and to establish a systems engineering design process pertinent to a specific problem, as this thesis proved. The U.S. DoD already recognizes the usefulness of systems engineering methodologies and tools, and the DoD already uses these tools within its acquisition programs. The DoD 5000 series gives guidance on the principal application of these methods within programs. The German MoD should extend its guidelines to include current knowledge of systems engineering and to educate its personnel about these methods.

The capability gap will become a reality in the near future if the ASW-capable ships receive no redesign and construction to accommodate the new multi-mission helicopters, like the MH90. It depends, of course, on the political and military decision makers to decide how to proceed concerning ASW in the German Navy. However, the research and analysis on ASW has shown that only properly equipped and compounded ASW forces can be successful in conducting ASW missions. Assuming that ASW remains a primary capability in the German Navy, then the ASW capable ships must have a new aerial ASW system which should show improved capabilities over the current ASW systems in terms of endurance and availability. Multi-mission helicopters are always a compromise to accommodate all their missions, and so, they are necessarily limited. Therefore, only ASW-specialized systems promise an increase of performance and availability that might also reduce costs. A highly integrated solution in a system of systems should be preferred in ASW because it opens new possibilities for increased performance when considered against the background of different aerial and surface assets. The German ships already have the advantage of embarking two helicopters, which opens further capability composition possibilities. Multi-mission helicopters could

work with specialized ASW aerial systems, or if necessary, two ASW systems could work together to increase their availability and effectiveness.

This thesis could only conduct a study on a basic level due to time constraints and a lack of available data. That leaves room for more research in respect to the ASW problem and its related need. In particular an operational study on the German ASW issue will certainly illuminate the problem even more and would help to specify the need and requirements for a possible solution. Furthermore, a comprehensive systems-engineering process could be conducted to deliver real data solution proposals for the ASW problem. Further research could lead to the implementation of improved managerial methods and could also provide an expanded view of managerial and decision maker roles and activities in a military acquisition program.

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