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Requirements Management in the Portuguese Navy

An Application to Shipbuilding Projects

Dissertação para obtenção do grau de Mestre em Ciências Militares Navais,

na especialidade de Administração Naval

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Orientação de: Professor Pedro Borda de Água

O Aluno Mestrando	O Orientador
ASPOF AN Marques Ferreira	Professor Pedro Borda de Água

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“Sometimes it is the people no one
can imagine anything of, who do the things
no one can imagine”

Alan Turing

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I would like to extend my sincere thanks to the professors and officers that I have met and collaborate with in the last five years at *Escola Naval*, for the inspiration and enlightenment. This master thesis is the culmination of what I have learned and experienced as a midshipman, so I am thankful to those who help me along the way. I am also grateful to my comrades that supported me since the beginning. To them, I wish the greatest success and best wishes to the next years with the Navy, that lies us ahead.

Finally, I would be remiss in not mentioning my family, especially my parents and my sister. If I am what I am today, it is because of them and because of everything they did for me.

Abstract

Within project management, Requirements Management is considered a critical capability which is accountable for a big slice of a project's success. Since the Portuguese Navy is willing to ensure the acquisition (and construction) of new ships, to guarantee its numerical and qualitative presence in its operational environment, requirements management has become crucial for projects' goals achievement. The aim of this study is to find "where" and "what" it can be improved towards the Navy's improved requirements management. This research is framed according to William Dettmer's Constraint Model Management and its respective logical thinking tools, using a set of steps: (1) defining the paradigm, (2) analysing the mismatches, (3) creating a transformation, (4) designing the future, and (5) planning the execution. In order to get a realistic perception of the current reality of the Navy's requirements management practices, in-depth interviews were performed to core members of the Navy's project management teams.

The main causes for the underperformance of projects are inherent to organizational issues, such as teams' resilience and training, absence of internal instructions for requirements development, weak engagement with stakeholders and the inadequate requirements statements definition. Consequently, the solution for these concerns rely in the implementation of new strategic guidelines. The implementation of this proposed solution is expected to deliver a requirements management perspective to effectively ensure budget, schedule and scope conformance. Moreover, it also intends to encourage the growth of organizational knowledge concerning requirements management and to enhance a cooperative environment that ensures an appropriate stakeholder engagement.

Keywords: Constraints Management Model, Project Management, Requirements Management, Shipbuilding Projects, Strategy Analysis.

Resumo

Na gestão de projetos, a Gestão de Requisitos é considerada um fator crítico responsável por uma grande fatia do sucesso de um projeto. Uma vez que a Marinha Portuguesa pretende assegurar a aquisição (e construção) de novos navios, para garantir a sua presença quantitativa e qualitativa no seu cenário de operações, a gestão de requisitos tornou-se vital para a concretização dos objetivos dos projetos. O objetivo deste estudo é encontrar "onde" e "o quê" pode ser melhorado na gestão dos requisitos da Marinha. Esta investigação é enquadrada de acordo com a *Constraint Management Model* de William Dettmer e as respetivas ferramentas de *logical thinking*, seguindo os passos: (1) definir o paradigma, (2) analisar as diferenças, (3) criar a transformação, (4) desenhar o futuro, e (5) planear a execução. Para obter uma perceção realista das atuais práticas de gestão de requisitos da Marinha, foram realizadas entrevistas em profundidade a alguns membros das equipas de gestão de projetos da Marinha.

No caso estudado, as principais causas da ineficácia dos projetos são inerentes a questões organizacionais, como a resiliência e formação das equipas, a ausência de instruções internas para o desenvolvimento dos requisitos, a desvinculação das partes interessadas e a definição de declarações de requisitos inadequadas. Por conseguinte, a solução para estas preocupações assenta na implementação de novas orientações estratégicas. Espera-se que a implementação destas novas linhas estratégicas proporcione uma nova perspetiva para a eficaz conformidade orçamental, temporal e de âmbito. Além disso, pretende também incentivar o crescimento do conhecimento organizacional sobre a gestão de projetos e criar um ambiente cooperativo que garanta o envolvimento adequado das partes interessadas no projeto.

Palavras-Chave: Análise da Estratégia, *Constraints Management Model*, Gestão de Projetos, Gestão de Requisitos, Projetos de Construção de Navios.

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List of Abbreviations and Acronyms

CMM – Constraint Management Model

COLREG – International Regulations for Preventing Collisions at Sea

CONOPS – Concept of Operations

CRT – Current Reality Tree

CSF – Critical Success Factors

DE – Desirable Effects

DTIB – Defence Technological and Industrial Base

EC – Evaporating Cloud

FRT – Future Reality Tree

INJ – Injections

IO Map – Intermediate Objectives Map

JSPS – Joint Strategic Planning System's

LPM – *Lei de Programação Militar*

LTP – Logical Thinking Process

MBSE – Model-based Systems Engineering

MoD – Minister of Defence

OODA – Observe, Orient, Decide, Act

PM – Projects Management

PMCI – Project Management Certification Institute

PMI – Project Management Institute

PPBS – Planning, Programming and Budgeting System

PRT – Prerequisite Trees

RACI – Responsible, Accountable, Consulted and Informed

RC – Root–causes

RCM – *Resolução do Conselho de Ministros*

RM – Requirements Management

RQ – Research Question

SLR – Systematic Literature Review

SOLAS – Safety Of Life At Sea

TOC – Theory Of Constraints

UDEs – *UnDesirable Effects*

Introduction

This master's thesis focuses on an approach to *Requirements Management* (RM) in the management of shipbuilding projects at the Portuguese Navy. It intends to test the framework for RM proposed by *the Project Management Institute (PMI)* and evaluate the current management policies practiced by the Navy. This assessment will result in a new strategy proposal to approach RM and associated problems. This research intends to achieve the following objectives (O):

O1: Defend the relevance of RM for projects and project management and its impact on projects success.

O2: Approach the PMI's RM process model and adapt it to the Navy's reality, as an integrated management model.

O3: Clarify how RM is currently practiced in the Portuguese Navy.

O4: Identify the problems and aspects to be improved in the current RM within the Portuguese Navy.

O5: Suggest measures that can be applied to improve the RM capability.

The proposed objectives arise from the need to adopt processes and procedures used in the management of naval construction projects in order to sustain the implementation of the ships provided in "Strategic Initiative 50" as per the *2022 Strategic Navy Directive*. Effective and correct RM can support the building of "a navy numerically and qualitatively sufficient to fulfill the assigned missions and tasks " (Estado-Maior da Armada, 2022).

In addition, requirements management plays a key role in the formulation and contracts awards, which is relevant from the legal and *systems engineering* aspects.

The developed research assumes the use of: (1) a systematic review of the existing literature on RM, (2) a methodology based on a strategic planning model based on the Theory of Constraints, and (3) a set of interviews with current actors and subject matter experts related to shipbuilding projects.

The literature review will include research dedicated to objectives O1 and O2. Some historical cases will be revised, referring some *lessons learned* and reference will also be made to the PMI-oriented model for requirements management. As for the O3 objective, there will be an interpretation of the results obtained from the systematic review of the literature with those of the "In-depth" interviews in order to characterize the current state of MRI in the Navy. The remaining objectives, O4 and O5, will be achieved through the strategic application of the Constraint Management Model (CMM) which will propose a solution for a more effective RM.

Given the singular nature of this thesis, it is important to define the conceptual, thematic, and semantic limits of this research. This work is focused on RM as a constituent part of projects management (PM), so the most indicted details for the contractual and technical issue of the projects will not be deepened. On the other hand, this work will be focused on the organizational environment of the Portuguese Navy and the entities that cooperate with it, such as the National Ministry of Defense and the Directorate-General for National Defence Resources.

It is considered legitimate to state that other areas of knowledge will have their influence on the RM issues addressed, such as: systems engineering, Requirements Change Management, MBSE, Public Procurement and the company’s performance.

This thesis is divided into three main chapters. The first chapter is dedicated to the systematic review of the literature which covers the issues associated with the definition of concepts, semantic framework, definition of the relevance of the theme and exposure to the practices used by the Portuguese Navy. In turn, this chapter is subdivided into four sections. The first is dedicated to the definition of Research Questions which are guidelines for SLR. The second is dedicated to the explanation of the adopted review protocol. Subsequently, the selected bibliographic references are displayed and finally the results achieved are presented, and organized by answers to the research questions,

In chapter two, a brief explanation of the used methodology and the adaptations made are clarified. this chapter is divided into three sections: (1) background, (2) adaptation of the Constraints Management Model, and (3) In-Depth Interviews. First, the three theories behind the formulation of the CMM are explained using brief descriptions of them. Later, the model proposed by Dettmer (2003) is described step by step, highlighting the changes made to the original model and the *raison d'être* of each stage. Finally, some explanations are given regarding the interviews conducted, which were also a rich source of information.

In the third chapter, the methodology is put into practice, and divided into five parts, each dedicated to one of the stages of the methodology adopted. Finally, some conclusions drawn from this investigation.

1. Systematic Literature Review

This Systematic Literature Review (SLR) embraces the project management's topic of RM with particular focus on the defence shipbuilding associated with the Portuguese Navy Ships.

A quick search through *Google Scholar* has outlined a few systematic reviews in this field with its own specific focus, beyond shipbuilding industry. However, it was evident that some of them share the same references, terms, concepts and even procedures (such as Garcia et al., 2019; Jayatilleke & Lai, 2018; Loniewski et al., 2010; Schön et al., 2017; Svensson et al., 2010; Torkar et al., 2012).

Although some research on RM has been done during the last decades, most focus on subjects directly concerned to a specific kind of project or a specific requirements characteristic. Hence, it is advisable that a SLR incorporating shipbuilding industry and RM should be developed.

A model for SLR could be an answer to uniformize procedures related to RM and development for shipbuilding projects. It could also be a way of assessing different sources and schools of thought, synthetizing knowledge into wisdom and the origin of new research questions to be explored. Even though SLRs are not yet a well consolidated tool for literature reviews in the management field, it has been considered as a powerful instrument for "developing an understanding of what we know and what we do not know about a given topic" (Briner & Denyer, 2012).

1.1 Research Questions

To develop a careful systematic review that covers not only the main concepts, practices, procedures, and frameworks of RM but also the associated challenges, research new findings and gaps, the following research questions were stated:

RQ1: What is the importance (benefit) of having an efficient and effective RM?

The motivation behind this question is to clearly justify the role that RM has within the current projects and how they are so frequently influenced by management and relevant stakeholders. In an attempt to answer this question, an investigation through historical and recent events was conducted. The expected outcome was to find strong evidence of cause-effect chains that directly relates RM dictating the success (or misfortune) of projects.

RQ2: What is the state of art in what concerns RM? What are the commonly adopted standards? What techniques are being used by project managers to deal with RM?

This particular question strives to achieve the principal purpose of the systematic review – "provide collective insights through theoretical synthesis into fields and sub-fields" (Tranfield et al., 2003). The answers to these questions lie in three distinct lines of research: (1) the construction of a conceptual web that lists the terms considered central to characterise the state of knowledge; (2) the comprehension of the role of RM in a project management performance and the interfacing with systems engineering; and (3) the research on standards, policies, techniques, and frameworks promoted by international recognized entities.

RQ3: How is RM developed within the Portuguese Navy shipbuilding projects?

The motivation behind this question demands the meeting with the individuals currently integrating the respective RM team and clarifying their practices along the project life cycle management. Aiming to answer this question, intern standards, norms, and policies are revisited with the objective of understanding what are the actions taken, activities developed, and decision-making techniques used during the various stages of RM.

1.2 Review Protocol

In a first attempt to establish criteria for deciding if an article from a search merits inclusion in the review, a protocol was made to govern the process and minimize bias

(Williams et al., 2021). It is considered a first attempt because this is an iterative process – first the protocol is built, then it is clarified and put into action, and finally it is refined to generate a new optimized protocol. The final criteria used was:

1. References should have been published during the last twenty years, ideally from 2002 to 2022.
2. References must be in one of the following languages: English, French, Spanish or Portuguese.
3. References must be related to one or more of the following disciplines: project management, systems engineering, defence, or shipbuilding.
4. References can be of any of the following types: articles, books, case studies, literature reviews, practice guides, editorials, journals, internal standards, or newspapers.

During the collecting process, the following databases were used: IEEE Xplore, Springer Link, Science Direct (Elsevier), B-On and Google Scholar. The searching terms used were: “requirements management”, “requirements engineering”, “requirements”, “shipbuilding projects” and “systems engineering”. Besides these databases, the Portuguese Navy Engineer Officers from the Directorate of Ships (*Direção de Navios)* and the Officers from Navy’s Chief of Staff *(Estado-Maior da Armada)* supplied documents and reports used across projects.

In analysing the articles, a methodical reading was executed in order to optimize the validation of each reference. Usually, the reading would start by the abstract and key words, which should state a clear and coherent summary on the subject. Then, if the abstract was validated, a prospect of the general structure of the article (including images, tables, graphics, and chapter titles) was conducted ending at the evaluation of the introduction section. At this point if the article was considered reliable, the reading would proceed to the conclusion. The few articles that made it to this point were completely read and considered significantly relevant, in comparison.

During the search process, an Excel spreadsheet was developed for recording all the findings. A table was designed with the following head columns: title, author(s), year of publication, journal of publication, journal’s rating (according to SCImago - https://www.scimagojr.com) and observations. The parts of the articles that were analysed were listed and given a reference code, for research reference purposes.

1.3 Selected References

The initial pool had a total of 115 references. Using the review protocol and the defined criteria, the SLR ended at 28 references (appendix A details the study selection flow diagram). The following table addresses each one of such 28 references for each of the research questions:

Research Question	Reference
RQ1. What is the importance (benefit) of having an effective RM?	(Kessler et al., 2004), (Sullivan, 2013), (Subarna et al., 2020), (Thompson, 2013), (Fairley & Willshire, 2003), (Gertler, 2012), (Bevilaqua, 2009), (Sheridan & Burnes, 2018)
RQ2. What is the state of art of RM? What are the commonly adopted standards? What techniques are being used by project managers to deal with RM?	(PMI, 2016), (INCOSE, 2012), (Balaji, 2012), (Johansson & Bucanac, 1999), (Malaek et al., 2014), (Hood et al., 2008), (B S Blanchard & Fabrycky, 1981), (Yasseri, 2014), (Stemm, 2001), (Nadeem et al., 2022), (Finkelstein & Emmerich, 2009), (Gebreyohannes et al., 2018), (Rossi & Tuunanen, 2004), (Yu & Shen, 2013), (Woodcock, 2019), (Mathiassen & Tuunanen, 2011), (Kar & Bailey, 1996), (Panis, 2022)
RQ3. How are RM developed within the Portuguese Navy shipbuilding projects?	(Estado-Maior da Armada, 2020) (Estado-Maior da Armada, 2013)

Table 1. Association between research questions and references

1.4 Results of the Systematic Literature Review

RQ1: What is the importance (benefit) of having an efficient and effective RM process?

History is fraught with multiple cases of projects that failed to fulfil their expectations due to lack of proper RM. Indeed, one of the most common factors behind project's failing schedules, overbudgeting and defective performance is related to poor elicitation, specification, analyses or requirements validation (Subarna et al., 2020).

Back in the XVII century, during the Thirty Year's War, the Swedish Empire was in its prime age in terms of naval force and dominance of the Baltic. Due to a series of unfortunate events, King Gustavus Adolphus ordered the construction of four new powerful warships from the renowned Dutch Master Shipwright Henrik Hybertson, which would be overseen by the Admiral Kaus Fleming. The initial scope of this programme was to build two large ships together with two smaller ones, with a keel of 136 foot and 108 feet, respectively. One of the larger ships was meant to be the jewel of the Royal Swedish Navy – the *Vasa*.

The problems started in the first year of the construction at the Stockholm shipyard. The developments of war with Poland, made the King rush the constructor to deliver Vasa promptly adding some new requirements changes. Hybertson tried to counterargument the new changes with the premise that timber had already been cut for the ships under construction, but that was not accepted – King's orders were absolute. A few months later the Dutch Master found himself ill, dying in the Spring of 1627. His assistant Hein Jacobsson (a newbie with weak managerial experience) took the wheel of the project, inheriting no detailed records or descriptions of the Vasa's requirements. Apart from this, the shipyard received its first specification for Vasa's armament, totalling a senseless excess of 70 tons. Admiral Fleming conducted many tests through the different phases of construction of the warship, but although the results were expressively doubtful, he relied on the shipbuilder's experience (Kessler et al., 2004).

The hoarding of all these circumstances, came to the 10th of August 1628 – the day *Vasa* made its first and final voyage. Having not completed its first mile, a succession of strong wind gusts made the ship heel to portside letting water inside the ship through the lower gundeck. Rapidly, the water filled the deck making the ship lost her stability and sinking in the deep Stockholm harbour – the Swedish jewel would never come to fulfil its destiny. After the catastrophe, an inquiry was conducted to determine responsibilities among the guilty parties, but no one was ever found guilty. However, Jacobsson claimed that the ship had conformed to all the measurements submitted and approved by the King.

A more recent case also connected to the field of Defence is the notorious project of the US military's F-35 Lightning II. This project, included in the Joint Strike Fighter Program, was meant to satisfy the needs of the United States Air Force, Navy and Marine Corps foreseeing a fair benefit on the government's investment (Sullivan, 2013). F-35 was supposed to renew the tactical aircraft fleet, replacing the US General Dynamics F-16 Fighting Falcon, the British Aerospace Harrier II, among others. One of the principles adopted by Lockheed Martin (the F-35's prime contractor) for this project life cycle was the concept of *concurrency*. Loren Thompson (2017) defined this concept as:

> *"Concurrency is defined as the overlap in the development and production phases of the acquisition program. Concurrency introduces the risk that aircraft built in early production lots will require modification due to discoveries made during qualification, flight, and ground tests, or as a result of engineering analysis."*

Concurrency is usually used in highly adaptive projects that have a critical impact in the requirements process by supporting an iterative approach to requirements elicitation and analysis, higher stakeholder collaboration and progressive planning. This approach assumes an efficient cost management, with special regard to the planning component – and that was the project's main flaw. The way the project manager dealt with sunk costs compromised the project's costs policy, denigrating the capital budgeting's image and showing that the money should have been better used in other Defence projects.

"The most affordable, lethal, supportable and survivable aircraft" (as stated by the Pentagon) not only had an overbudgeting issue but also a behind schedule problem. This derived from the regular tests that took place before the widespread use of the aircraft. As this project had a large pool of accountable stakeholders, many of them wanted to "put their hands" in the prodigy aircraft. This normally takes huge amounts of time and often brings requirements changes and new requests. One thing leads to another, and the schedule ended up falling in the planning fallacy - the tendency to underestimate the amount of time needed to complete a future task even when they have experienced similar tasks before. In the end, the numbers speak for themselves: the development and procurement of the F-35 is estimated at $323 billion; each fighter jet costs around $769 million over its operational lifetime and the total life-cycle cost for the whole programmes expected to cost American taxpayers a total of $1.7 trillion throughout its lifecycle (according to the Pentagon's Cost Assessment and Program Evaluation Office's 2020 estimate).

RQ2: What is the state of art of RM? What are the standards commonly adopted? What techniques are being used by project managers to deal with RM?

Requirement is a concept that may have different meanings in different contexts. Taking that into account, for the propose of PM, an appropriate definition of *requirement* is "a statement identifying a capability, physical characteristic, or quality factor that bounds a product or process need for which a solution will be pursued" (Hood et al., 2008). There is another difference between concepts that is also very important: *requirements development* and *requirements management.* Whereas *requirements development* refers to the tasks of eliciting, identifying, planning, analysing, documenting, specifying, validating, and verifying requirements, *requirements management* entails managing the requirements of the project and ensuring alignment between those requirements and the project's plan and work products (PMI, 2016).

Although they seem quite similar concepts, *verification* does stand apart from *validation* in RM. *Verification* confirms that deliverables properly reflect the requirements specified for them ("you built it right"). Validation confirms that the product, as delivered, will fulfil its intended use ("you built the right thing") (Hood et al., 2008).

The definition of requirements itself, should follow a set of principles that suits adequately to the person who writes them and anyone who reads them. In order to ensure that requirements are well crafted, the International Council on Systems Engineering

(INCOSE) defined the following characteristics for requirements statements:

Characteristic	Definition
Necessary	Every requirement statement is necessary
Implementation Independent	A requirement states what is required, not how the requirement is met
Unambiguous	A requirement statement lends itself to a single interpretation
Complete	A requirement statement is complete in and of itself
Singular	A requirement statement addresses a single thought
Feasible	A requirement statement expresses something that is inherently feasible
Verifiable	A requirement statement is verifiable
Correct	A requirement statement is a correct expression of the stakeholder expectation
Conforming	A requirement statement conforms to standards selected as applicable to the organization

Table 2. Characteristics of requirements statements
Source: Adapted from (INCOSE, 2012)

Systems Engineering, as an independent concept, is a complex of distinguished process areas. Requirements development is one of them, alongside change management, test management, quality management, amongst others. More important than the value of these areas *per si* is the value they have when considered together, e.g., without change management, requirements development would be easily obsolete.

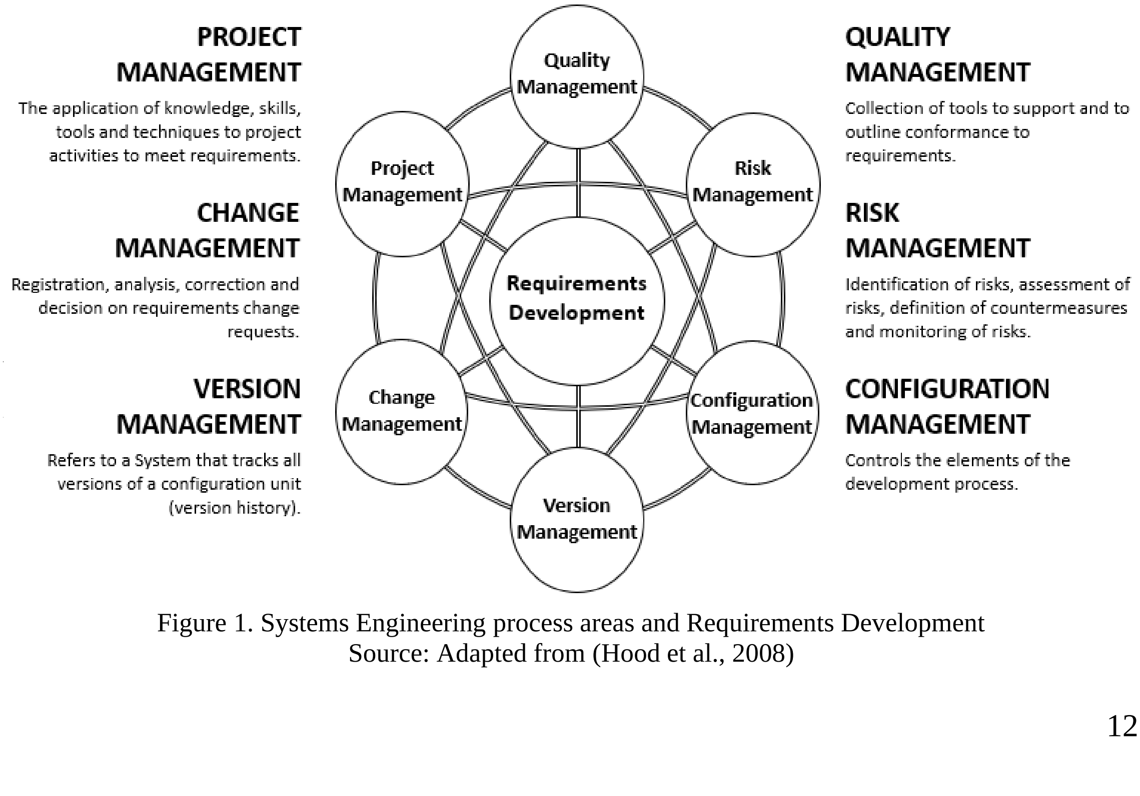

Figure 1. Systems Engineering process areas and Requirements Development
Source: Adapted from (Hood et al., 2008)

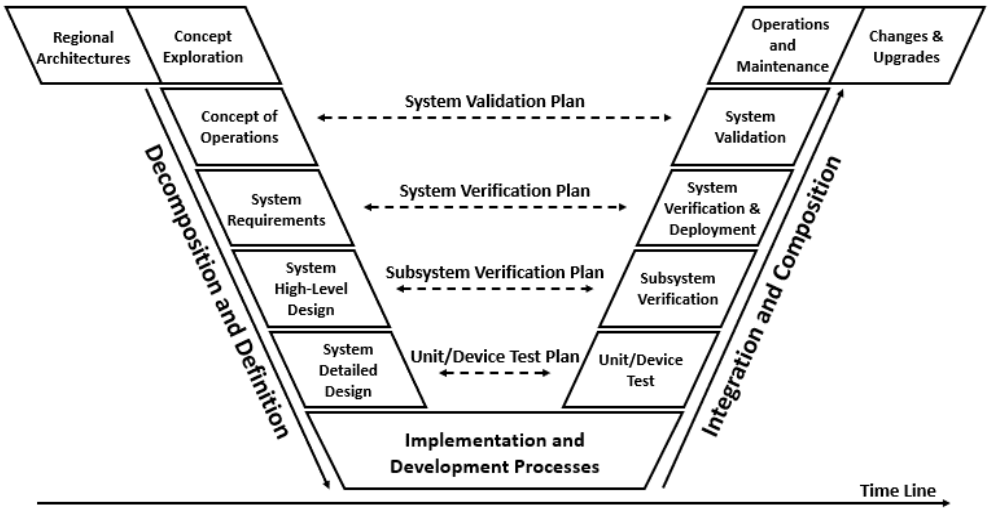

Figure 2. The V-Model
Source: Adapted from (Malaek et al., 2014)

Albeit having different meanings, systems engineering, and requirements management processes start in the same point: the *needs assessment*. Through PMI's insight on RM, the requirements process comprises the following six sets of activities: (1) needs assessment, (2) requirements management planning, (3) requirements elicitation, (4) requirements analysis, (5) requirements monitoring and controlling, and (6) solution evaluation. A seventh stage could be considered – project closure – notwithstanding that this is an extension to the solution evaluation phase. These are simple stages that can be easily fit into the PMI's project management process.

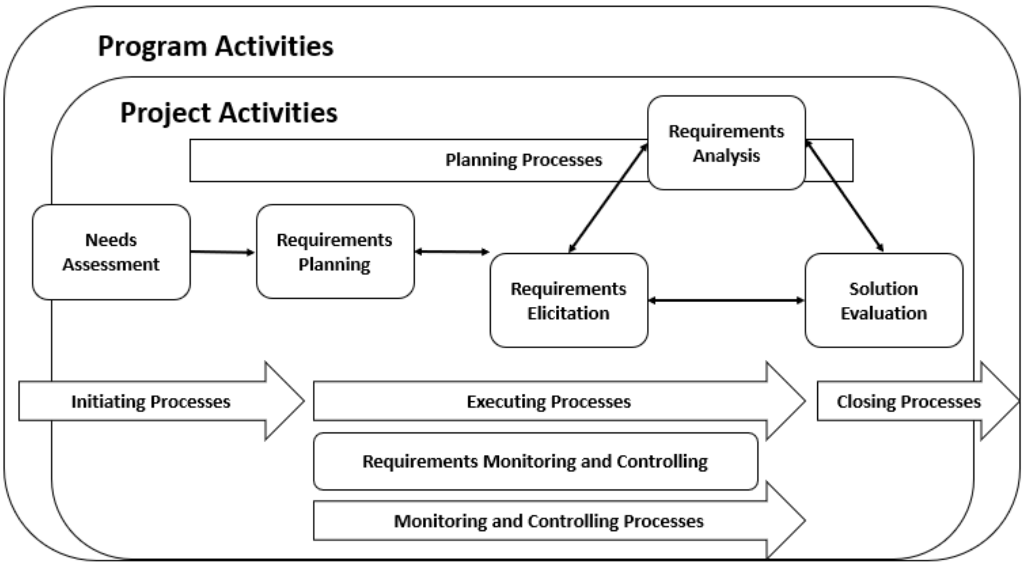

Figure 3. Mapping of the Requirements Process to the PM Process Groups
Source: Adapted from (PMI, 2016)

RQ3: How is RM developed within the Portuguese Navy shipbuilding projects?

In the Portuguese Navy, the requirements process starts with a needs assessment and concept exploration phase. Concerning the acquisition of new naval vessels, there is two distinct scenarios: (1) an existing unit needs to be replaced and then is stated the necessity, or (2) the Portuguese Navy is entrusted with new types of missions which require the deployment of more units, increasing its capability. There is a conceptual document supporting this, called "System of Forces" (CONOPS) – what type of ships is needed by the Navy and what missions the Navy wants those ships to accomplish – that, in a way, predicts with a certain advance when the capability is going to be requested.

Defined the needed capability, the first declaration of planning for the acquisition takes the form of a legal document - *Lei de Programação Militar (LPM)*- which is approved by the Parliament. Alongside this publication, the Navy's Chief of Staff develops an internal document which states the concept for employment of the future ship(s) – IOA. This document defines certain military aspects that the project's product must strategically achieve, such as: characterization of the operational environment, missions, tasks, threats, opportunities, and operational profile.

Then, following the IOA, it is stated the operational requirements in another publication entitled POA. POA defines more detailed information about the employment of the class of ships (Figure 4). It could be understood that the POA defines the System's constraints within a technical and operational approach, whilst LPM is the budget and schedule constrainer.

Figure 4. Principal Documents of RM in the Portuguese Navy

The next step is the budget approval which is discussed in the Council of Ministers. In this step there is a formal participation of the *Direção-Geral dos Recursos da Defesa Nacional* and the Navy representatives. From that occasion, results a *Resolução de Conselho de Ministros* (RCM). Published the RCM, starts the discussion of the contractual parts. The contract itself, is divided into different parts that are not all requirements related. Some parts of the contract are associated with insurance clauses, the engineering project, State’s supplied items, logistic support, and others. Alongside this it is defined exclusion factors and merit factors, which will be useful for the analysis of proposals within the Public Procurement process. Settled the contract, the Public Procurement process is conducted, and from that it will result a contractor from the program.

During the project development, there is a team composed by Navy personnel that is entrusted with the monitoring and inspection of the construction. They are the ones responsible for the correct and timely validation and verification of requirements. These requirements are reviewed in the floatability trials, the harbour trials and the sea trials.

2. Methodology

The methodology used to answer the posed questions is based on the Constraint Management Model (CMM) introduced by Dettmer (2007). The methodology provides a solution for the problems, in what regards strategic planning, which Dettmer pointed as: (1) disregard for dependencies, (2) inflexibility, (3) greater emphasis on "the plan" (rather than on "the strategy"), (4) and difficulty in implementation. CMM is intended to be a robust strategy development model that strives for versatility, flexibility, and a hierarchical foundation amongst other objectives.

This model comprises a six-step process (being the seventh an evaluate-and-adjust step) that starts with the clear definition of the organization's goal and boundaries and is set to finish with the deployment of a meticulous, customized strategy. The first five steps of the CMM are linked with a tree (or logical map) of the Logical Thinking Process (LTP). CMM results from a synthesis of theories as it emerges from the alliance between the Department of Defence's approach to strategic planning, Goldratt's Theory of Constraints and Boyd's theory of manoeuvre warfare.

As it is not a statistical model, CMM relies in a logical thinking process of cause-and-effect bonds. This model was designed as a contemplation of seven main principles that a methodological framework must follow: optimal, fast, flexible, integrated, deployable, visible, and accountable. The coherence with these principles was the first reason why this methodology was chosen, being the second one it's applicability to the matters under study. The CMM can be used as an optimization tool for management strategy formulation purposes.

Nonetheless, this model was not considered totally suitable for the investigation process. Not only because this study is not intended to evaluate the application of the strategy developed (it is mainly aimed at diagnosing the current state of requirements management and pointing to some solutions), but also because deployment is beyond this study. As a result, this study will only be conducted until the fourth step ("Design the Future") as the fifth step ("Plan the Execution") is already related to the execution itself and falls beyond the pure academic focus. In addition, some other tools, frameworks, and techniques will be used as needed to complement the approach.

2.1 Background

At its core, the CMM is a synthesis of three theories, as demarked before. Each one of them have its own perspective and processes and the CMM rises from the blending of the three. Dettmer (2007) took the US Joint Strategic Planning System's (JSPS) hierarchical character, combined it with Boyd's OODA "spiral" and Goldratt's Theory of Constraints and made a model that helps organizations adapt and be capable of agility, variety, harmony, and initiative.

The Department of Defence's JSPS is a global strategic planning approach that is established every five years (and reviewed every two) in order to operationalize the National Military Strategy of the United States. It's a five-phase process that comprehends: (1) the *strategic assessment* (reception of inputs), (2) the *strategic direction* (statement of objectives and tasks), (3) the *strategic plans* (create the current plans), the (4) *program advice* (reception of input from the missions initiated) and (5) the PPBS – Planning, Programming and Budgeting System (report for future budgeting). Among the advantages of this system, we can refer to: (1) its goal or objective-oriented scope, (2) its vertically integrated, (3) traceable hierarchy and (4) its lateral, as well as vertical coordination. On the other hand, this theory revealed to be very inflexible and sometimes unresponsive, and complex and time intensive as well.

Perhaps the most important lesson that can be taken from OODA loop is that, as opposed to standing by stable and predictable scenarios, instability and unpredictability should be included on the decision process and promoted, since the OODA loop

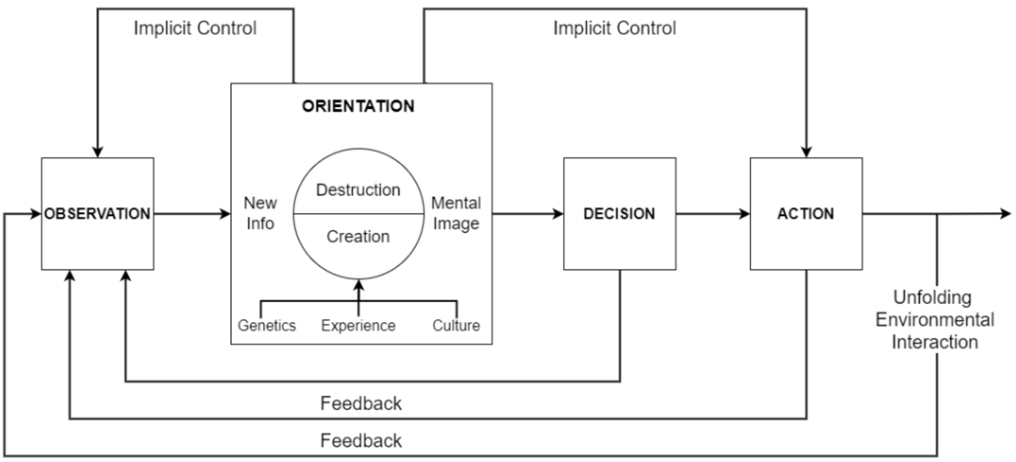

Figure 5. Boyd's OODA Loop
Source: Adapted from (Hammond and Tedrick, 2001)

empowers users to deal with ambiguities characteristic in unusual situations.

The third theory is a vastly discussed and developed ideology of logical strategy development processes. The *Theory Of Constraints* (TOC) introduced by Eliyahu M. Goldratt gives the graphical tools for CMM's process design, relating the thinking process to the other theories (Goldratt & Cox, 1984). Goldratt's theory takes the major credit for Dettmer's model as it is deeply related to TOC's logical thinking process and concepts of system constraints and categories of legitimate reservation. The CMM also inherits the three basic system management questions from TOC: "*what to change?", "what to change to?"* and "*how to cause the change?".*

The CMM is a way of creating strategies based on the three theories presented before. From the JSPS, CMM uses its hierarchical character and the concept of a "family of plans". Then Boyd's theory of manoeuvre warfare, through the OODA loop, gives insights about how to manipulate the strategic environment and how to deal with uncertainty in an attempt to go through the loop faster in face of the environmental constraints. Goldratt's Theory of Constraints incorporates a complete set of frameworks, including statements about how they work and act, their inward and outside conditions, solutions on the best way to oversee them, and different devices to do so.

<table>
<tr><th>Military Planning</th><th>Boyd's OODA Loop</th><th>Goldratt's Theory of Constraints</th><th>Constraints Management Model</th><th>Logical Thinking Process Tools</th></tr>
<tr><td rowspan="2">Strategic Assessment (1)</td><td rowspan="2">Observe (1)
Orient (1)</td><td>Why change?</td><td>Step 1: Define the Paradigm</td><td>Intermediate Objectives Map</td></tr>
<tr><td>What to change?</td><td>Step 2: Analyse the Mismatches</td><td>Current Reality Tree</td></tr>
<tr><td rowspan="3">Strategic Direction</td><td rowspan="3">Decide</td><td rowspan="2">What to change for?</td><td>Step 3: Create the Transformation</td><td>Evaporating Cloud</td></tr>
<tr><td>Step 4: Design the Future</td><td>Future Reality Tree</td></tr>
<tr><td>How to cause the change?</td><td>Step 5: Plan the Execution</td><td>Prerequisite Tree</td></tr>
<tr><td>Strategic Plans</td><td>Act</td><td rowspan="2"></td><td>Step 6: Deploy the Strategy</td><td rowspan="2"></td></tr>
<tr><td>Strategic Assessment (2)</td><td>Observe (2)
Orient (2)</td><td>Step 7: Review the Strategy</td></tr>
</table>

Figure 6. Relationship between the synthesized theories
Source: Adapted from (Dettmer, 2003)

2.2 Adaptation of the Constraints Management Model

The CMM used in this dissertation is an adaptation from the original model proposed by Dettmer (2011). This research will only proceed up to the fifth step – *Plan the Execution* – as it is the last step before the phase of deployment starts. As such, the five steps that will be developed are: define the paradigm (1), analyse the mismatches (2), create a transformation (3) design the future (4), and plan the execution (5). This is a linear project as there is no evaluate-and-adjust step or turnback on process's steps (Figure 3). Therefore, each one of these steps embrace a logical thinking process on itself: *define the paradigm* embraces the Intermediate Objectives Map (IO map), *analyse the mismatches* the current reality tree, and *create a transformation* and *design the future*, use the evaporating cloud and the future reality tree, respectively.

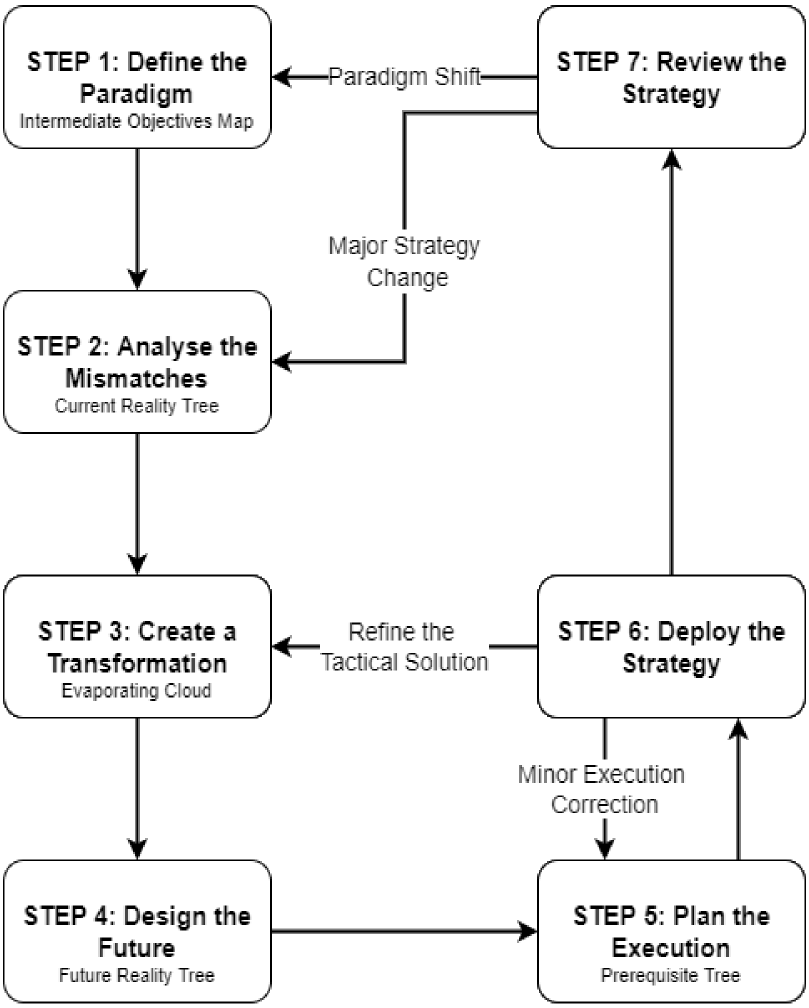

Figure 7. Constraints Management Model
Source: Adapted from (Dettmer, 2003)

2.2.1 Define the Paradigm

"*Defining the paradigm*" is all about stating the main goal, the boundaries of the system under interest and the *Critical Success Factors* (CSF). The first question to be asked should be "*who the strategy is for?*". Perhaps, this seems an obvious question to answer, but it helps define the limits of the organization that will be involved in the strategy making process and which will make use of the results.

Then, it is important to establish *the goal* – the "final destination" for the intended strategy. The goal is the point where the organization wants to be in the future based on the director, chief or leader's vision. But by only having a goal it is not enough to succeed since there are always barriers and setbacks.

CSFs are those elements that enable the organization's current position towards the elected goal. Although the CSF concept itself suggests a limiting feature, it should be seen as necessary conditions to achieve the goal. The interaction between the boundaries, CSFs and the goal can be assembled in an IO Map. By completing this map, an organization defines the benchmark of desired performance (Dettmer, 2006).

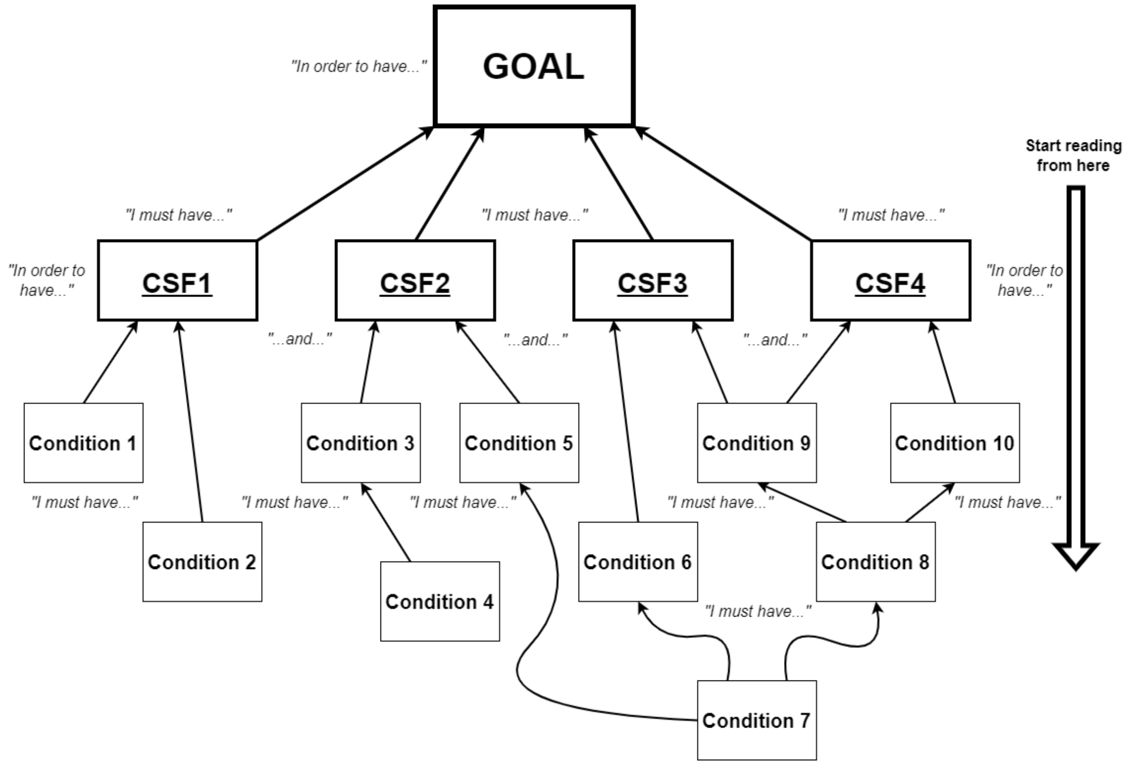

Figure 8. Intermediate Objectives Map
Source: Adapted from (H. W. Dettmer, 2006)

2.2.2 Analyse the Mismatches

The second stage of the process concerns the evaluation of the system current status and performance through the scrutiny of the source of deviations and inconsistencies. The gap between "*what is*" and "*what should be*" could be considered an undesirable effect (or constraint). Some of them may be impossible to fully remove, but the important thing to consider is to mitigate them as possible.

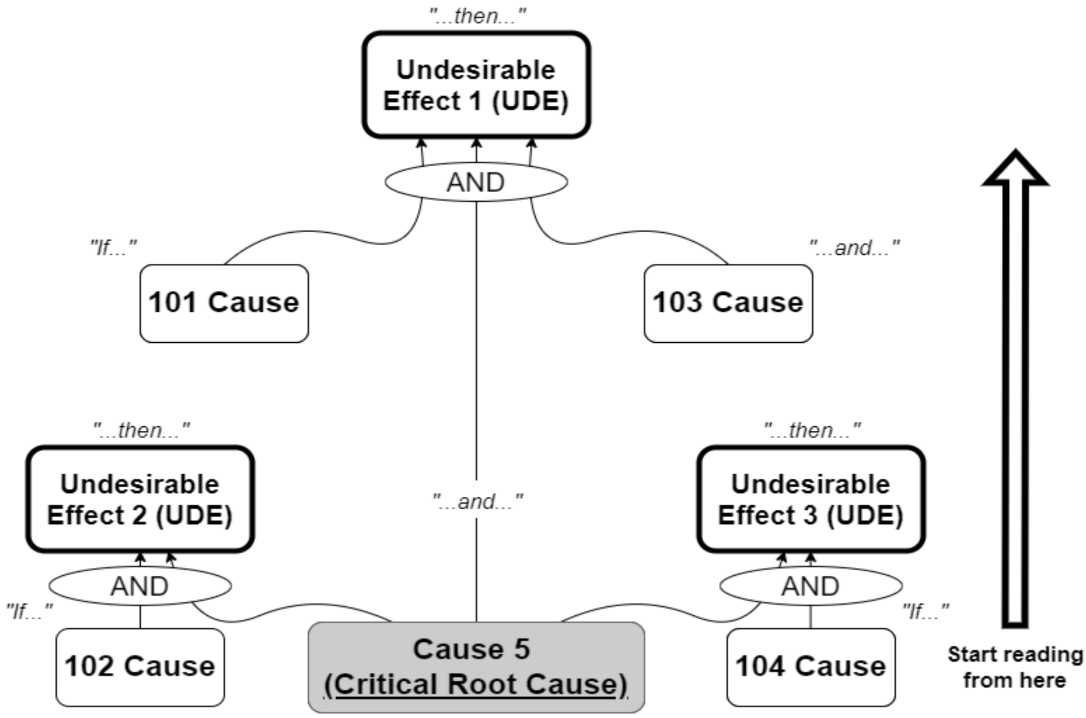

Figure 9. Current Reality Tree (Example)
Source: Adapted from (H. W. Dettmer, 2006)

The *Current Reality Tree* (CRT) aims to unleash the procedures that are behind the divergences by means of a cause-and-effect diagrams. This tree relates the *UnDesirable Effects* (UDEs) and intermediate effects to the root causes responsible for the deviations, highlighting the critical root causes – "the ones that, if addressed, solves the problem".

2.2.3 Create a Transformation

This is the point to approach the question *"What to change to?"*. It is also the point where the resistance to change is most critical and when the design of the strategy starts.

The new strategies considered may cause conflicts, not only with the strategy design process but also among the people involved within the system. The objective now is to remove (or mitigate) the core issue with a new perception of reality.

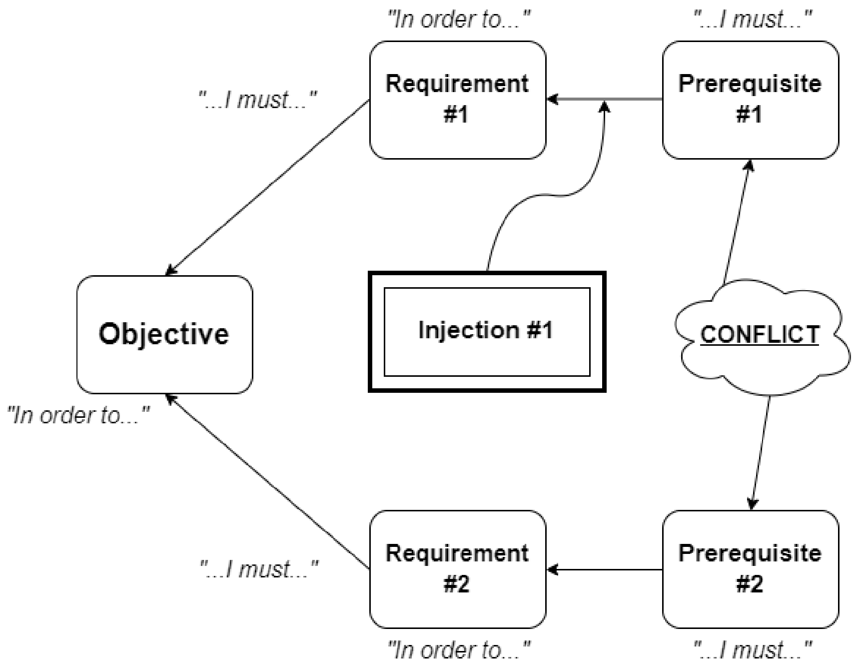

Figure 10. Evaporating Cloud (Example)
Source: Adapted from (H. W. Dettmer, 2006)

The Evaporating Cloud (EC) presents that argument in the form of an injection – an idea for a solution to the dilemma. This diagram, read from right to left, starts with the conflict from which derivates the prerequisites and the requirements, that finally leads to the objective. The injection is an input that usually stands between prerequisites and requirements in a rational position. Injections will later be developed in the Future Reality Tree (FRT).

2.2.4 Design the Future

The culmination of the strategy assembled so far is represented in the form of a FRT. The main purpose of this tree is to ensure that the designed strategy will deliver the desired outcomes and identify which of the proposed injections may lead to a negative consequence (the negative branches). Basically, the fourth step is “the satisfaction of all

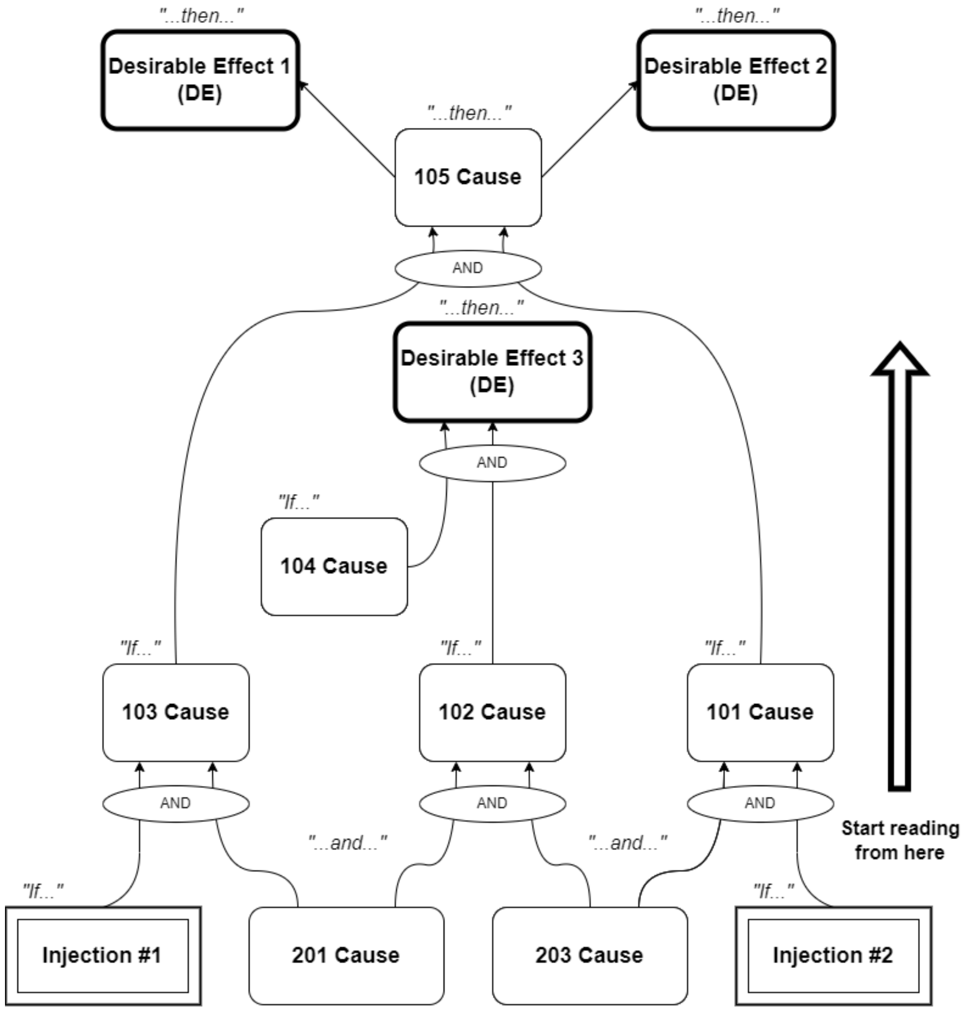

Figure 11. Future Reality Tree (Example)
Source: Adapted from (H. W. Dettmer, 2006)

future necessary conditions leading to the system’s goal”.

The FRT is also a cause-effect diagram including injections, desirable effects, undesirable effects, and assumptions. It brings back the *goal*, CSFs and conditions from the IO Map and puts it on the top of the diagram. These will become the desirable effects produced by the injections. The FRT brings understand about where the organization is going and what is needed to achieve the goal.

2.2.5 Plan the Execution

Plan the Execution is the phase dedicated to the planning of strategy implementation. This could be referred to as "how to make the change happen" step, as it is mainly concerned with stating the activities and tasks that support the new strategy. *Plan the execution* is an essential part of every project's life cycle since it is the primordial statement of a project's functional area assignments and hindrances. In other words, *Plan*

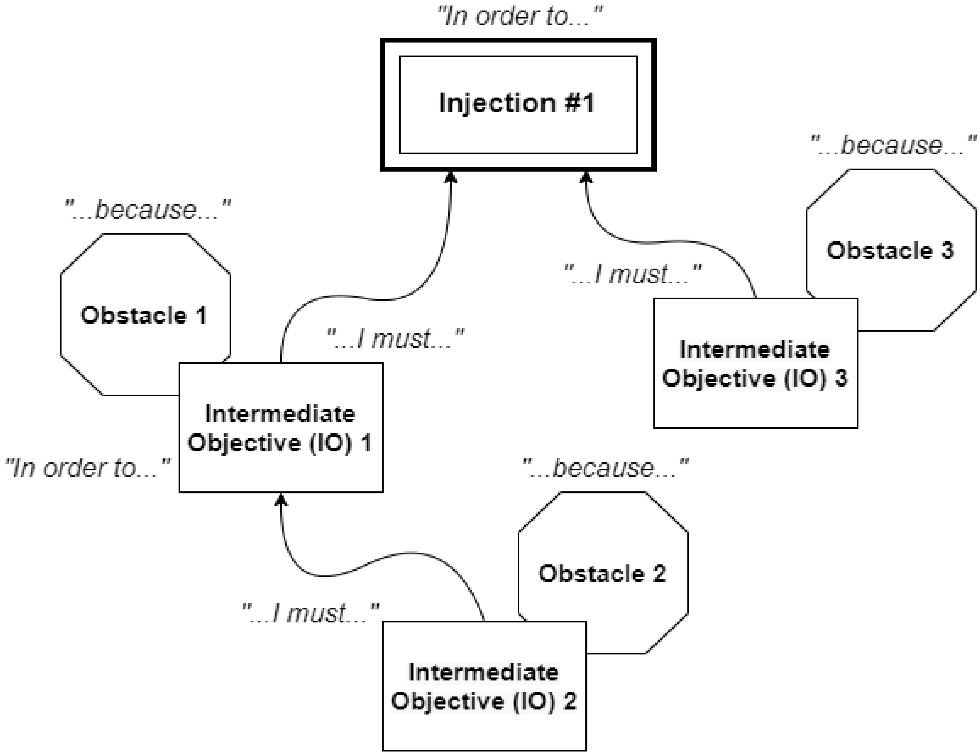

Figure 12. Prerequisite Tree (Example)
Source: Adapted from (H. W. Dettmer, 2006)

the Execution tests the effectiveness and applicability of the FRT through planning.

The diagram that structures the implementation planning is the Prerequisite Tree (PRT). The PRT is composed by the injections from EC, obstacles (hexagonal blocks) and tasks (rectangular blocks). Tasks are paired with obstacles and linked with an injection. This tree is read from top to bottom, following a "in order to… we must…" conditional logic. Being a strategy deployment diagram, the tasks are represented sequentially (where a task must be finished before another one starts) or in parallel (if they are supposed to occur simultaneously).

2.3 In-Depth Interviews

Apart from the model presented, the research process also developed In-depth interviews to complement the information from the Portuguese Navy processes and internal standards.

“In-depth interviewing is a qualitative research technique that involves conducting intensive individual interviews with a small number of subject matter experts to explore their perspectives on a particular idea, program, or situation” (Boyce & Neale, 2006).

The point of choosing In-depth interviews instead of other data collection methods, such as surveys, remains in the advantages that this type of interview provides, specifically the detailed information about the interviewee’s experience and knowledge about the subject under study. Moreover, the researcher can always get to a level of first-person context, in what refers to organizational or management issues, and get a new set of perspectives on “how things should be done”.

The six interviews conducted addressed military personnel that, directly or indirectly, had or have an important participation in the requirements management and process. The interviews took place in the Navy facilities, in person, during April and May. A template of the interviews conducted is available in Annex C.

3. Strategic Revision

3.1 Defining the Current Paradigm

"Before we begin problem solving it is a good idea to have a sense of our place in the universe" (Dettmer, 2007, p. 70). To find our place in the universe, we must shape our span of control (the things over which we have unilateral change authority), our sphere of influence (the things we can influence, to some degree) and the external environment (the context in which we have little or no influence). The figure 13 is a simplified view of such endeavour.

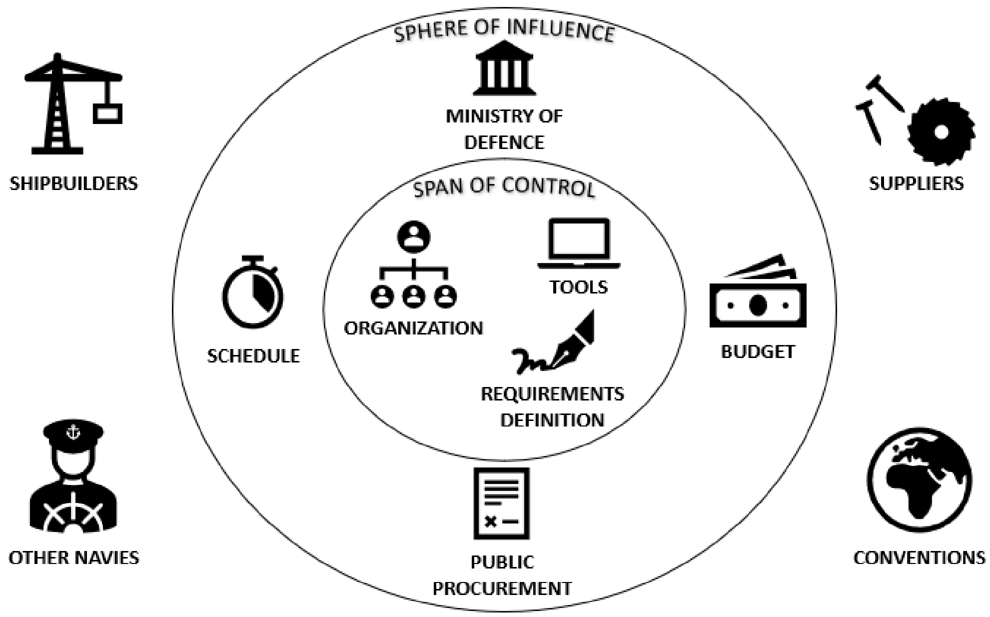

Figure 13. Boundaries definition

The Navy has no direct control over the shipbuilders, suppliers, and international conventions dictating requirements. Although the Navy has no control on those aspects, some of them have a certain level of influence over the Navy, e.g., International Regulations Preventing Collisions at Sea (COLREG) and Safety Of Life At Sea Convention (SOLAS) can influence certain requirements of shipbuilding such as lights disposal and life-saving appliances.

Since it is the LPM that defines the budget and schedule policy for the acquisition plan, and since a change of requirements brings budget and schedule changes into the project, which must be approved by the Minister of Defence (MoD), it is noticeable that the Navy has no total control over such aspects. However, the Navy has great influence over these aspects considering that is the Navy who states the needs, and which reports the need for a change of requirements. The Public Procurement has a particular influence in the Navy's projects of this kind. Even though the Public Procurement process brings an effective way to develop the accountability perspective of the constructors hiring, it narrows the Navy's ability to achieve what it needs.

There are, however, things the Navy can define and use unreservedly. The Navy can create project teams responsible for particular issues; use any tool, technique, or software to do the appropriate RM; and can also define what requirements it wants to be satisfied.

Defined the limits, it is now important to determine the goal. "Beginning with the end in mind" (Covey, 1989), the goal must be a status where we want to be at the end of the strategic implementation. The will to change the way Navy addresses RM should not urge from the need of a new strategy, but from the need of a revision of the actual one. So, the real purpose of this revision is to find a way of delivering an effective and efficient project performance, and consequently an effective RM strategy.

An effective RM "helps control quality, cost, organization, and schedule, thus substantially improving the odds of a successful project" (Halbleib, 2004). Indeed, quality from a PM perspective should be seen as the conformance to requirements (Crosby, 1979). Defining requirements in an adequate manner can induce proper traceability of costs and schedule planning, not disregarding that RM involves an ample stakeholder's engagement (Hood et al., 2008). If these points are well addressed and optimally executed, there will be an effective RM, and that is half-way towards project's success.

It is important to define what means to achieve an effective RM. To find the Critical Success Factors (CSF), an approach to three structural bases was built: operations, communication and information. From these three points, four CSFs were inducted.

Operations stands for a matrix of procedures that states "what we need to do" with our system. According to Blanchard & Blyler (2016), a system is "an assemblage or combination of functionally related elements or parts forming an unitary whole". The usage that is given to those elements and the ways they interact is a process. The PMI Requirements Management Process stated before could be applied to the Navy's RM, however some adaptations would be needed. It is important to have a process designed to the organizational reality, which means having an effective needs assessment and elicitation focused on the Navy's requests. So, in order to have an effective RM we must guarantee that we have a process that corresponds to the Navy management specifics.

Communication management has an active role regarding requirements management, and it involves the timely and appropriate planning, distribution, storage, monitoring, and disposition of all relevant project information. In fact, the communications management plan describes how, when and by whom information will be available and distributed (Project Management Institute, 2016). Perhaps, more important than the internal interactions between the Navy's teams, is the external contacts established with stakeholders. During the entire project's life cycle it is vital to promote a cooperative and assertive style of communication, i. e., "adapt behaviour to interpersonal situations on demand so that positive consequences are best and negative one – minimum" (Pipaş & Jaradat, 2010). In order to do so, it is also imperative to have a deep intelligence regarding the Defence Technological and Industrial Base (DTIB) and the major entities engaged.

The third pillar of an effective RM is an effective flow of information and technical management knowledge. In what concerns information and its spread in the form of knowledge, Nonaka (2007) as wisely explored the synthetization of tacit knowledge into explicit knowledge and then into intrinsic organizational practices. To guarantee that these practices do stay in the organization it is crucial to define standards for future generations to follow. Not only process standards, but also management standards and requirements writing standards, which should be implemented and susceptible of renew, according to knowledge and technological development.

Gathering these three CSFs, is concluded that none of them could be fully successful if the people involved in the Navy's RM are not conscious and capable of deploying these new methods. Besides everyone knowing what's their place in the organization and what are their responsibilities, it is relevant that they have their appropriate and sustained involvement (Holland et al., 2000). To ensure that teams are prepared to embrace RM, training programs should be conducted with focus on the RM process, the relations with stakeholders and the specified standards (with particular emphasis on requirement writing standards, a critical RM task).

The stated CSFs are critical to achieve an effective RM. Without any one of them, the effectiveness of RM would be impeached, and therefore, the project's success. The IO Map, shown in figure 14, reveals the nexus amongst the goal, the CSFs, and the necessary conditions. However, a question remains – *how can we ensure that our RM strategy is being effective?*

To ensure that, we need to turn effectiveness in RM into a tangible capability which can be traced and measured. Therefore, adopt the Loconsole (2001) questions and measurements of the RM key process area. The table in Annex B is an intensive fill-in-the-gap list, that helps us determine if our RM is fulfilling its potential. The measures produced by Loconsole, provide an enhanced visibility and superior insight of RM activities. When it comes to deploying the strategy developed in this dissertation, a similar table could be personalized to keep track of RM improvement and teams' awareness.

The next step would be taking a closer look to our organizational status regarding RM and go through the critical roots that unleash undesirable effects.

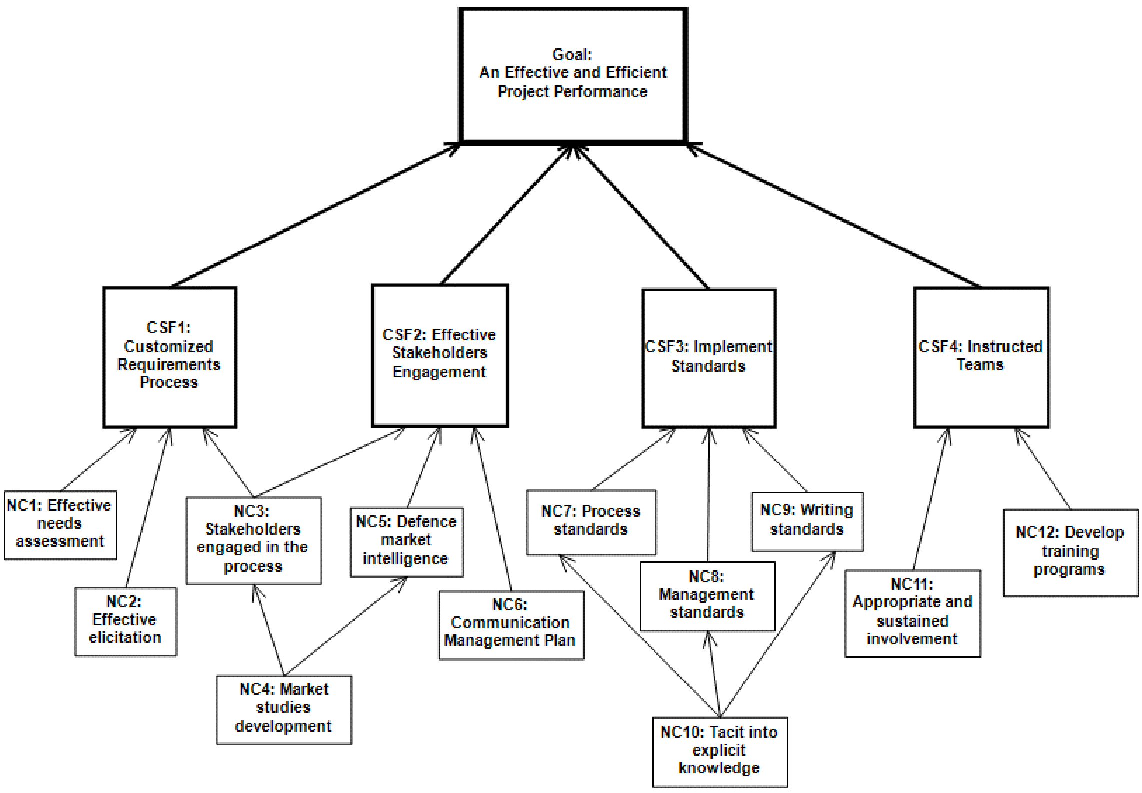

Figure 14. IO Map for an Effective RM

With the goal in mind, we must now take an introspective insight regarding the contemporary Navy paradigm and try to understand the nature of the differences that exist between the paradigm, represented by the IO Map, and the current situation, as represented by the CRT, in figure 15.

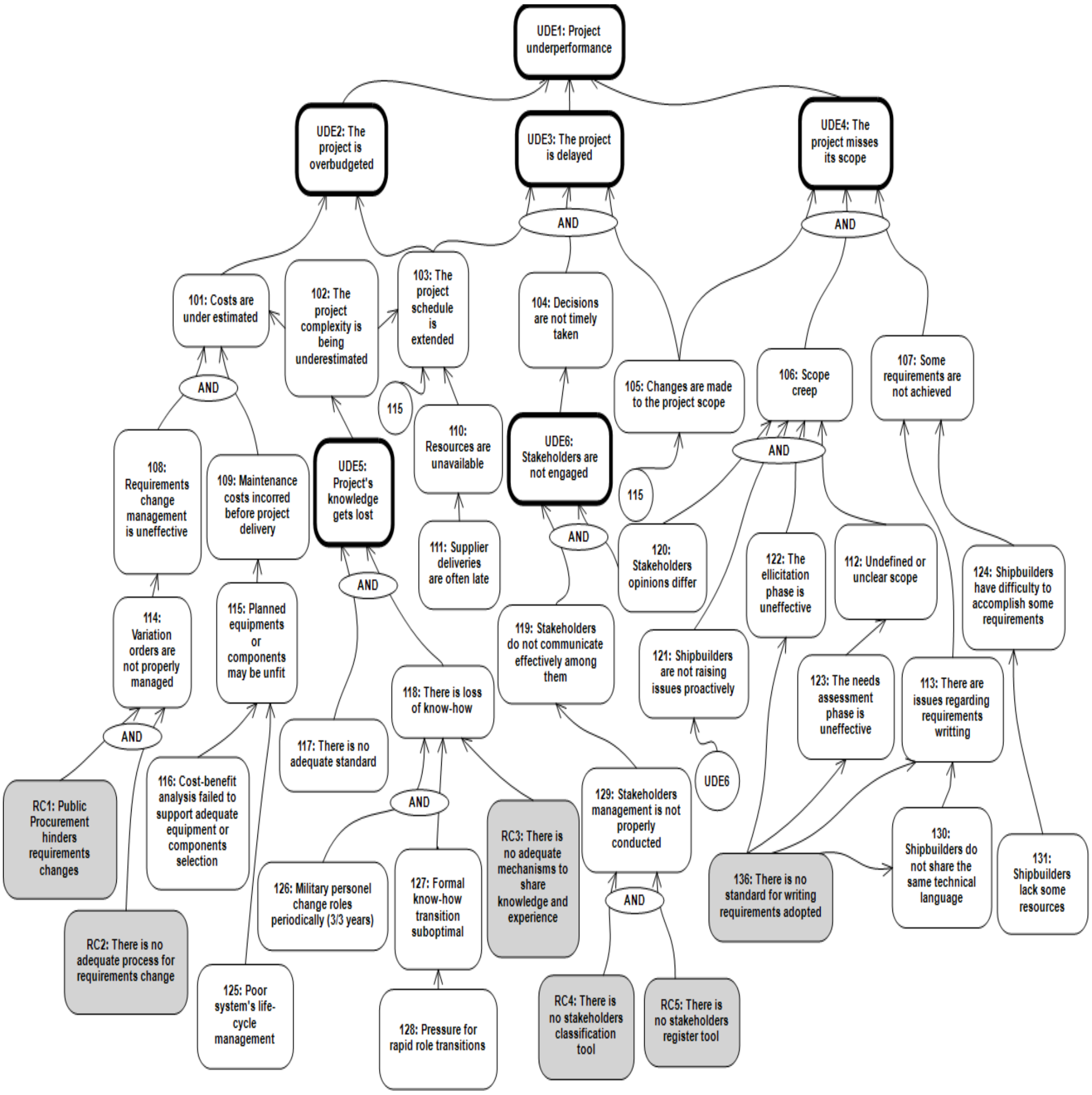

Figure 15. Current Reality Tree

The CRT is a cause-and-effect tree which reveals the UDEs that ineffective requirements management originates. The cause-and-effect relationships that are derived from it, have origin in root-causes, and will be the problems to be solved. This CRT was built based on the information obtained from the conducted interviews. Six UDEs were identified, with UDE1 being the underperformance of the project itself.

The “UDE 2 – The project is overbudgeted” is an effect that affects most projects and represents a difference to what was originally planned (Flyvbjerg, 2011). In the Navy, overbudgeting is the result of: (1) underestimated costs, (2) underestimation of a project’s complexity, oftentimes due to lack of PM experience, and (3) the unforeseen extension of the project schedule, related to scarcity of resources. The reason why costs are being underestimated is due to the lack of effectiveness in managing requirements changes and the occurrence of unforeseen maintenance costs.

Although there is a legal mechanism that allows the change of requirements, this procedure is sometimes controversial since it may raise the possibility of appeals raised by public tender competitors. Moreover, this is always a mechanism that leads to a project being extended for a longer time span and incurs in more costs that could be avoided. The absence of an accountable process that makes the correct management of requirements change is a root cause of this UDE alongside with the obstacles generated by the legal contingencies of Public Procurement.

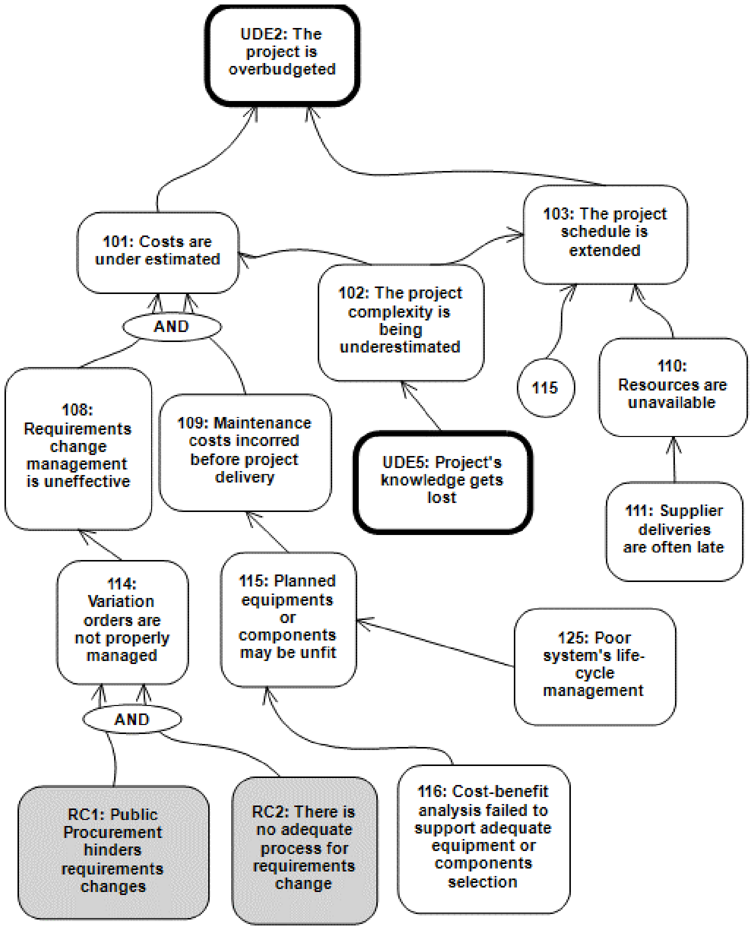

Figure 16. UDE2 - The project is overbudgeted

The other point related to costs underestimation is the maintenance costs. Sometimes, in an early phase of the project, some equipment or components are acquired which will later be part of an integrated system, because there is a commercial opportunity or a similar benefit. What often happens is that, in the delivering phase, those machineries, are already in need of maintenance or even worst, in need of replacement. Fails in cost-benefit analysis and poor system's life-cycle management are a common root-causes of this issue.

Another UDE that leads to project underperformance refers to the project being delayed. The delay in the project is also caused by prolonged project schedules, just as well by changes in the project scope and the lack of stakeholders engagement.

It is common that in this type of projects, resources are not always in a ready-to-use basis, and some of the component systems or equipment are unusually hard to produce or find within the DTIB. Often the project depends on suppliers' deliverables which are frequently not on time. This causes further delays to projects and originate additional costs.

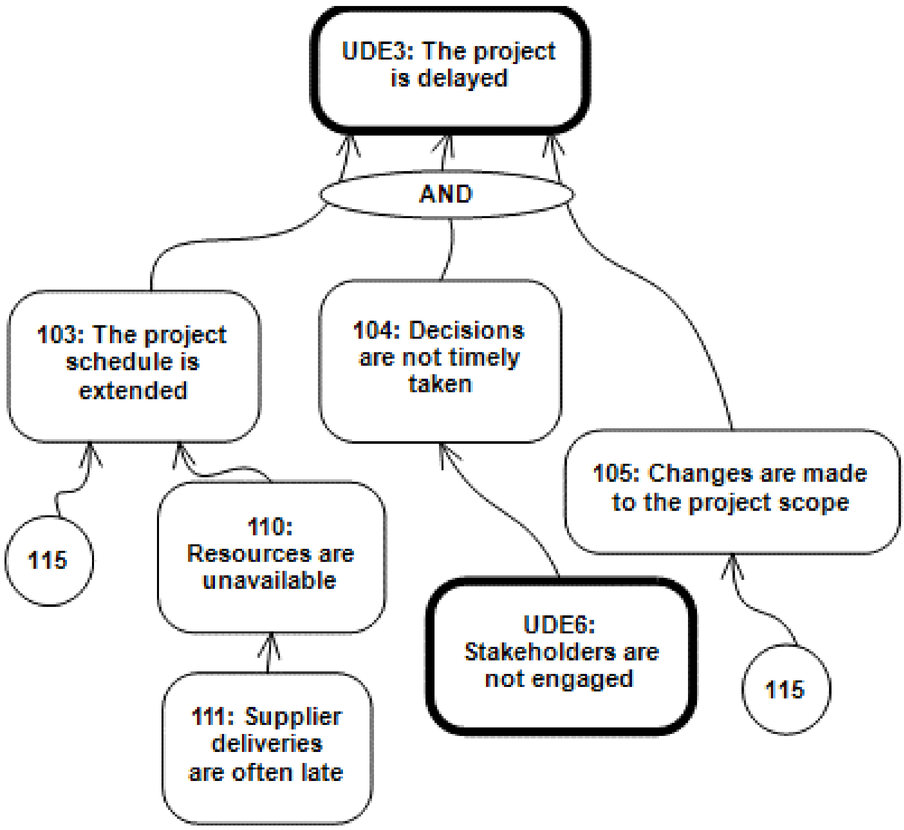

Figure 17. UDE3 - The project is delayed

"UDE4 – The project misses its scope" is usually the result of three main causes: (1) changes in project scope, (2) scope creep, and (3) unfulfillment of requirements. Changes in the scope often originate from changes in the operational requirements which are not properly managed within the requirements change subject. Scope creep is a term used to define a project that is constantly changing its scope, increasing the deliverables and its requirements (Komal et al., 2020). Scope creep is a cause of conflict between stakeholders whose opinions differ, having their own way of seeing the project outcome. It is also caused by an ineffective needs assessment phase, which stated an unclear scope that becomes difficult to achieve when the elicitation generates requirements that are not conformant with the planned scope.

Shipbuilding projects also fail their scope objectives due to the noncompletion of requirements. This is caused by misunderstanding aspects on the requirements statements. Although the Navy and shipbuilders have an understanding of ships terminology, there are some concepts that are not equal. Alongside with other writing aspects, the

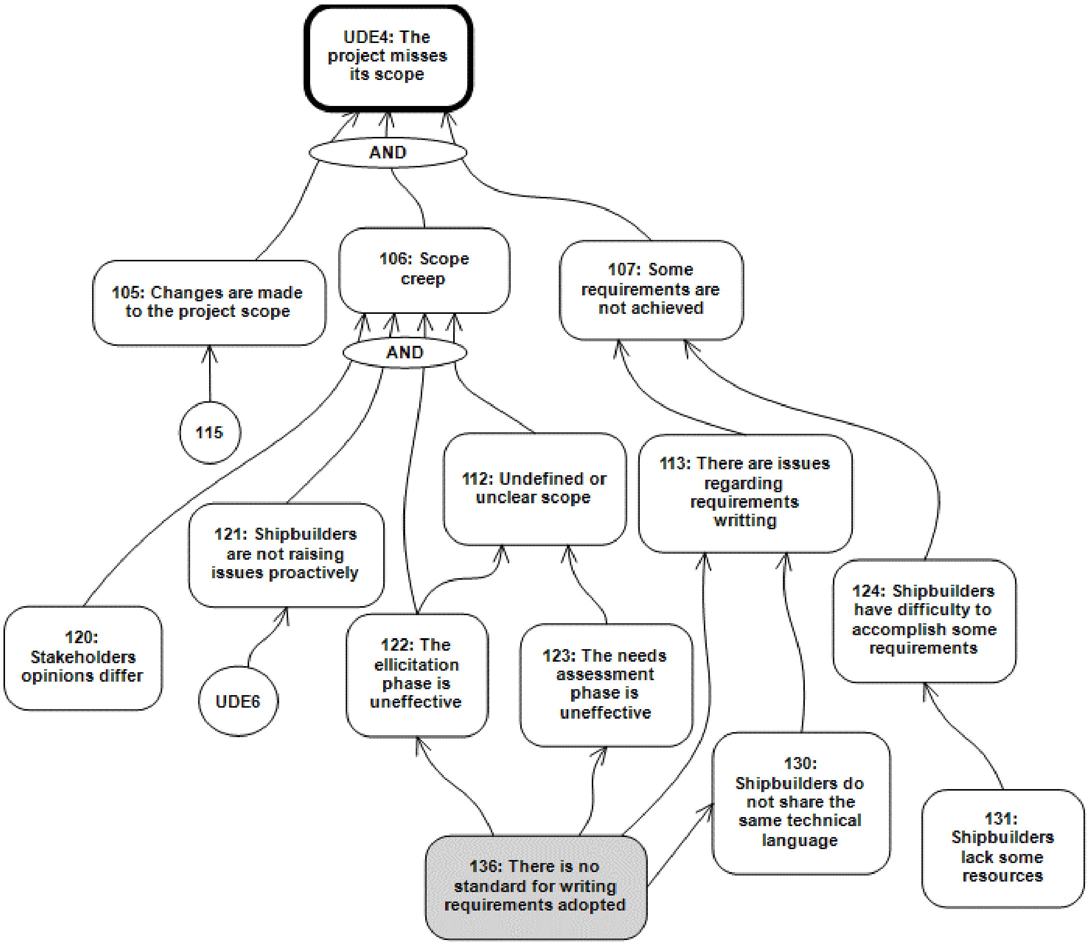

Figure 18. UDE4 - The project misses its scope

requirements statements usually drag into ambiguity clauses that are not raised by the interpreters, resulting in misleading executions. The lack of writing standards in the elicitation phase and in requirements definition stage is a main cause regarding this concern. However, the problem for the completion of requirements is also connected with the fact that oftentimes shipbuilders do not possess proper tools to ensure some requirements. Some requirements imply that shipbuilders would use a certain specialized equipment that does not exist in the shipyard. Instead of searching for a way to solve this problem the shipbuilders may opt to miss the requirement.

The "UDE5 – Project knowledge gets lost" is intrinsically connected to the absence of detailed standards, adequately implemented, for project management, and more specifically RM. If there were standards implement, and certified people accordingly, the person that assumes a new function as project manager or part of a project management team, would not have to develop his/her new own way to address project management. Hence, every time personnel change roles, know-how is lost. In the handover stage there is no time for a proper transmission of experiences and practices due to an urge for a quick role transition. Since there is no formal mechanism for knowledge sharing or *lessons-learned* implemented, the knowledge related to project management stays with its owner.

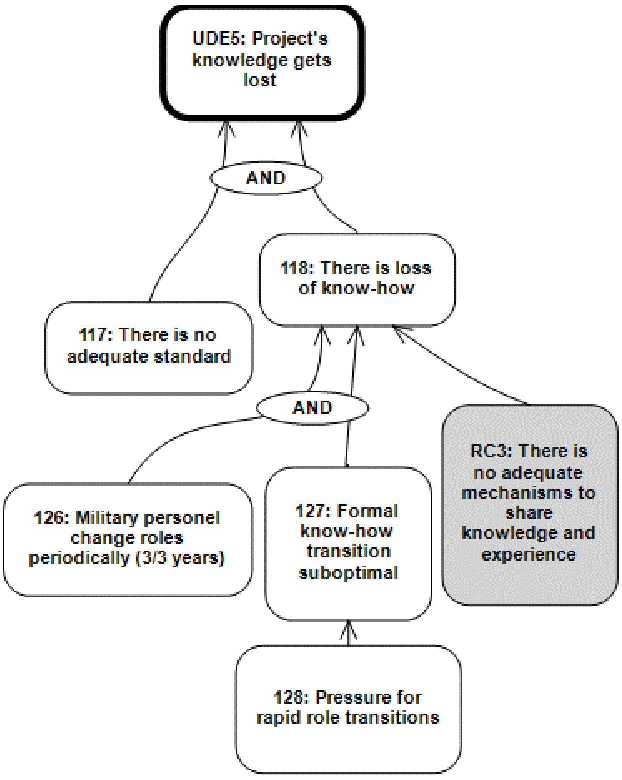

Figure 19. UDE5 - Project's knowledge gets lost

As seen before associated with other UDEs, there is the matter of stakeholders not being engaged in the project. This is attributed to miscommunication, different perspectives for the project and ineffective stakeholders management. Shipbuilding projects encompass a large set of stakeholders who have their own expectations and roles in the project life cycle. Starting from the main suppliers of a ship's systems up to the future crew of that ship, they all share the same objective - achieving a fully operational vessel. The failure aspects in stakeholders engagement is a result of the absence of a stakeholders register and classification system, and the need for improving conflict management skills.

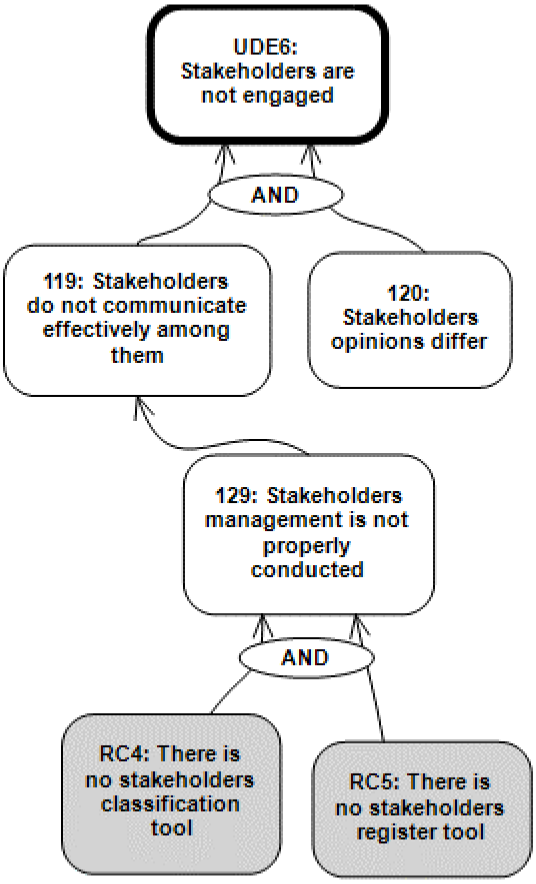

Figure 20. UDE6 - Stakeholders are not engaged

From the analyses of the CRT, it can be concluded that most of the deviations between the current reality and the desired performance paradigm arise from cultural, legal, and management constraints. Projects performance is being affected by six main root causes. The principal key issues to work on will be explored in the next section.

3.2 Design of a Solution

From the CRT, we could conclude that the UDEs were being caused by a set of root-causes. In this section, a set of countermeasures (injections) will be discussed in order to develop a strategy to eliminate such UDEs. To clarify these injections, we can use three possible paths: (1) go back to the IO Map and study the deployment of one (or more) of the necessary conditions, (2) deduce the injections directly from the CRT root-causes, or (3) create injections through a strategic EC.

ECs are usually used to create injections when there is a deployment conflict regarding some injection. This usually arises from some type of resistance from team members, or a conflict among resources or similar. However, from the interviews conducted, it was clarified that this resistance is not a real issue in strategy deployment in the current subject under study, since there is a common sense for the need for change in what requirements management concerns. Teams are willing to change their approach to project management (in fact, they have been trying to do it for a while) but they consider such a vastly time-consuming task, when their oftentimes already busy agendas. Hence, as there is no apparent conflict that justifies the application of an EC, the other two paths will be followed, together with information gathered from the interviews. From the analysis of both, IO Map and CRT, seven injections were inferred. The following table associates both root-causes and injections.

Root-causes (RC)	Injections (INJ)
RC1 - Public Procurement hinders requirements changes **RC2** - There is no adequate process for requirements change **RC3** - There is no adequate mechanisms to share knowledge and experience **RC4** - There is no stakeholders classification tool **RC5** - There is no stakeholders register tool **RC6** - There is no standard for writing requirements adopted	**INJ #1** - Public Procurement policies are reviewed, in order to accommodate highly adaptive projects **INJ #2** - Requirements management tool is deployed **INJ #3** - Standards for requirements writing are adopted **INJ #4** - Knowledge sharing is stimulated **INJ #5** - Standard for requirements management are internally implemented **INJ #6** - Project management personnel are certified **INJ #7** - Comprehensive stakeholder management tool is implemented

Table 3. Root-causes and injections

Similarly, to the CRT, the FRT is also a cause-and-effect tree, read from the bottom to the top, in a "if-then" logic. The "fruits" of this tree are the Desirable Effects (DE), here seen as being the opposite of the UDE of the CRT. The DEs in this case, converge to the goal initially stated in the IO Map – An effective and efficient project performance. This goal shall be sustained by the Project Management Institute (2021) triangle of projects success: time, cost, and scope. Besides that, two other DEs are produced. The next figure shows the entire FRT with the five DEs and the injections at the bottom.

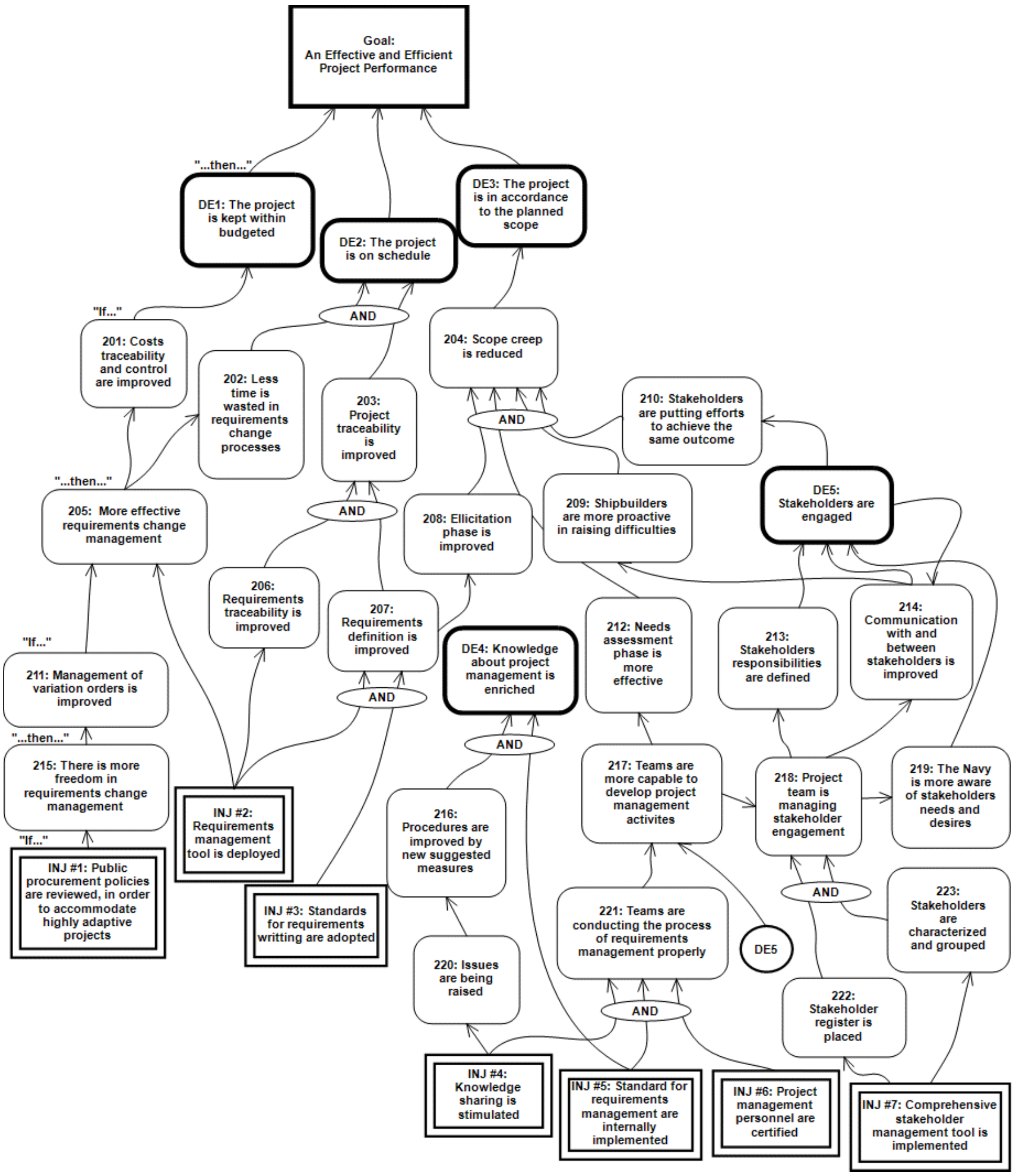

Figure 21. Future Reality Tree

The “DE1- The project is kept within budgeted” is originated from the deployment of two injections: Public Procurement policies are reviewed, in order to accommodate highly adaptive projects (INJ #1), and requirements management software is deployed (INJ #2). The revision of Public Procurement policies can be a significant measure for any Defence Acquisition programme. This type of mega programmes that incur in a vast public bill, could have cost reductions if the requirements revision were facilitated. When there is the possibility to revisit some requirements during the execution phase in such highly adaptive projects, the project costs can be reduced (Heindl & Biffl, 2005). This would help in the management of variation orders, that consequently would improve requirements change management, and help keep projects on track. The correct deployment of a RM software tool is also a solution for the raised problem. Besides other effects, a RM tool can also be used in cost traceability and control.

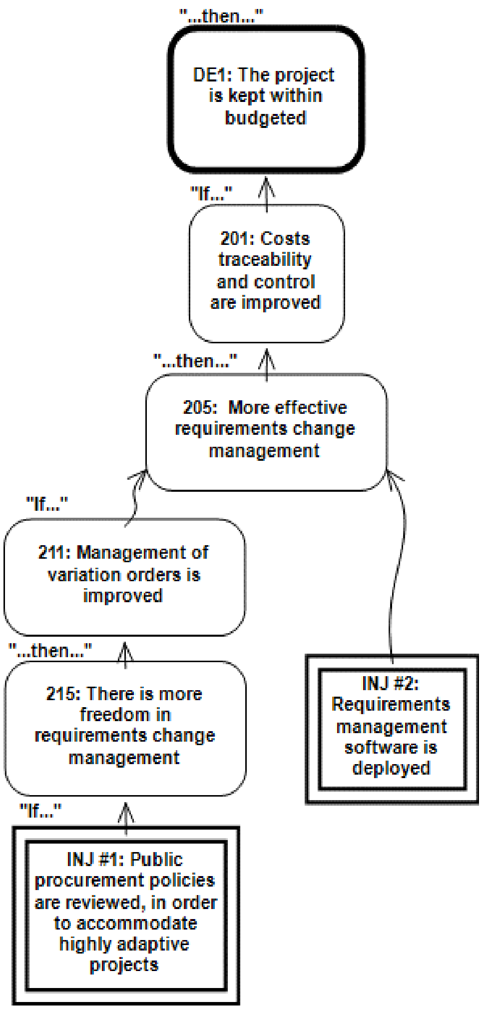

Figure 22. DE1 - The project is kept within budgeted

In addition to helping with costs traceability, the deployment of a RM software tool can also help the traceability along projects development. From the requirements change management perspective, this can also assist in saving time by preventing conflicts in requirements from happening. However, most of the problems associated with missing requirements originate from wrong execution, due to misleading requirements definitions. The "INJ #3 – Standard for requirements writing are adopted" is an effective measure to solve this issue. At the same time, the adoption of a requirements writing standard can bring the implementation of a new document form for requirements definition, different and independent (but in concordance) to the legal contract requirements. This would have a direct effect in requirements definition that, alongside with RM software tool deployment, would increasingly improve projects traceability, and therefore, projects schedule.

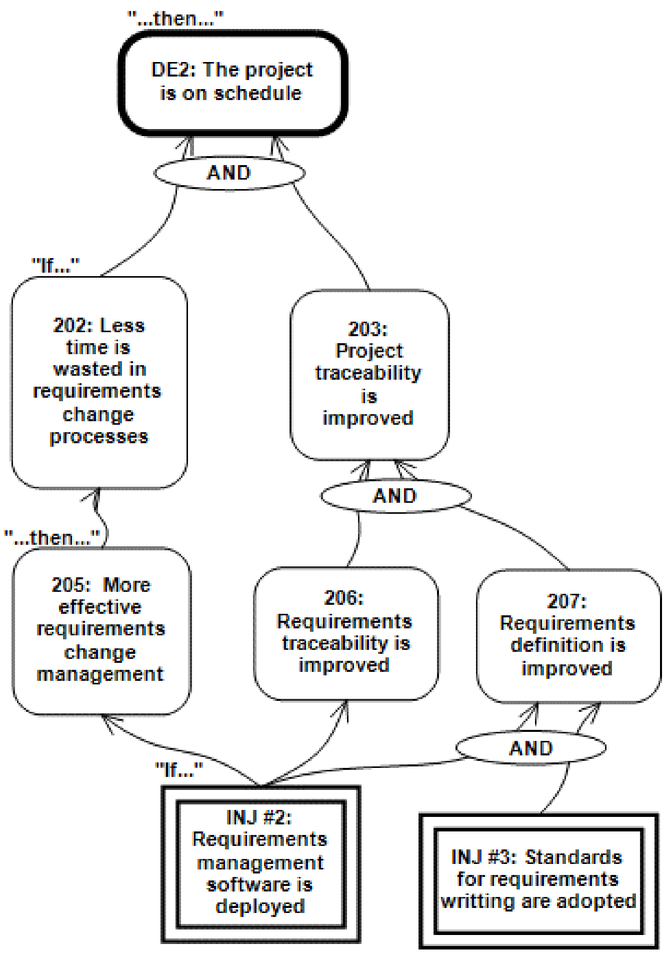

Figure 23. DE2 - The project is on schedule

The last vertex of the projects success triangle is scope. Recalling the CRT, one of the main causes of a missed scope is scope creep. To solve scope creep three new injections were added. The stimulation of knowledge sharing (INJ #4) with the implementation of standards for RM (INJ #5) and the certification of projects personnel (INJ #6) guarantee the team's train for project management. Theses injections remember that not only good tools and techniques solve strategical issues. Without stakeholders and project team members' commitment and an effective normalized process, scope creep is a certain call. The three injections together (INJ #4, INJ #5 e INJ #6), result in teams being ready to develop PM activities that ensure the effectiveness of needs assessment. However, scope creep also surges from unfulfillment of requirements; with the INJ #3 causing de improvement of requirements definition, that enhances the elicitation phase, preventing scope creep.

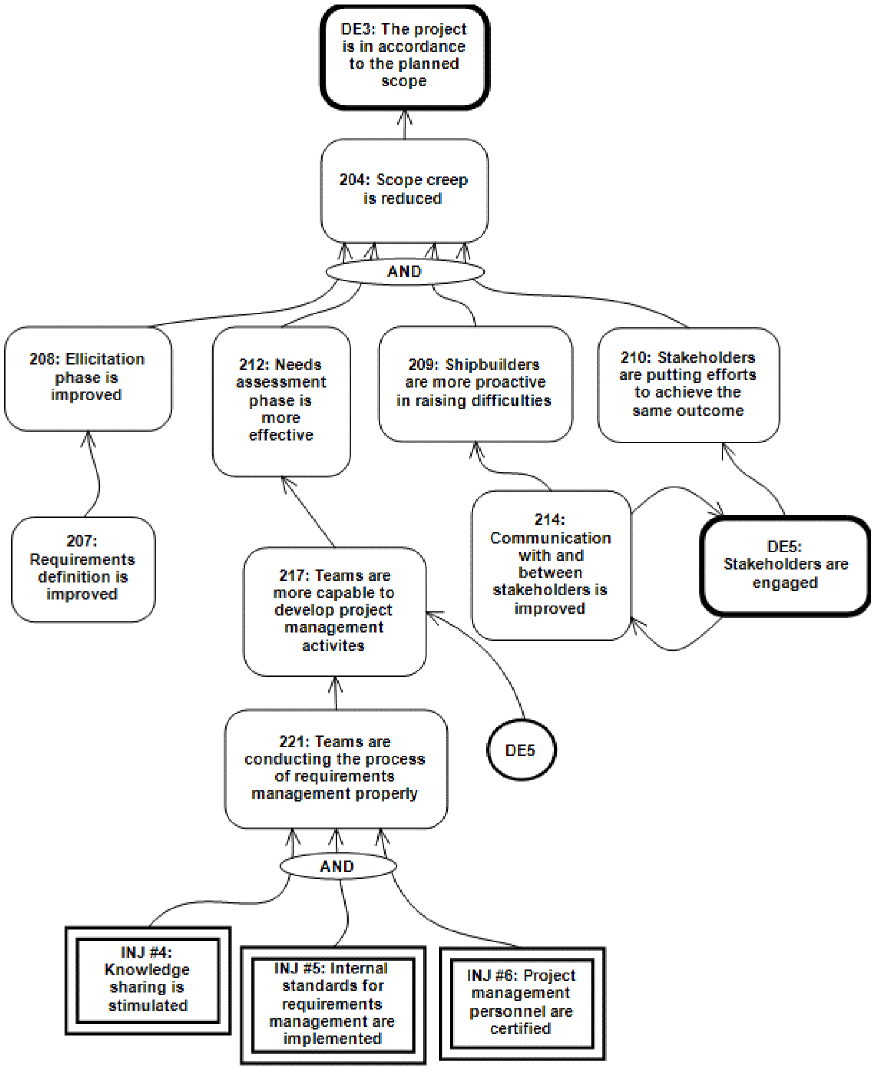

Figure 24. DE3 - The project is in accordance to the planned scope

The lack of stakeholders engagement also takes an important role in projects where scope creep is verified. Adequate stakeholders engagement can ensure that communication is improved and *vice-versa* (systemic reinforcing effect), resulting in shipbuilders being more proactive in proactively raising difficulties and aligning efforts to achieve the common goal – improved project performance.

In order to achieve adequate stakeholders engagement, the injection suggested (INJ #7) consists in the implementation of a comprehensive stakeholders management tool, where the register, classification and group of stakeholders would be ensured. This is important since a considerable number of the stakeholders never get to be identified in the needs assessment phase. Alongside with the team's ability to develop project management activities, stakeholders engagement activities would be managed, covering their responsibilities, communication plans, needs and desires. Stakeholders engagement is a key foundation for projects success, hence a healthy cooperation between the Navy and the stakeholders is always to be encouraged.

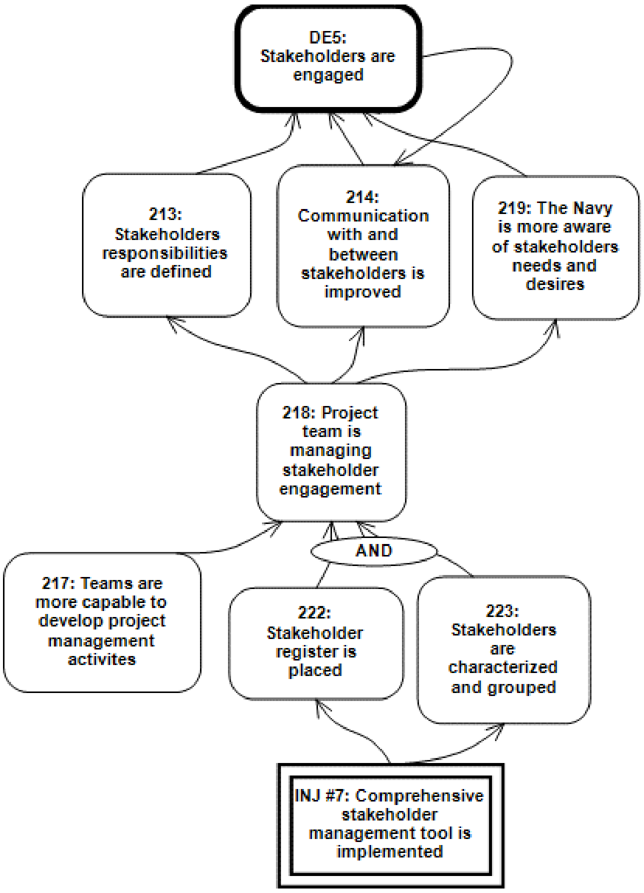

Figure 25. DE5 - Stakeholders are engaged

The final DE represented in the FRT is the enrichment of project knowledge (DE4). Organizational wisdom is considered to be a true asset for every organization and is considered a competitive advantage. Another golden rule of organizational management is the current practice of continuous innovation. For any team, its important to dialogue and keep track of everyone's opinion and suggestions. The stimulation of knowledge sharing shall rise the appetite for procedures and techniques renewal. That will keep the organization updated and in touch with the most recent innovations in project management, defence systems acquisition, and DTIB knowledge. Combined with the teams' integration and knowledge sharing, know-how is preserved and is built-in the organizational culture. This ensures that projects knowledge is enriched and so is their personnel.

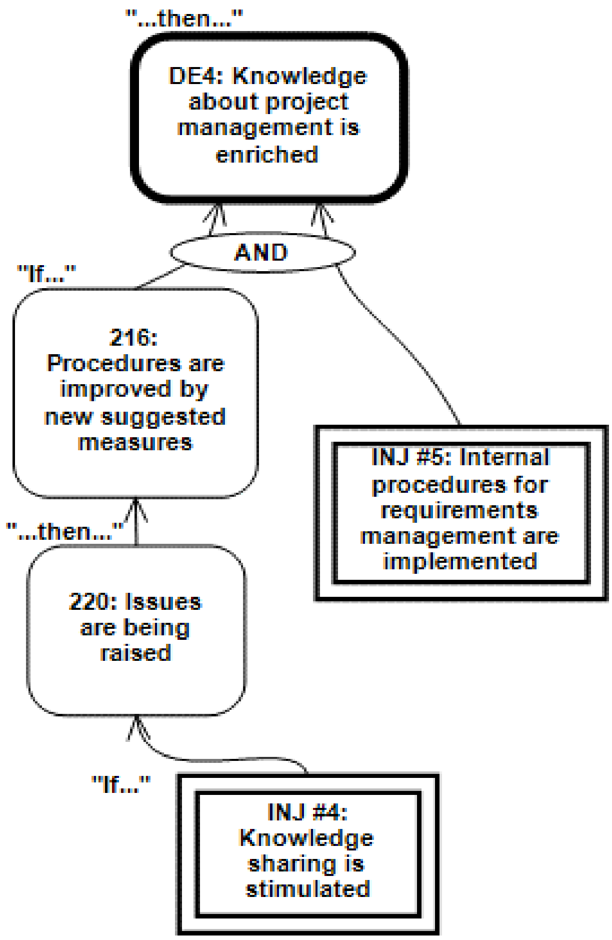

Figure 26. DE4 - Knowledge about project management is enriched

3.3 Implementation Considerations

This section has the purpose of reviewing the previously stated injections and study their deployment within the Navy's actual context. This "plan the execution" step is illustrated by PRT which aim to unfold the tasks and events that are beyond the injection statement. "The PRT structures those tasks and events into a logical sequence that culminates in the achievement of the injections" (Dettmer, 2003). PRTs are composed by the injection under focus, the obstacles encountered for its application and the actions to be developed. However, some injections do not need a detailed PRT due to its simple and straightforward nature.

The INJ #1 – Public Procurement policies are reviewed, in order to accommodate highly adaptive projects, is intended to solve the constraints related to requirements change after the contract celebration. Unfortunately, since the requirements only take the contractual form, its change is not usually seen with good eyes. The revision of requirements in the context of the current policies usually incurs in additional costs and more time expenditure. Public Procurement has an inverse proportionality with the project management subject. As the constraints inflected by Public Procurement decrease, the freedom for proper requirements change management increase. Nevertheless, it is important to state the important role that such policies have in the legal aspects of accountability, equity, and cost/time control.

INJ #2 – RM tool is deployed, is justified by an ever-missing aspect of Navy shipbuilding projects. Although Microsoft Enterprise Project Management software has been employed for some PM areas, it doesn't answer to all the essential parameters, especially the ones concerned with RM. A quick walkthrough RM software packages available in the market, demonstrates the vast portfolio of software that targets the requirements management and related aspects. The choosing of a RM tool can be a difficult ask, so it is important to define a responsible manager to select the tool. Since the Navy hasn't a defined role responsible for developing the actions related to requirements management, the first step should be the appointment of a responsible requirements manager, preferably certified within an adequate standard or methodology.

The responsible manager would then study the various software packages available, with special focus on the capacities of each available RM tool. He/she should be looking for traceability, costs monitoring, schedule control and requirements, requirements registry, competition rates tools, which could be synthesized in a sort of balanced scorecard, for example. For this selection a cost-benefit analysis could be conducted in order to present the rationale behind the choice.

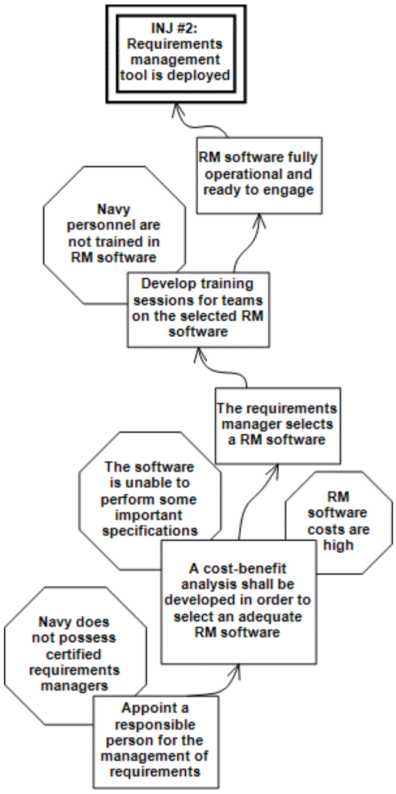

Figure 27. Prerequisite Tree of INJ #2 - Requirements management tool is deployed

Afterwards, the next obstacle in the RM tool deployment would be the managers lack of familiarity with this type of tools. To overcome this obstacle, training sessions for project management teams should be arranged. This training sessions can be conducted by the responsible person for the RM tool selection or by an invited expert on the software. As soon as all members are familiarized and conscious about the tool capacities, the software will be ready to engage in the project management.

Related to this new strategy it is worth discussing the INJ #3 – Standards for requirements writing are adopted. This injection in particular can be addressed in two strands that come for the same principle – the right and effective definition of requirements. The requirements in the Navy actual process only take the form of contractual clauses. The writing of legal clauses are ruled by a pattern of standards that are distinguished from the requirements writing standards in a PM perspective. One first step to adequate requirements writing is the translation of the contractual clauses to a formalized document of project requirements.

Then, the writing of requirements should follow a set of principles: necessary, implementation independent, unambiguous, complete, singular, feasible, verifiable, correct, and conforming. The INCOSE Guide for Requirements Writing (INCOSE, 2012) establishes a set of forty nine rules that sustain a rigorous and effective criteria for requirements definition. These rules can be easily adopted for the Navy reality, with no need for special arrangements or adaptations.

INJ #4 – Knowledge sharing is stimulated, has three obstacles for its implementation: (1) the absence of a formal communication mechanism for knowledge sharing, (2) knowledge gets lost once the project is closed, and (3) new managers usually start from a knowledge zero base point. A lot of meetings are realized during the project execution, but actually none of them usually as the direct intuit of sharing knowledge and develop internal policies for projects development. This type of meetings where Navy personnel get around a table to discuss the actual panorama of a project, to share different points of view, and to make decisions, should be a periodic and recurring practice.

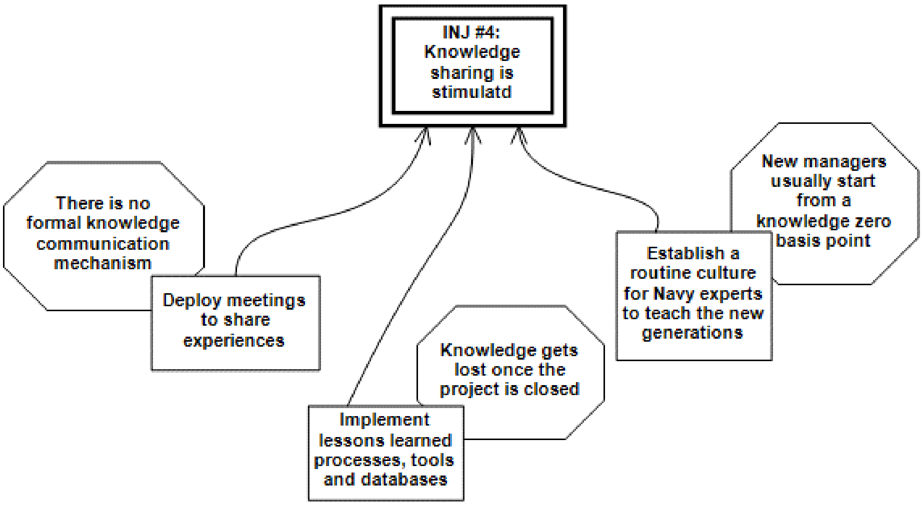

Figure 28. Prerequisite Tree INJ #4 - Knowledge sharing is stimulated

Subsequently, once the project is closed, the lack of knowledge sharing and review of the projects performance is still an organizational gap issue. Actually, there are no formal report of lessons learned or similar practice. This would cause the know-how to be kept for each one of the PM team members despite of being transmitted between everyone. The importance of lessons learned purpose is unquestionable, as stated by Rowe & Sikes (2006, p.2):

> *"We learn from our own project experiences as well as the experiences of others. Project managers, team members and leadership can all participate in the lessons learned sessions, review the lessons learned reports and make decisions on how to use the knowledge gained. Sharing lessons learned among project team members prevents an organization from repeating the same mistakes and also allows them to take advantage of organizational best practices. Innovative approaches and good work practices can be shared with others. Lessons learned can be used to improve future projects and future stages of current projects."*

The same authors propose a "Lessons Learned Process" which encompasses five steps: identify, document, analyse, store and retrieve. This could be a really helpful process to implement, enabling future projects to take tacit knowledge from previous ones.

The final obstacle in this injection rises from the fact that new managers usually get the role without having a formalized knowledge of PM, preferably under some certification. The need for quick handover of service leaves the new managers unnoticed about "what to do" and "how to do it". This is a concern that could be easily fixed if new members could take training from experts before assuming a new management role. This is a practice that will be analysed later in this section.

INJ #5 – Standard for requirements management are internally implemented, is related to the fact that there is no publication designed for requirements management and development. Although, the IOA and POA represent suitable documents for the addressing of the employment concept and the operational requirements, there is no official standards for the conception of this documents and the requirements description thereafter.

The first thing that should be stated, should be the requirements development process. The Navy could adopt the "PMI Requirements Process" stated in the systematic literature review with some proper adaptations. Besides that and the writing of requirements already discussed, the Navy should establish: (1) needs assessment techniques, (2) elicitation techniques, (3) validation and verification policies, (4) documentation and communication of requirements standards, (5) requirements analysis techniques, (6) monitoring and controlling techniques, and (7) traceability measures.

The implementation of INJ #6 – Project management personnel are certified, brought the uncovering of a possible conflict regarding the training of PM team members. The objective of this injection is to have team members capable of conducting project management activities. The conflict raises from three assumptions. First, the Navy is clearly willing to have certified professionals during the development of its projects. However, money is a scarce resource that should be adequately spent (second assumption) and the Navy does not want to waste a lot of time with the certification processes, being typically defined a timeline of one month (third assumption).

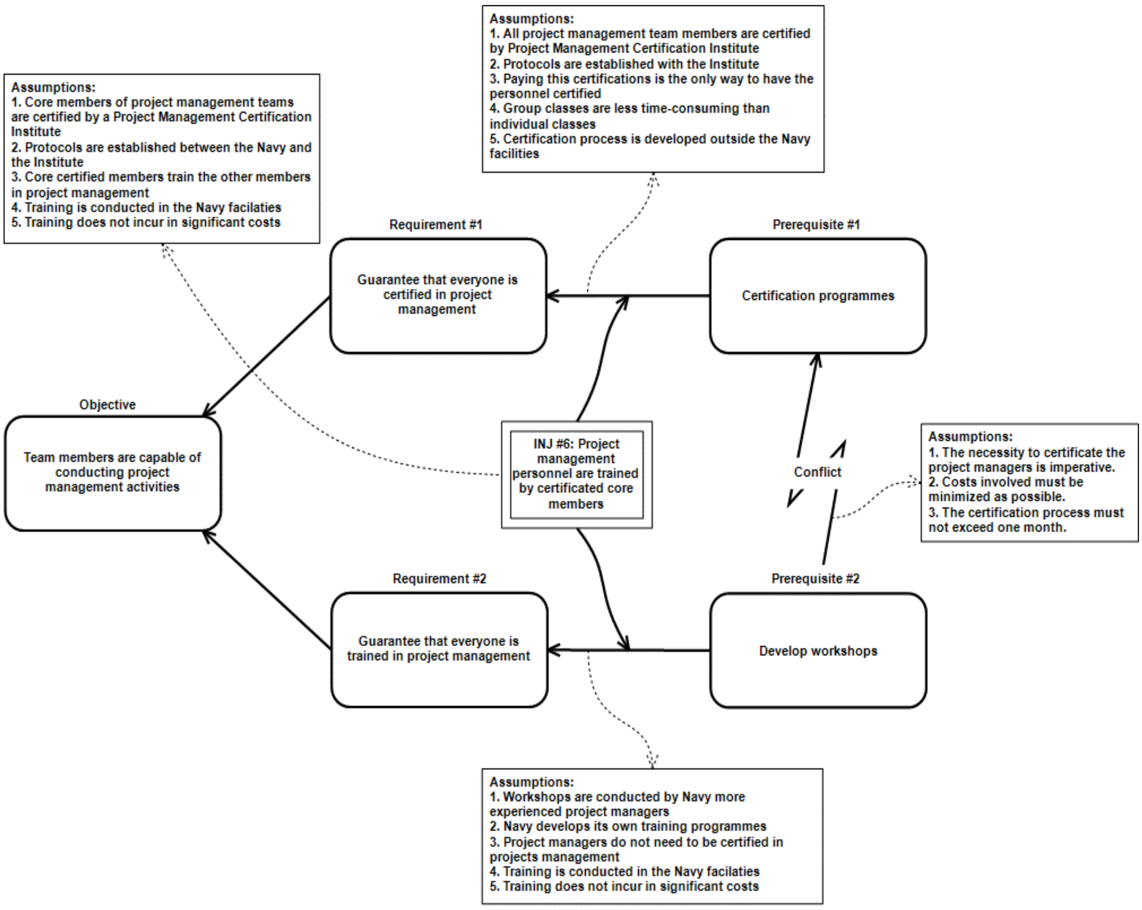

Figure 29. Evaporating Cloud for INJ #6 - PM personnel are certified

Two positions stand. One defends that certification programmes must be developed in order to ensure that everyone is certified in project management, while the other defends that by developing workshops, the Navy can guarantee that everyone is trained in project management. These two perspectives have their pros and cons, but none of them can be a one hundred percent effective strategy.

The certification programmes are certainly an ambitious alternative. The Navy could celebrate protocols with a Project Management Certification Institute (PMCI) in order to get discounts in the certifications. Moreover, certifying the PM team members in a PMCI don't require the Navy to dispend of its facilities or his own resources. Additionally, the group classes would always be less time-consuming than individual classes. The greatest problem with this alternative is the amount spent in the certifications. Even with the discounts associated with a potential protocol, certifying twenty to thirty people in Project Management could be very expensive.

From that constraint surges the alternative of developing workshops for PM training within the Navy. From this point of view, Navy PM experts could conduct formalized workshops to instruct PM team members, to qualify them for the right development of PM activities. In this way would not certify any of the Navy personnel, being the workshops conducted in the Navy facilities, not being predicted any significant costs.

The proposed solution to solve this conflict is a "win-win" mixed alternative. In this proposal the Navy would focus on certifying only a few core member of the PM teams that would later conduct training classes for the other members. With this solution, the positive assumptions from both sides would be preserved, being the negative ones minimized. The certification of the core members represents an added value to the Navy organizational status and to the members self-valorisation and self-motivation. The discounts could also be applied trough the protocols celebrated and, in the training phase, the Navy would use its facilities, with no significant costs and no compromising to the achievement of the objective. This evaporating cloud brings an update to INJ #6 – Project management personnel are certified, being now INJ #6 – Project management personnel are trained by certified core members.

The final implementation considerations go to INJ #7 – Comprehensive stakeholder management tool is implemented, which intends to ensure the proper stakeholders engagement in the project. The stakeholders engagement is an aspect of RM that starts as soon as the needs assessment phase is executed. During this stage, it should be envisioned which entities will have an active participation in the project and the ones that will be influenced by it. Identified the stakeholders, the management of their engagement is continued by the stakeholders register, group and characterization activities.

The registration of stakeholders presupposes its screening by a set of initial groups characterization that, in a way, define the role they will have in the project. For example, some of these registered groups may be: (1) entities that benefit from the project outcomes, (2) entities that supply equipment and products, (3) entities that are responsible for the project outcomes, (4) entities that are provide support, amongst others.

The grouping and characterization activities are usually developed using a RACI matrix, (responsible, accountable, consulted and informed). This matrix helps managers to have a comprehensive view of each stakeholder importance for attaining the project success, and what actions should be taken to keep them engaged.

Conclusion

This master thesis addressed the Requirements Management subject within the Portuguese Navy with particular focus on the shipbuilding projects. Initially, a systematic literature review was conducted to find answers to three research questions. To the question that raised the importance of an efficient and effective RM, it was illustrated with the case study of Swedish warship Vasa and the F-35 Lightning II of the United States Air Force, the relevance and criticality that RM had and still has for effective project management. Then, in order to answer to the state of art of RM, a brief definition of nuclear concepts was conducted, apart with a clarification of the INCOSE approach to requirements statements. Also concerning this research question, the systems engineering, V-model, and PMI requirements processes were presented as a framing of standards usually adopted across other endeavours where complex projects are normal. The last question was answered by the conducted in-depth interviews as it was meant to describe the actual process of requirements management within the Navy's.

The second chapter stated the adopted methodology - the Constraint Management Model. Firstly, the background of the model that is firmly grounded in the Goldratt's Theory of Constraints, the Boyd's OODA loop, and the Department of Defence's Joint Strategic Planning System was studied. Then a step-by-step walkthrough the CMM was described with particular focus on the adaptations made to the original model. At the end of this chapter, it was briefly described how the in-depth interviews were conducted and the information captured.

The final chapter covered the implementation of the adapted methodology. In "define the paradigm" it was found that in order to achieve an effective and efficient project performance, it needs the design of a customized requirements process, an effective stakeholders engagement approach, the implementation of adequate standards, and the proper training of teams.

Then the current reality tree showed that existed six main root-causes that were causing six related undesirable effects. In fact, the actual embraced practices were causing the project to be out of budget, schedule, and scope, and also conveying loss of know-how in addition to lack of stakeholders engagement. Scrutinising the causes behind those effects it was noticed that they were being caused by: (1) Public Procurement constraints to requirements change, (2) the absence of an adequate process for requirements change, (3) the inexistence of mechanisms for knowledge and experience sharing, (4) the absence of a stakeholders classification tool, (5) the absence of a stakeholder register tool, and (6) the lack of requirements writing standards.

In the "design the future" stage it was revealed the seven injections that would help eliminate the undesirable root-causes. These injections turned the undesirable effects into their opposites, desirable effects. But in order to achieve them, it is needed: (1) a Public Procurement policies revision, (2) the deployment of a requirements management tool, (3) the adoption of standards for requirements writing, (4) the stimulation of knowledge sharing, (5) the implementation of requirements management standards, (6) the certification of project management core team members and then, the training of the other members, and (7) the implementation of stakeholders engagement tools.

The final step in the model was to plan the deployment of the injections with some implementation considerations, showing that the main obstacles for the deployment of the strategy were related to financial constraints, accountability measures and ineptness to the development of project management activities. Moreover, it was suggested some actions which can be taken in order to avoid or minimize those obstacles.

Regarding all the matters studied, the main conclusion of this master thesis is:

> **In order to achieve an effective and efficient performance in the Portuguese Navy's shipbuilding projects it is imperative to ensure the accurate and active management of five crucial factors: budget, schedule, scope, knowledge and stakeholders engagement**

Looking back to the objectives stated in the introduction, it is recognized that they were accomplished in their wholeness. However, a consideration note should be taken in what regards "O3: Clarify how RM is currently practiced in the Portuguese Navy". Since the start of the building of the new fleet of oceanic patrol vessels, the Navy has been adopting new project management approaches in order to improve from one series to the next one. This is a procedure that should be cherished and kept ongoing. However, within this master thesis the characterization of the Navy RM process took a more generalized perspective. It was not considered the special features that distinguished among the different shipbuilding projects for the last twenty years. The purpose of this was to have a common basis of study and comparison between different past projects that could be applied to the future shipbuilding projects.

The conducted research raised new questions and exploratory fields that should concern the Navy's project management capability. Bellow, there are three research suggestions for future research:

1. **Evaluation model for selecting projects options** – development of a quantitative decision support tool that would the benefit and the cost associated. This tool should evaluate the increase of the benefit, until the point where an added investment does not translate into a proportional increase of the benefit.

2. **Research the applicability of Model-Based Systems Engineering (MBSE) and its applicability to Projects Management within the Navy** – research the applicability of MBSE to new vessels projects, either by taking a whole systems engineering approach or focusing on the enhancement of particular areas, such as requirements management, communications, the reduction of projects risk, the improvement of quality and knowledge transfer.

It is vastly reckoned the importance that the Navy has been giving to project management and its related subjects. Given the current circumstances regarding shipbuilding investment and sea economy and exploration in Portugal, it is relevant to keep on developing knowledge in these areas. Concluding, the importance of this research for Project Management and to the Navy's strategic approach should be elevated.

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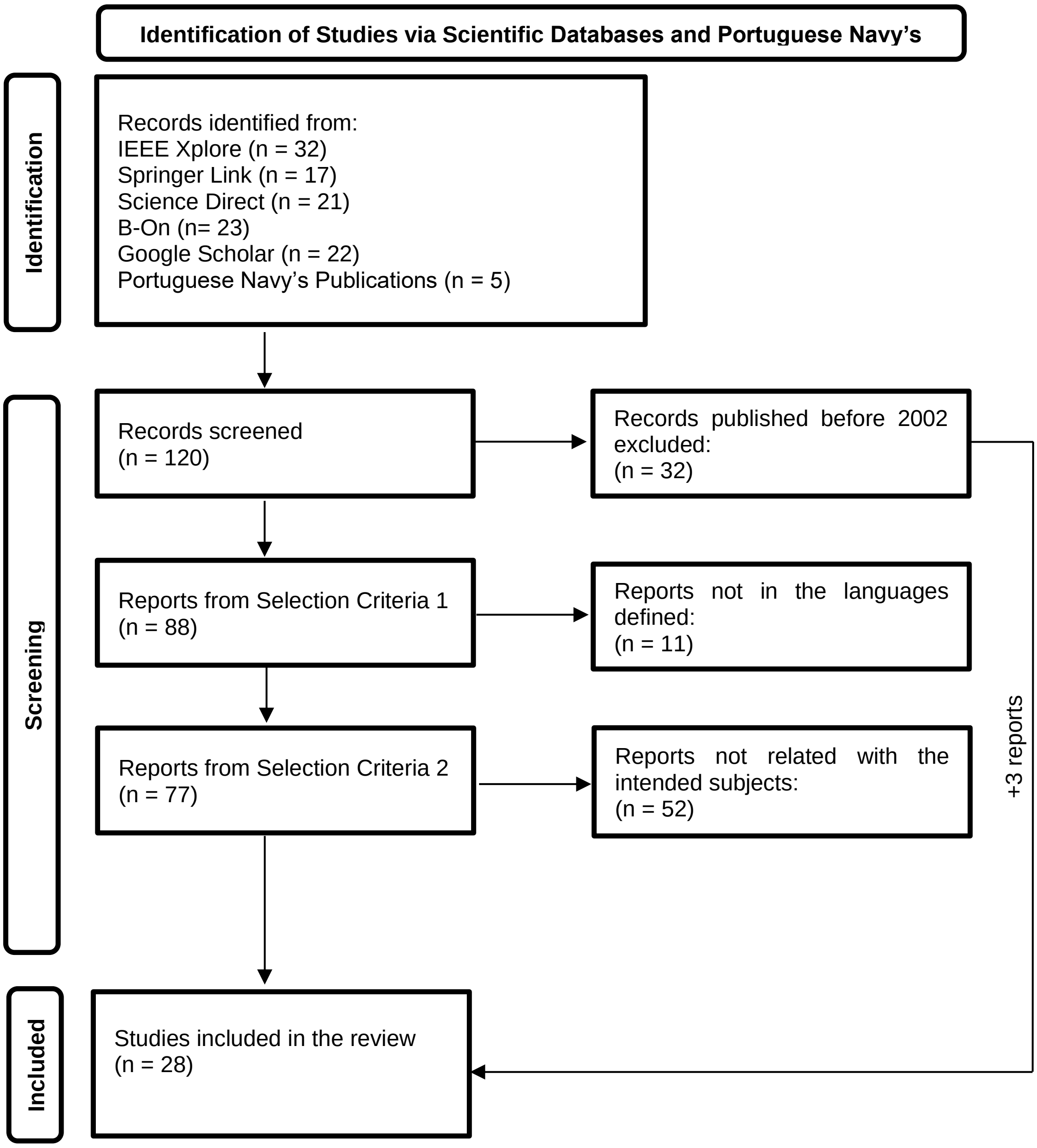
Annex A – Study Selection Flow Diagram



Annex B – Measuring Requirements Effectiveness

Questions	Measures
1. What is the current status of each requirement?	Status of each requirement
2. What is the level of the stability of the requirements?	# initial requirements # final requirements # changes per requirement
3. Why are the requirements changed?	# initial requirements # final requirements # changes per requirement # test cases per requirement Type of change to requirements Reason of change to requirements Major source of request for a change to requirements Phase where change was requested
4. What is the cost of changing the requirements?	Cost of change to requirements Size of a change to requirements
5. Is the number of changes to requirements manageable?	Total # Requirements # changes to requirements proposed # changes to requirements open # changes to requirements approved # changes to requirements incorporated into base line # changes to requirements rejected The computer software configuration item(s) affected by a change to requirements Major source of request for a change to requirements Requirement type for each change to requirements # requirements affected by a change
6. Does the number of changes to requirements decrease with time?	# changes to requirements per unit of time
7. How are affected groups and individuals informed about the changes?	Notification of changes shall be documented and distributed as a key communication document # affected groups and individuals informed about notifications of changes
8. How many other requirements are affected by a requirement change?	#requirements affected by a change
9. In what way are the other requirements affected by a requirement change?	Type of change to requirements Reason of change to requirements Phase where change was requested
10. Is the size of the requirements manageable?	Size of requirements
11. How many incomplete, inconsistent and missing allocated requirements are identified?	#incomplete requirements #incosistent requirements #missing requirements
12. Does the number of “To Be Done” decrease with time?	# “To Be Done” in requirements specifications # “To Be Done” per unit of time
13. How are the requirements defined and documented?	Kind of documentation
14. Are the requirements scheduled for implementation into a particular release actually addressed as planned?	#requirements scheduled for each system or equipment
15. How many requirements are included in the baseline?	#baselined requirements Phase when requirements are baselined

Adapted from (Loconsole, 2001)

Annex C – In-Depth Interviews

Good morning, Mr. ______ I wanted to thank you for your willingness to welcome me here today. I am ASPOF Marques Ferreira, from the Naval Administration class and I wanted to talk to you about your experience in the Management of Naval Construction Projects of our Navy. I wanted to address the theme of Requirements Management, which is the object of study of my Master Thesis.

This interview lasts about an hour. I'll make use of a recorder in order to collect as much information and not to waste too much time taking notes. Please note that all your answers are confidential. The only people who will have access to the materials in this interview will be me and eventually my advisor, Professor Pedro Borda de Água. Furthermore, in my dissertation there will be no reference to the names of the interviewees or associates, thus maintaining their confidentiality.

I also remind you that you can always choose not to answer a question. Do you have any questions about what has been explained so far? If not, I will start this interview.

1. Describe, briefly, the process of building Navy Ships, starting with the LPM, until the day the ship is delivered to the Navy?

2. Is there any internal instruction, publication or directive designed especially for the management of these types of projects? Do you consider the policies expressed actual and appropriate? Would you recommend the production of new internal standards for this area?

3. How is requirements management done? Who adopts the role of requirements manager? Is it used any tool or software or technique for this type of management? What is your opinion on these tools?

4. In detail, how is the requirements elicitation phase developed? What are the

parties involved? Is it a phase that occurs sporadically or is it something that occurs repeatedly several times throughout the process? Who participates in this phase?

5. How is the management of *project stakeholders* in the context of requirements management? How is the Navy's relationship with them? What mechanisms are there to keep them informed?

6. As for the writing of requirements, who is responsible for performing this task? What do you think are the characteristics that requirements must meet to avoid ambiguity and lack of validation modes?

7. How are the requirements processed? Is there a "check out" of the requirements? How does the project management team deal with requirements changes?

8. What methods are used to validate requirements? At what time(s) is requirements validation performed? Who is responsible for this validation?

9. At the end of the project, is any assessment made to the requirements management developed? Are reports drawn up on the basis of this assessment? If so, which entities are committed to this task and what are their recommendations?

10. In your opinion, what is the big problem with the management of Navy's ships construction projects?

11. What would you do to change current processes and procedures to make this management more efficient and effective? Do you think Model-Based Systems Engineering could be a way to improve requirements management? What about project management itself?

12. What strategy would you recommend implementing so that requirements management can be optimized? What do you see as the main barriers to this good management?

13. What is your experience with the construction of the latest generation of NPOs in the shipyards of Viana do Castelo? Do you believe that the fact of betting on the development of the National Naval Industry is an asset for the Portuguese Navy? What do you think went better in these projects?

14. What recommendations would you like to make for future studies in this area?

I have no further questions. I wanted to thank you for participating in this interview. Is there anything else you'd like to add? Any clarifications, opinions or comments? I will now analyze the collected information and study it with the data that I already gathered.

Thanks for your time and have a nice day!