NTNU – Trondheim
Norwegian University of
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Conceiving a Lean and Participative Project Management Framework Suited to Large-Scale Scientific Projects:

How to Adapt Existing Systems Engineering and Project Management Best Practices to CERN's Projects?

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Project Management
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MASTERKONTRAKT

- uttak av masteroppgave

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Studieprogram **Project Management**

3. Masteroppgave

<table>
<tr><td>Oppstartsdato
15. jan 2013</td><td>Innleveringsfrist
23. jul 2013</td></tr>
<tr><td colspan="2">Oppgavens (foreløpige) tittel
Conceiving a Lean and Participative Project Management Framework Suited to Large-Scale Scientific Projects.
How to Adapt Existing Systems Engineering and Project Management Best Practices to CERN's Projects?</td></tr>
<tr><td colspan="2">Oppgavetekst/Problembeskrivelse
The purpose of the thesis is to participate in developing a concept document for a framework for managing projects at CERN.

The background for the project is: Large-scale scientific projects, and that developed in organizations like CERN (and many others in Europe and around the World), lack of an appropriate framework for managing their projects. Three different "guidelines" are more or less followed:
— the PMI's PMBoK
— the ECSS (European Cooperation for Space Standardization) released under the auspices of the European Space Agency)
— the NASA's Systems Engineering Handbook
The two latter are really good, but they are focused to space projects (satellites, ISS, etc.) and they do not address key issues such as that of facilities emitting ionizing radiations, e.g. transverse engineering activities such as teleoperation, remote handling, radiation protection, etc. So it appears that releasing a kind of handbook for managing projects in scientific facilities emitting ionizing radiations will be of great value for all project stakeholders.

Moreover, in the framework of an European funded initiative called PURESAFE (http://cern.ch/puresafe), involving CERN as a partner,...</td></tr>
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Førsteamanuensis Tim Kristian Andreas Torvatn</td><td>Medveileder(e) ved institutt
Anandasivakumar Ekambaram</td></tr>
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Pierre Bonnal</td></tr>
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4. Underskrift

Student: Jeg erklærer herved at jeg har satt meg inn i gjeldende bestemmelser for mastergradsstudiet og at jeg oppfyller kravene for adgang til å påbegynne oppgaven, herunder eventuelle praksiskrav.

Partene er gjort kjent med avtalens vilkår, samt kapitlene i studiehåndboken om generelle regler og aktuell studieplan for masterstudiet.

Genève 15/1-13
Sted og dato

Student | **Hovedveileder**

Originalen lagres i NTNUs elektroniske arkiv. Kopi av avtalen sendes til instituttet og studenten.

Preface

To the reader,

This paper is written as the final work of the 2-year master's programme in project management at the Norwegian University of Science and Technology (NTNU). Furthermore the research is carried out in collaboration with CERN, where the author has been employed as a part of their Technical Student Programme for the last 6 months.

I would like to thank CERN for getting the opportunity to carry out my thesis in collaboration with them. In particular I wish to thank the members of the projects support office, for patiently answering any questions I have had, and for all help given during the working period.

Thanks to my supervisors Pierre Bonnal, Anandasivakumar Ekambaram and Tim Torvatn for their help and feedback all along the semester.

A special thanks to my family for all support and encouragement, not only during the work on this thesis, but also throughout my entire study period. It is much appreciated.

June 20, 2013

Ørjan Husby

Abstract

The use of project management methodologies has increased within most sectors the recent years. While project management earlier was an optional asset to an organization, the discipline is increasingly acknowledged as a necessity for modern organizations. Despite this, many organizations, among them CERN, lack an appropriate framework for managing their projects. This thesis investigates the best practices of systems engineering and project management, and tries to lay the foundations for a project management methodology at CERN. Through an extensive study of literature, complemented by a case study investigating the current project management practices at CERN, the thesis adds up information on the necessary aspects for the start-up of a project management methodology. The empirical data for the case study was mostly collected by the use of semi-structured interviews and 17 experienced members of personnel at CERN contributed with their opinions. The thesis is mainly focused on the areas of project life cycles, roles and responsibilities, and documentation. The main findings suggest that incorporating the idea of a centralized methodology to the organizational culture, centralizing a life cycle for the organization on an overall level, identifying clearly the roles and responsibilities, reducing the amount of unnecessary documentation, and explicitly stating needs in the front-end, are all important aspects to consider for a successful development of a methodology. Moreover the continued use and development of the earned value management tool is believed to be advantageous for CERN. The work suggests to use these aspects as a point of departure for designing a project management methodology within the organization.

Sammendrag

Bruken av metodologier for prosjektledelse har økt innen de fleste sektorer de siste årene. Mens prosjektledelse tidligere ble sett på som et valgfritt verktøy i en organisasjon, blir det stadig oftere ansett som en nødvendighet for moderne organisasjoner. Til tross for dette ser det ut til at mange organisasjoner, blant dem CERN, mangler et hensiktsmessig rammeverk for prosjektledelse. Denne masteroppgaven undersøker nåværende praksis innen "systems engineering"[1] og prosjektledelse, og forsøker å bygge et fundament for en prosjektledelsesmetodologi for CERN. Gjennom en utvidet litteraturstudie, komplettert av en case-studie som undersøker CERNs praksis innen prosjektledelse, forsøker oppgaven å identifisere nødvendige momenter for å utvikle en metodologi for prosjektledelse. Til å skaffe nødvendig bakgrunnsinformasjon ble det hovedsaklig benyttet semistrukturerte intervjuer, og 17 erfarne medarbeidere på CERN bidro med sine synspunkter. Oppgavens hovedfokus er tredelt: prosjektlivsløp, roller og ansvarsområder, samt dokumentasjon. Hovedfunnene viser at for å skape en metodologi er det nødvendig å fokusere på flere punkter. Tanken om en sentralisert metodologi bør innlemmes i organisasjonskulturen. Det bør dannes et sentralisert livsløp for prosjekter på et overordnet nivå i organisasjonen samt at roller og ansvarsområder bør defineres entydig. Mengden unødvendig dokumentasjon bør reduseres og behov må defineres eksplisitt i tidlig fase. I tillegg antas det at videre utvikling og bruk av verktøyet "earned value management"[2] vil være fordelaktig for CERN. Oppgaven foreslår å bruke disse punktene som utgangspunkt for å utvikle en metodologi for prosjektledelse for organisasjonen.

[1] Det eksisterer meg bekjent ingen god oversettelse, så det internasjonale begrepet er valgt beholdt.

[2] Se 1.

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List of Acronyms

CDR	=	Conceptual Design Report
CERN	=	European Organization for Nuclear Research
CHF	=	Swiss Francs
EDH	=	Electronic Document Handling
EDMS	=	Engineering and Equipment Data Management Service
ESA	=	European Space Agency
EVM	=	Earned Value Management
HERMES	=	Handbuch der Elektronischen Rechenzentren des Bundes, Methode für die Entwicklung von Systemen
INCOSE	=	International Council on Systems Engineering
LHC	=	Large Hadron Collider
NASA	=	The US National Aeronautics and Space Administration
NTNU	=	Norwegian University of Science and Technology
PM	=	Project Management
PMBOK	=	Project Management Book of Knowledge
PMI	=	Project Management Institute
PMM	=	Project Management Maturity
PO	=	Projects Support Office
PRINCE2	=	PRojects IN Controlled Environments
QA	=	Quality Assurance
QAP	=	Quality Assurance Plan
RAM	=	Responsibility Assignment Matrix
R&D	=	Research and Development
SE	=	Systems Engineering
TDR	=	Technical Design Report
WBS	=	Work Breakdown Structure

Chapter 1

Introduction

TODAY an increasingly amount of work is conducted as projects, i.e. a temporary endeavor undertaken to create a unique product, service or result [52]. Project environments demand more flexibility towards management routines than what is necessary in pure manufacturing organizations. The latter are often process oriented and focus more towards performing repetitive activities as efficiently as possible [49]. This is especially an issue for organizations where the size of the projects is huge, and the overall impact of actions on a subproject is not easily visualized on the top-level. One of the major problems with these ”megaprojects” is insufficient cost control [26] but delays are also common [27].

It appears that large-scale scientific projects like the ones developed in scientific research organizations like CERN or NASA, are developed without an appropriate framework for project management [11]. Within each organization each project manager has their own way of managing their projects, among others in terms of terminology used, way of documentation, resource handling and similar.

The handbook of the Project Management Institute (PMI) encompasses the standards which organizations should adhere to, and should be used as a supporting tool in developing a firm-specific project management methodology, and not as a guideline itself [5].

Currently there exist several practices for how the projects are planned and executed at CERN, including use of different terminologies, definitions of work tasks for different roles, and at what points throughout the project life cycle different decisions are being made. Kerzner writes in his work from 2004 about the importance of having a standardized methodology for project management (PM), and about the benefits this will give to an organization [38]. He states several advantages both on a short- and long-term basis. Among the former he mentions factors highlighting the improvement of the execution of project management, for example in terms of decreasing cost and time and making communication more effective. In a long-term view the critical success factors and customer satisfaction is regarded important, where the latter is argued to be the largest benefit of a methodology. He argues that when a company has a methodology that can be proven superior or equally good as that suggested of a customer, chances are its way of doing things will be accepted, rather than the customer imposing it their management system.

The importance of designing a standardized methodology is also emphasized from other authors. Loo found, in his study of best practices in Canadian organizations utilizing project management, that the standardization of PM practices was one of the main technical aspects that needed improvements [44]. In a study from 2012 Pinto and Dominguez concluded that four out of five companies in the Portuguese metalworking sector has developed a formal methodology to suit their needs [50]. Moreover McHugh and Hogan showed that Irish companies tend to adapt internationally recognized methodologies for their projects [45]. So it can be argued that there is a general opinion stating that it is beneficial to utilize some kind of standardized methodology within an organization.

Nevertheless one should keep in mind that the development of a standardized methodology for project management is not suited to all kinds of organizations [38]. It takes quite a lot of effort to be able to create a working system for the projects of your organization, so for firms that merely deal with small short-term projects this will not be the most appropriate way. This extra effort is highly appreciated for companies dealing with projects on the other side of the scale which are huge, complex and long-term-oriented, and Kerzner argue that a standardized methodology should be mandatory in these situations [38]. The European Organization for Nuclear Research (CERN) is an example of such an organization. Currently there does not exist one for this entity, so each project more or less develop their own methods and best practices for project management.

This thesis seeks to: identify the current theoretical (as seen from literature) best practices of project management and systems engineering with regards to large-scale scientific projects; gather the experiences of a selection of project personnel at CERN to assemble project specific best practices within the organization; and finally use the findings of these two to create a basis for conceptualizing a standardized methodology for the future conduction of projects, mainly for use in this research facility. Depending on the outcome, this concept design could be used as a point of departure also for similar organizations, but it would then be important to bear in mind the local adaptations that are necessary.

1.1 Formulation of Research Questions

To be able to concretize the research, and to pinpoint the topics of relevance, the paper will try to answer three main questions:

1. What are the current best practices in terms of project management and systems engineering in theory?
2. How are projects at CERN currently managed?
3. What are the main elements from theory and from CERN's practices that are necessary to design a project management methodology for the organization?

The formulation of the questions is a result of an existing need at CERN to assemble the different project management experiences across projects to a united framework.

The term "best practices of project management" has a vague nature, so to be able to find some useful results the scope of best practices has to be defined. It is apparent that the industry lacks a general framework for how to execute project management in both cost- and time-efficient ways. A study by Flyvbjerg shows that 90 % of large-scale projects have overruns either in terms of cost or time, and those that are able to finish within the borders of these often deliver a quality that is inconsistent with the expectations of the customer [27].

To investigate the nature of project management a natural point of departure would be to take a look at the life cycle of a project. This concept gives an overview of how the project is intended to develop throughout its life, and functions as a useful tool for the manager in charge. Moreover a project environment deals with a lot of resources and responsibilities, and the identification of these will also be beneficial for the management of projects. Goold and Campbell found that by explicitly defining responsibility areas for different business units, the chances for success increase [29]. For large scale projects, which are prone to a lot of changes both in terms of scope and personnel, a systematic process of documentation is necessary, unlike the case for short-term projects where changes are not that frequent. However project participants, and in particular engineers or specialists, are not very happy about documenting every step they take, so the necessary documents should be made without much efforts and detail. As Einstein said:

> "As simple as possible, but not simpler."

By that is stated that the documents should contain all necessary information, but only to a minimum, so a lean approach (see section 2.3.1) is desirable.

The Project Management Book of Knowledge [52] gives an overview of several of the important aspects of the project life that have to be monitored and controlled to be able to achieve a successful project and is a standard. CERN considers to use the HERMES-methodology (see [62]) as a point of departure, so the third of my main research questions will be answered with the three aspects of HERMES in mind:

(a) What **phases** constitute a life cycle for a large-scale scientific project at CERN, and how could one optimize this?

(b) Who are the main participants, and how do their **roles** contribute to the best practices at CERN?

(c) What **documentation** is necessary throughout the project, to ensure that it

(i) is able to achieve its goals?

(ii) is able to transfer knowledge to subsequent projects?

The justification for looking at only three aspects, and the chosen three in particular, is to satisfy a desire from the organization to explore these practices internally on a deeper level.

It could be noticed that these questions solely seek to reveal aspects of what Crawford and Pollack name "hard systems" [24]. Project management also has another important area which they label "soft systems". This covers approaches related to what Jackson names leadership in comparison to management [36], and how to treat the social aspect of projects: How to ensure the welfare of your employees, to keep them motivated, to staff projects with the right combination of competencies and other social challenges. These are obviously very important to master for your project to succeed, and are aspects that should be considered taking into account when designing a project management methodology, but due to the scope of my work this side of project management is not further discussed in the thesis.

1.2 Limitations

The limitations of this thesis are several:

1. The interview as a research methodology is probably one of the most difficult ones to manage properly. One cannot omit the occurrence of bias in the question-formulation, although measures were taken, and one can not be sure that the respondents have answered in good faith. Moreover the candidates for the interview were handpicked by my supervisor and his colleague, based on who they regarded as being most suited to answer my questions. Another important thing to be aware of is that every interview is unique, so it is impossible to predict how the interview will elapse in advance. However these are uncertainties that have to be accepted in an interview environment.

2. Time-constraints has made reruns impossible. It would probably have been advantageous to talk to people again to provide clarification on some of the discussed topics.

3. Although this thesis tries to conceptualize a general good practice for managing large scientific projects, one has to be aware of the difficulties such an ambitious goal constitutes. Earlier research advocates that it is not possible to create a general framework for the management of large-scale projects, due to the many unique characteristics of each and one of them

[57]. The intention is nevertheless good, but one has to keep in mind that a framework will also have liabilities that limit its outreach.

4. Despite the fact that the thesis gives a large focus to some project management best practices and methodologies, it does not cover all the major frameworks that practitioners tend to use. Methodologies as PRINCE2, Agile and Scrum are all commonly used in different sectors, but due to the scope of this paper I have deliberately chosen not to discuss these. The same goes for the ISO21500-standard published in September 2012. Moreover the explored HERMES-methodology was recently updated to the 5th edition, but this is also not taken into account. This gives the thesis a narrower perspective and it may be slightly biased towards the discussed practices.

It may seem strange that I have not taken an acknowledged methodology like PRINCE2 into account when writing this thesis. The rationale behind this is simply that I did not find the time. This is an obvious weakness with my work, since it misses out on a practice that is commonly used across a large selection of organizations. But even so, it is only one guiding star that is left out, and there may be several paths leading towards the same goal, so the thesis should give sufficient depth despite the omitted focus on PRINCE2.

1.3 Structure

Chapter 2 initially gives an introduction to the current best practices within the fields of project management and systems engineering. This is based on findings from the literature where different perspectives have been gathered. The section presents the necessary foundation for the following research.

Subsequently chapter 3 presents a description of the literature study and the research methodology used for the work. The methods that were considered, used or finally rejected with corresponding justification are described, and a discussion of reliability and validity issues follows at the end.

Chapter 4 gives at first an introduction to CERN as the case organization. The organizational structure is described in brief, before two section with the research data follows. This first section contains information about the documentation that I have read, and highlights three types of documents used at CERN. The second part describes the current practices at CERN based on the experiences of project personnel who mostly have worked more than 10 years for the organization.

The analysis in chapter 5 is a presentation of my own thoughts concerning the current approaches used at CERN based on the documentation and the results from the interviews. The strengths and weaknesses of the results from the previous chapter are identified and discussed, and some of the main topics are highlighted for use in a conceptual design for developing a project management methodology at CERN.

Finally the paper concludes with a summary of the main findings followed by suggestions for a further study.

Chapter 2

Literature

IN the development of this thesis two main types of literature have been used: one that covers the basic aspects that are necessary to be understood for the comprehension of the subsequent sections, and one that investigates more in detail the chosen subtopics for the thesis. Moreover I have assessed the pros and cons with the theory. The literature chapter is thus divided into basic concepts, selected focus areas and strengths and weaknesses with the theory.

Basic Concepts

This section gives an introduction to the basic concepts that are used as a foundation for the thesis. One should be familiar with the content of these although they are not being applied directly in the further work.

2.1 Systems Engineering

> *"The whole is more*
> *than the sum of its parts"*
>
> —Aristotle

Imagine that you have been given a set of LEGO-bricks; there is a fixed amount of them, and there is an exact number of shapes and colors among them. Now: Build a house. At the same time, this exercise will be given to another person in another room. The terms are exactly the same: Same bricks, shapes, colours and task. Will your houses look the same? Probably not. But in terms of resources you both did have the exact same point of departure (overlooking eventual experience in LEGO-house-building). Why did your results in the end then become so different? You would argue that it is an easy question to answer: Pure mathematically an amount of 100 bricks will give rise to more compilations than you probably can count, so the probability of building two identical constructions will be negligible.

But let us analyze this problem from another point of view. We already assume that an identical set of bricks can give two different outcomes based on how they are put together. In other words: $x + y + z$ is not necessarily $= z + x + y$. The way one chooses to combine the bricks will determine the outcome of the situation, not the properties of the bricks alone. This is one of the major issues for a system engineer and a project manager. Two projects are never the same, even if they are based upon the same premises. The concepts of systems engineering (SE) and project management will be further explained in the upcoming sections.

2.1.1 Definition

> ”The function of systems engineering is to **guide** the **engineering** of **complex systems**.” [41]

This definition contains four words (highlighted) that has to be explained to give a complete description of the term:

A **system** could be defined as: ”A set of interrelated components working together toward some common objective [41]”. This makes it a broad term, that can be used in almost any context, from any mechanical device constructed of subcomponents to make it fulfill a need (e.g. a computer), to social relations working towards a common goal like environmental groups or even your working community.

The term **complex** refers in this context to systems that contain elements that are related to each other in a complicated way. A common misunderstanding would be to claim that a fine Swiss watch is a complex system: Evidently, it is a masterpiece of a work, with perfect combinations of small details that have to cooperate in a specific way for it to run smoothly, so that it is *complicated* to construct is beyond all doubt. However, the mechanisms of the system are well known, i.e. if constructed properly anyone can tell how it works (what is the next move), so it is not *complex* as by this definition. On the other hand a conversation between two persons could be looked upon as a very simple system, because the actions required are not very troublesome – speaking is (for most people) intuitive. Here however, there are a lot of possible actions with a lot of (different) outcomes, so even though a conversation is simple to conduct, this system will have a high complexity.

Engineering is the term that excludes systems like the social ones from the definition of systems engineering. This leads the focus more towards systems of a technical nature, receiving a lot of inputs and returning several different outputs. For example would the development of a car nowadays be an example of a system where engineering is necessary. The general development of the car for driving purposes are not as such a complex system, but with all the electronic systems that are required for present cars it makes sense to use it as an example.

To **guide** is a term that highlights the essence of the SE practice. This tool is developed to keep an overview and to do the necessary modifications to the engineering process of complex systems, and to make sure that the execution runs as good as possible.

With this definition in mind it follows that a lot of projects would be objects for a systems engineering approach, from construction projects, through maintenance and software development projects, to projects combining several of these approaches.

Another definition is given by Stevens et al. who state that:

> ”Systems engineering is about creating effective solutions to problems, and managing the technical complexity of the resulting developments.” [58]

As we can see the definitions seem to overlap and unite about the fact that systems engineering is a discipline whose purpose is to manage the technical complexities of systems (projects or problems) in an effective way. One has to acknowledge the holism, that the whole is more than the sum of its parts, which also is in alignment with the work of Jackson [36].

2.1.2 History of Systems Engineering

> *”Life was simple before World War II.*
> *After that, we had systems.”*
>
> Rear Admiral Grace Hopper, (US Navy).

As Rear Admiral Hopper points out, the invention, or at least the formal acknowledgement of systems is attributed to the period of time after the second world war. The existence of systems could probably be traced back to both the pyramids of Egypt [41] or the impressive constructions of the Roman Empire. If these huge and impressive constructions were to be rebuilt today one would most likely have categorized them as systems, and the approach of systems engineering would probably have been useful. So it is fair to state that systems have existed for a long time, but I have found no information documenting a systematic approach back in those days.

The emergence of this systematic and defined method of thinking got is nascency during the second world war and in the post-war period, when the complexity of technology and the race of new technologies for battling the war peaked, facilitating the need for a new, more efficient level of both planning and organization of projects [41]. Moreover the introduction of information technology with its features and complexities during the 60s and 70s was also a significant contributor to the necessity of the SE approach.

James Brill claims in his work from 1998 that the first comprehensive systems engineering document published was the one of the United States Air Force (USAF) in 1966 [12]. This book has gone through several revisions, but can be seen as a startup point for the official documentation of systems engineering.

The systematic use of this discipline has also reached out to several organizations. Currently NASA is using their own ”Systems Engineering Handbook” [65], the European Space Agency (ESA) has their standardized framework [25], and the US Department of Defense uses their framework for managing systems of systems [48]. The common denominator for these organizations is that they are large and deal with unique projects, so they have adapted a general SE process to their own needs.

2.1.3 Systems Engineering Method

According to Kossiakoff and Sweet the systems engineering method is a way of systematically applying a scientific method to the engineering of a complex system [41]. The method consists of four main activities that are applied successively through all the phases of a system:

Requirements Analysis

The first point of solving a problem is to understand what the actual nature of the problem is, or from a project's point of view: ”What do we actually want to obtain by conducting this project”. Stevens et al. point out that users often state their requirements in terms of solutions [58]: A customer might state that he ”needs to save his data once a week”, while a better statement could have been ”wants to avoid losing more than one week of work”. Saving data once a week could be done simply by saving the work (f.ex. ”ctrl+s” at a computer), but if the real need is not to lose information it would be necessary to save the work in several locations. There is a slight difference there, and discovering the *real* requirements is thus a very important part of achieving a successful project. One way to do this could be to ask specific questions as ”why do you need this” or ”what is the objective of this”.

Each phase of the project life cycle starts with the identification of the actual requirements. Often these are from a higher level of the project, so that new more specific levels of needs have to be defined for the lower tiers of the system. This process can be quite ambiguous so it is necessary to have it followed by a clarification process, in which user interaction is the main element contributing to clarifying the actual needs of the users.

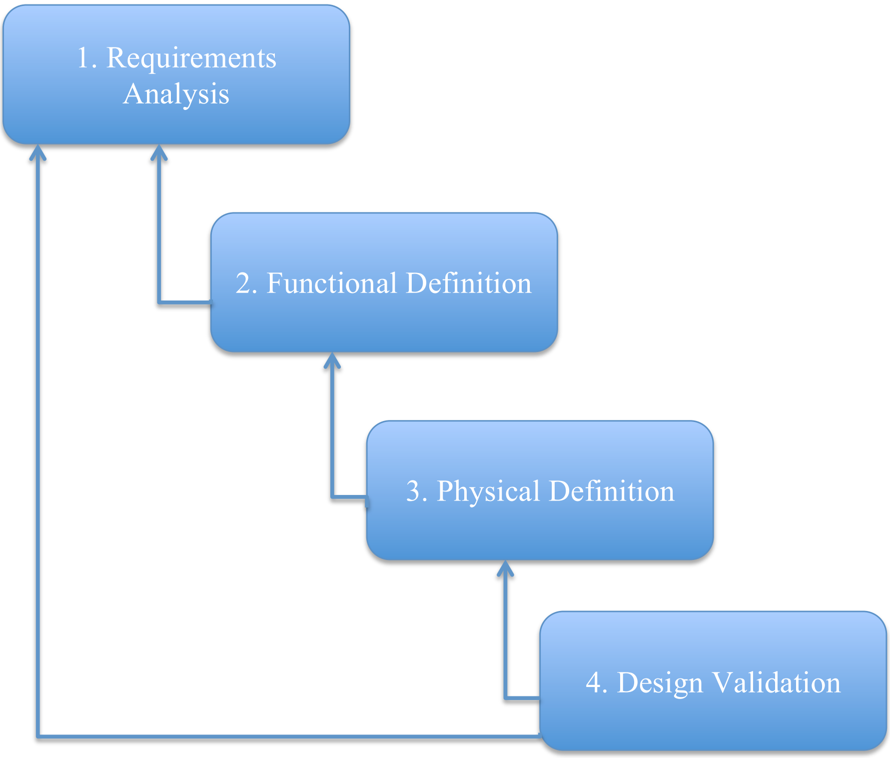

Figure 2.1: The SE Method, reproduced after [41]

Functional Definition

The process of functional definition spans the actual transformation of stated requirements into tangible functions. If the requirements are as stated above, the functional definition could be the creation of a cloud service or an external physical hard drive.

The selection of one functional element on the cost of another is usually done by trade-off analysis. A lot of alternative implementations are considered to make sure one does not overlook the "master" solution.

The identification of functional interaction is also an important aspect of this part of the method.

Physical Definition

The physical definition is when one transfers the functional design into tangible assets, i.e. either hardware or software components and integrate these components into the entire system. For the simple case of data storage, given selection of cloud service, this will be to decide e.g. number of servers and location. In phases of the project where the elements are not yet realized, it is still useful to visualize the corresponding connections.

Design Validation

The design validation is the final step of each stage where one makes sure that the actual design has been designed in accordance with the requirements. Experience has shown that too often the desired design is not completed at this point, so one needs an approach to make sure that this will be the case in the end. To make the validation one has to create a virtual environment similar to the real one and see if the system performs as desired in this setting. This could be compared to the development of a prototype and doing beta-testing in a test-environment.

The final steps of the validation are when the system is put under real tests that can reflect whether the system satisfies the requirements or not.

Additional Comments

NASA uses a similar method with its ”systems engineering engine”. This method is specified to a more detailed level than the method presented here, but the main idea is still the same (see [65] for elaboration).

2.1.4 Strengths and Weaknesses of Systems Engineering

As we have seen the increasing complexity and size of modern projects have been a major driving factor for the need of systems engineering [41], so it is apparent that these projects would have had a hard time being conducted without a systematic method. Below I will take a look at some of the attributes that make system engineers a valuable asset in the management of projects:

Multidisciplinary Knowledge Large systems often consist of many subsystems spanning different disciplines of special competence, ranging from engineering to administration. For each group of experts there exist different terminologies used, making the communication between disciplines difficult. This is one of the major qualities of a systems engineer. The possession of knowledge across several areas makes them able to work as a translator, or a catalyst if you want, minimizing the risk of miscommunication. [41]

Approximate Calculation The ability to make quick estimate is also an important side of being a systems engineer. By being able to quickly get a rough overview and an idea whether a system is on the right track or not, the systems engineer can immediately identify whether the current progress of the system is ok or if the specialists have to be called in to make the appropriate adjustments. [41]

Skeptical Positivism Skepticism is a very good attribute of a systems engineer, because it makes sure that one does not get overly optimistic about the design of a system, but rather tries to see where the liabilities are and wants validation of design before trusting in it.

The positive attitude in the form of a ”can do it”-spirit combined with this skepticism, is what makes the systems engineers able to find solutions to situations where other people are plunged into despair. [41]

Ignorance of Soft Thinking Systems engineering is despite its advantages not alone enough to secure project success. A method is not better than the people utilizing it, so one can have the best tool in the world and still fail to do the work if one cannot convince the employees to use it properly. Thus managing people in a good way is crucial to succeed. This is one of the major criticisms towards the systems engineering as it only focuses at the systems itself and not on the actual users. Crawford and Pollack refers to this aspect as the soft systems, and argue that for a project to succeed it is necessary to focus on both soft and hard systems [24].

2.2 Project Management

Project management is a discipline that has increased in popularity the last 5 decades. It encompasses the detailed planning and scheduling of work-tasks in terms of the well-known iron-triangle of project management: cost, time and quality. To achieve all three at once is very difficult, but the management methods try to optimize the total result of them combined. But in addition it spans the handling of people, so it combines both technical and human challenges [49].

2.2.1 What is a Project?

But if it should make sense to talk of project management, one first has to unite about the definition of a project. Many definitions do actually exist, but for the purpose of this paper the definiton from the PMBoK will be used [52]:

> ”A project is a temporary endeavor undertaken to create a unique product, service or result. The temporary nature of projects indicates a definite beginning and end.”

Projects exist in all organization and can be of both simple and complex nature, short or long in duration and of different importance. Simple short-term projects can often be managed through ad-hoc approaches, but when the projects reach a certain amount of complexity it will be beneficial to use some tools for managing them properly.

2.2.2 Programs

Programs are a collection of interrelated projects contributing to the same overall goal. A space shuttle program, would f.ex. be put together of different subprojects or even subprograms that all have to be completed to finish the program. The term is often overlapping with the term ”project” since the literature does not provide clear borders between the terms, and it is not strictly stated that a project consisting of subprojects always is a program [54]. Because of this overlap of terms the term ”project” will be used consistently in this work, but bear in mind that many of the same methods applying to projects easily can apply also to programs.

2.2.3 Characteristics of Large-Scale Projects

As stated in section 2.2.1 every project is unique in spite of the many commonalities existing across the project nature. Although small short-term projects can be easy to handle, the world of a project manager becomes completely different when they start to deal with projects of a larger scale. These are usually an assembly of smaller (but not necessary small) subprojects all with their uniqueness, and to make this an entity working all together can be a major challenge. Flyvbjerg defines the following characteristics for what he calls a ”megaproject” [26]:

- High risk due to long time horizons.
- Several decision makers (with conflicting interest).
- Significant scope change over time.
- Insufficient planning.
- Often cost and schedule overruns.

In addition to the five aspects he mentions, the amount of money involved is obviously an important characteristic.

Morris and Hough write that major projects are prone to extra-ordinary risk levels, and are only undertaken because of the great importance they constitute. A major project can be complex and difficult even though it is not large in monetary terms, such as a R&D-project, but it could also be occupying the entire budget of an organization. [47]

2.2.4 How Systems Engineering does Relate to Project Management

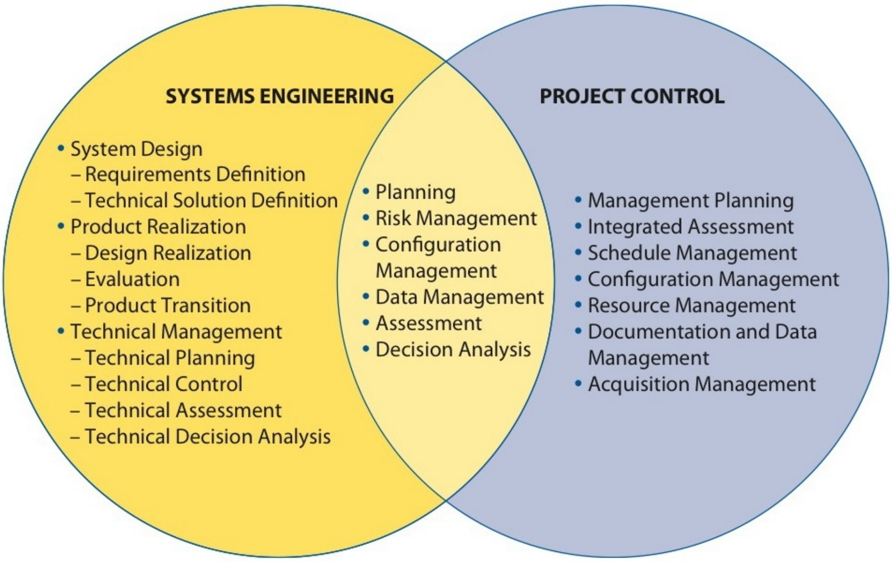

Figure 2.2: The Relation between SE and PM [65]

Systems engineering and project management are two terms that in many situations are used interchangeably, but there are some clear distinctions between the areas of validity for the two of them (see Figure 2.2). Systems engineering deals mainly with the technical aspects in a project environment like system design, product realization and technical management. On the other hand you have the tasks that are related to management planning, cost control, time management etc. commonly named project control. Project management is the combination of these two processes, that is, the integration of technical design with management tasks, so as to get a superior product in the end by high-quality management [65].

2.2.5 Project Standards and Methodologies

Have you ever bought a product from IKEA? If yes, you will immediately understand this analogy. All products that one can get from this Swedish furniture-company are delivered in parts, for you as a customer to put together to the final product. But how can you make sure that you from what you have bought will be able to in the end have your desired cupboard? This is done through a fine combination of standards and methodologies.

The standards in this example are several, f.ex. the number of screws and wood, the shape of them and the necessary tools (usually a single umbraco). If you get a set of randomly sized screws and wood with different size, it will be very hard to in the end assemble all of this to a final product. I.e. there has to be some kind of standards for the different parts.

But the standards alone are not enough. How to make sure that these basic items together will constitute your dream-bed in the end? Here is where IKEA provide you with their methodology: The user manual. This is a step-by-step procedure for how to put all the pieces together. If you follow this strictly there is no possibility to go wrong, and your product will in the end be exactly as in the product description (given that the standards were followed in the first place). So, what does this have to do with projects and project management? Well, there exists both standards and methodologies within this discipline, and as for the case with IKEA these have different areas of relevance.

A project standard gives all the methods and best practices that are optimal to use for some projects, some of the time. That is, one has to be familiar with one's own project to know what is relevant for the given environment. Actually, one can compare the nature of a project management standard to that of a tool box: It has in an optimal world all the tools that you will need to do whatever you would like, be it hammering nails, cutting wood, removing screws and so on. However, the saw is not necessarily suited to hammer the nails, while the screw driver should definitely not be used to cut the wood. Therefore, based on the content of your project, it is important to select the correct tools to use, i.e. to create an adapted methodology for your work [1]. So, a methodology is a selection of methods from a generally acknowledged standard adapted to your work.

A common mistake is to utilize a standard as if it was a methodology. By that is meant that often methods that are not suited for a given project are used, just because the standard states that it is the best way. This is not the intention of a standard, and the choice of tools for your methodology has to be adapted to the intended work. When a company adapts a standard to its own work, i.e. creating their methodology, they sometimes falsely name this a company specific *standard* [30]. Thus the boundaries between a standard and a methodology can seem unclear even to professionals.

Among the most famous standards for project management is the PMBoK, as mentioned in the introduction. This spans all the current best practices in project management and can be used as a basis for developing a methodology suited to your organization. To help assist companies adhere to good project management practices and to encourage the development of individual standard methodologies there also exist other initiatives that are recognized by experienced practitioners. Among the most important standards and methods are PRINCE2 [31], HERMES[62] and INCOSE [35]. Additionally organizations like NASA [65] and ESA [25] have already taken steps towards designing central methodologies for their own needs, and these could also be used as inspiration for other companies. For more details on this please consult the respective literature.

Although adhering to project management standards is seen as a necessity to enhance effective performance at the work place by many practitioners, Crawford's research on this hypothesis does not show any correlation on this matter [23]. Thus it is yet again evident that one should treat the aspect of using a standard, or parts of a standard, for an organization with care and not indiscriminately use a standard because it is supposed to be ”the one solution”.

2.3 Best Practices

The project management standards contain so-called ”best practices within the field”, but how are they actually defined? Kerzner defines best practices in project management as:

> ”...reusable activities or processes that continuously add value to the deliverables of the projects.” [38]

That said, a best practice can be literally anything and it can be different between companies. Often best practices are identified by looking at what has worked well for a company in the past and what is likely to work well in the future [38]. For example, if a firm has a good experience with team-building seminars, i.e. they see their employees back at work with new energy and lots of motivation, which increases their performance, another company can experience that the workers are not willing to go to work after this kind of approach. In other words, two similar practices do not universally classify as a ”best practice”.

Nevertheless, within project management theory, there exist both standards, methodologies and tools that are seen as generally applicable to all organizations. They will need adaptations to fit perfectly for each and one of them, but the basic framework can be relied upon.

A best practice can also be stated as the performance of the project manager, as found in a study of the Malaysian construction industry by Zarina Alias et al [2]. They found that the project manager should improve their capability in terms of knowledge, skills and personal characteristics.

The major factor to be aware of when it comes to best practices is that it is a dynamic term. What is a best practice today might be outdated tomorrow. For a long time delivery of letters per post was seen as the best option for transferring information. Nowadays with encrypted data-connections emails are more reliable and in many cases replace the former best practice. So the ability of a company to continuously adapt is very important for identifying best practices.

2.3.1 Lean Thinking

> ”...Lean thinking is the single most powerful tool available for creating value while eliminating waste in any organization.” [69]

The concept of lean thinking is good for organizations that want to increase their focus on value-creating activities, and to reduce the waste created in the process. Often organizations perform activities as a consequence of routine (”it has always been like this”) rather than based on the necessity of the activity. Womack and Jones state five main principles that apply for lean thinking [69]:

1. Value
2. Value Stream
3. Flow
4. Pull
5. Perfectionism

The first aspect of lean thinking is to specify the value as defined by the customer, or to specify the needs (as seen in the SE method, section 2.1.3). Only when one knows what is essential for the end user one can start to identify activities that are obsolete in the process of going towards the final target. There is often discrepancy between what the producer thinks the client wants and what he really wants, so this is a very important first-step to clarify.

Secondly one can identify the entire value chain of the product, to in more detail get an overview of all of the processes. By doing this one will be able to identify joints in the process that is redundant and could be removed to save costs.

Thirdly it is believed to be beneficial to create flow in the work process, that is to make sure that following steps in a process are done continuously and avoid batching of work in departments. This will in turn make the time from concept to delivery at the customer decrease significantly.

Fourthly the term of pull refers of the customers desire for a new product, and to what extent the company is able to deliver this at the time the client asks for it.

At last, when the four previously mentioned terms are in place, the perfectionism (or optimization) emerges.

If companies get accustomed to this approach, which many already have after the enlightenment from Womack and Jones, it can improve their performance effectively. It is not just a concept useful for large-scale manufacturing organizations, but a tool that can prove useful also in a project environment. By being conscious about all the processes in the project organization and what the purpose of each of them are, one can reduce unnecessary work and put the focus where it shall be. This would increase the likelihood of project success as well.

The brief introduction to the principles of lean thinking given here are included to understand the reasoning in the analysis on limiting the amount of documentation. For more details on the implementation the reader is suggested to consult Womack and Jones [69].

2.3.2 Project Organization and Maturity

The organization of a project can be done in several ways, but when projects and organizations reach a certain size and level of complexity the coordination of projects becomes difficult. When project organizations reach this level it is often an advantage to establish a project office [22].

Project Office

A project office is an entity within the organization that is created for the purpose of centralized and coordinated management of their projects [52]. Often this is an advantage since all the knowledge about either a specific project, or all projects, of a company is gathered in the same place. Thus the project office provides the infrastructure and necessary competence to manage multiple projects [46]. This makes it easier to learn from earlier experience and to coordinate resources.

Another responsibility of a project office is to develop project management methodologies, best practices and standards [52]. This gives a united understanding within the company of how to in one common way go on with the projects. If a central methodology does not exist, resources will have to learn how to deal with new processes when they change projects, based on how the respective project manager has designed his project [22], and this should be unnecessary within an organization.

Organizational Culture

De Wit and Meyer write that the culture of an organization has great impact on the performance [68]. Kerzner states that for a firm to succeed in implementing a project management methodology it is important that there is a solid foundation of acceptance all the way through the organization. This can only be achieved by over a longer period, often years, creating a consciousness of the challenges within project environments [38].

The introduction of, and corresponding acceptance of, a best practice in an organization depends a lot on convincing the people, thus making it a part of their daily work lives and the organizational culture. By making everybody aware of the ”McKinsey”-way to do it [53] the company has succeeded in making its strategic tools a standard for their organization. Their tools are also being acknowledged at the level of their clients, which is the next level once it is internally accepted.

Project Management Maturity

Project management maturity (PMM) is a term that defines how far an organization has come in implementing project management. Andersen and Jessen state that the term project maturity can be used as an indication of, or a measurement of, the organization’s ability to use projects for different purposes [3]. Models for PMM provide a systematic means to perform benchmarking and do therefore add great value to contemporary organizations; the frameworks make an organization able to compare itself against the best practice or competitors [40]. The development and implementation of a standard project management methodology for an organization is one of the final steps in its pursuit for project management excellence.

2.3.3 Informal Project Management

One of the criticisms towards developing standard methodologies is the lacking focus on informal management. When one has to follow certain standards and procedures managers can feel restrained from making the necessary decisions because of the bureaucracy of the organization.

One of the major advantages of the use of informal project management is the reduced amount of documentation and hence the increased effectiveness of operation. Historically the invention of formal project management and the need to document processes and procedures was customer-driven [38]. However this was not very practical so managers started to manage informally while producing the formal papers just to satisfy the client. Nevertheless, for an informal approach to guiding projects to be effective it is necessary to be focused on both trust, communication and solid collaboration [38].

Because of the advantages of using informal management, it is necessary to bear in mind that a methodology should keep a certain amount of flexibility.

2.3.4 Summary

The preceding sections describes a selection of aspects that can influence the implementation of project management in an organization. This is not a complete list but the topics are chosen so as to be able to compare the theory with the findings from my interviews. There is a fair chance that one in other organizations, or maybe even at CERN with different interviews, will find more interesting aspects but that goes beyond this study.

Selected Focus Areas

The following chapters are highlighted because they are expected to be the most relevant areas by the case organization.

2.4 Project Life Cycle

The development of a project throughout its life from the initial birth to the eventual closure is commonly described as a life cycle. This method of modeling the project gives a quick and useful overview of the different phases of a project, including the expected outcomes at the different parts of the project's life. Because of the unique nature of projects, professionals have not yet been able to decide on a uniform, or a master, life cycle for projects on a general level, so it exists several different ways to illustrate the span of a project. This section presents a selection of these, summing up the most essential procedures and outcomes of each phase (see the respective literature for more details), and makes a final comparison of the different models at the end.

2.4.1 PMI Project Life Cycle

The Project Management Institute (PMI) is a non-profit-organization that promotes the development of project management standards and methods. Their model [52] is a natural point of departure given the outreach of the PMBoK among practitioners. According to PMI the project life cycle can be divided into five main phases, see Figure 2.3 :

Initiation The initiation phase of a project is where the authorization to start the project is given, the initial scope, and the initial (financial) resources are committed [52]. This is also the phase where one identifies stakeholders, internal and external, that will influence the project. The major outcome of this part, i.e. the documents that marks the end of this phase, is a project charter and a stakeholder register. The former gives the details of the upcoming work in terms of scope, resources and the assigned project manager, whilst the latter provides an overview of the different stakeholders and their potential impact throughout the span of the project. The early involvement of potential stakeholders as customers or end-users is seen as a critical success factor for the project [56].

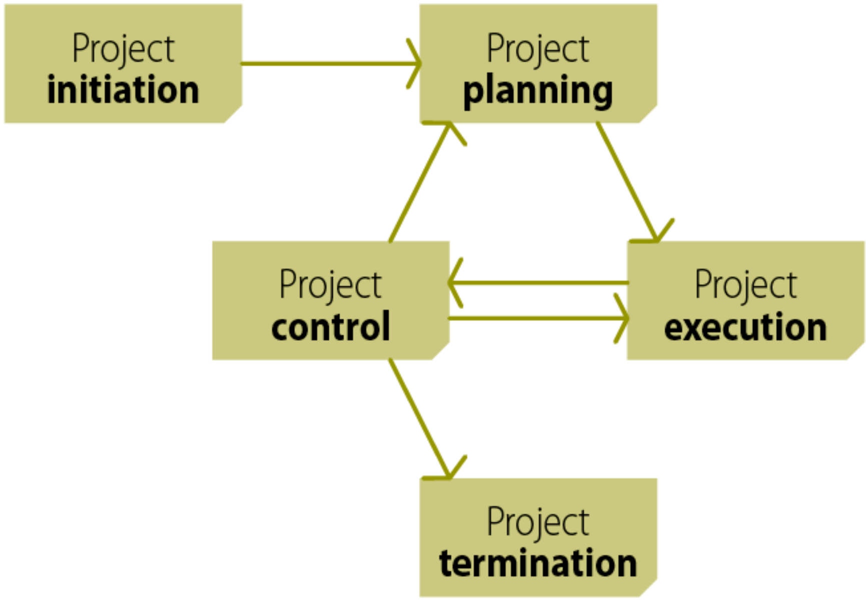

Figure 2.3: The PMI Project Life Cycle [52]

Planning The planning phase starts immediatly after the conclusion of the initiation, and it uses both the project charter and the stakeholder register as a point of departure. Here the establishment of the total scope of the project is made, the requirements and needs leading to the final objectives are identified, and the detailed scheduling and resource distributing is conducted. Detailed plans for the 9 different knowledge-areas of the PMBoK (see [52]) is created, and in the end they will all be put together as the total project management plan.

Execution The execution phase is where the input from the project management plan is performed, so as to fulfill the overall expectations of the projects. This stage of the project has its main focus on coordinating resources, as it is not unusual that one discovers factors that requires planning updates and adjustment of both resources and schedules. The execution process is usually among the most expensive parts of the total project.

Control The control process, is usually conducted as part of a feedback-loop with the execution. The results from this stage can give rise to changes that have to be implemented in the execution-phase, and these two stages will overlap throughout the project.

Termination The final stage of a project has its major focus on finalizing the project activities and making the deliverables ready to handover the project to the customer. But additionally it is important to take into account the after-work for the project team and the organization itself. An extensive end-review is necessary to be able to collect the lessons learned, so as to be more efficient in future projects. This is a necessary part that unfortunately often can be overlooked in the chase for new project contracts [49, 56].

Additional Comments

It is worth paying attention to that, although presented in a sequential form, it can be seen from Figure 2.3 that the phases of execution and monitoring are in a continuous cycle of input and feedback until the project eventually advances to the closeout phase. This is necessary to take into account eventual changes and modifications as new information is revealed during the execution phase. Moreover there are also overlaps among the other phases (see section 2.7.2).

2.4.2 HERMES Project Life Cycle

HERMES is a Swiss initiative for management of projects. The organization proposes a general life cycle that has to be tailored to the needs of each individual project [62]. The one describing a system development process is presented here. This model is included because CERN partly use it in their projects. Unlike the PMI this life cycle has six phases, see Figure 2.4 :

Intialisation The purpose of the initialisation is to create a defined starting point for the project by aligning the overall planning levels of the project with the levels of execution [62]. The main focus is to plan, consult and assess the project, so as to make it ready to enter the next phase. The phase is conducted in close cooperation between the customer and the contractor, and important documents as the project manual and a project plan is developed concurrently with the proposal. The development and release of a project charter defines the end of this stage, and the content is based on inputs from the already mentioned documents. Additionally the project conditions are stated in specific.

Pre-Analysis The pre-analysis stage of a project is a clarification process, where projects that obviously are unfeasible are abandoned. In this phase one tries to clearly state the problem area, a broad selection of solutions are assessed so as to create a basic solution for the system, and also the areas of application are determined. The search for solutions is based on the defined goals for the system. When a group of possible solutions is developed, the next step is to evaluate the organizational structure and the work processes necessary to be able to successfully

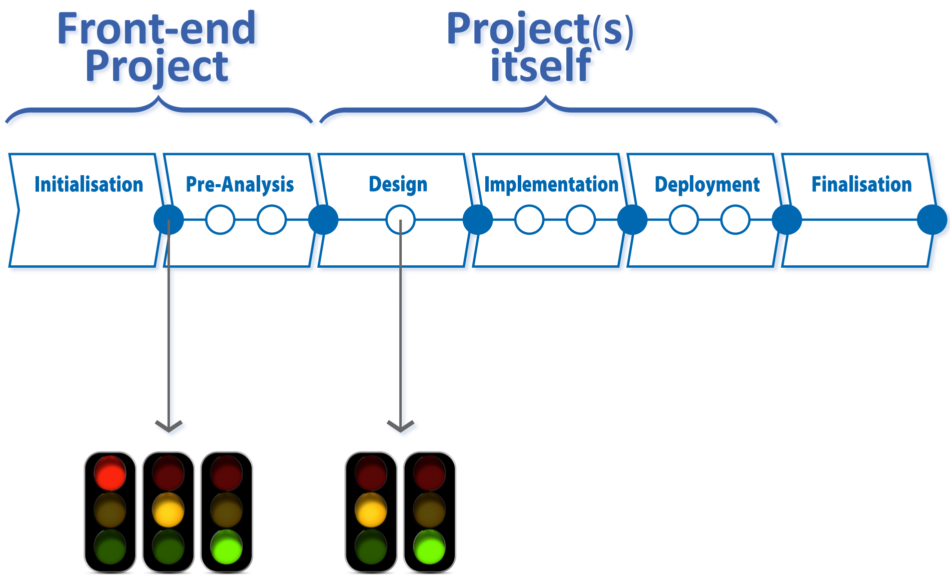

Figure 2.4: The HERMES Project Life Cycle [62]

implement the solutions. When all this is in place, the decision to go further to the design phase is made.

Design The design phase of a project is started by the handover of different solution-concepts from the pre-analysis stage. The main point of this part of the project is to choose the concept that appears most suited for the project from both technical, organizational and economical perspectives. Critical subsystems are highlighted, and a detailed conceptualization plan is created. If the project still will continue, the chosen concept will lay the foundation for the work in the successive phases.

Implementation In the phase of implementation the final specifications are developed within the conditions of the concept report. The system is developed in line with the design specifications, and preparations for the deployment is being made, including the migration process. For large projects the content of the concept report is iteratively reviewed for each subproject, and the implementation and deployment is made individually for each project (i.e. one project can be deployed before another is implemented). The output of the implementation stage is a prototype of the system, in addition to several different plans. Project guidelines, project plan, system design and specifications, integration and migration plans, and solution descriptions are among them. This stage of the project is the last one where a decision about cancellation can be made, if it turns out that the project is not manageable.

Deployment In this stage of the system development the actual installation of the system is performed. The system is implemented in the organization, and handbooks and other guidelines are being prepared for the customer to use. Moreover this phase also encompasses the educating of the end user on how to use the developed system.

Finalisation The purpose of the finalisation phase is to bring the project to and end in an organized way. The different project activities are concluded, end documents are created, and the deliverables are handed over to the customer, making sure that the lessons learned are saved for use in later projects. All this is summed up in the conclusion statements.

2.4.3 NASA Project Life Cycle

NASA (the US National Aeronautics and Space Administration) is an organization that works on developing highly complex space projects. Although their projects are different to CERN in terms of outcomes, it is safe to say that they share many of the similar processes and challenges given the nature of the organization, and their framework is therefore presented [65]:

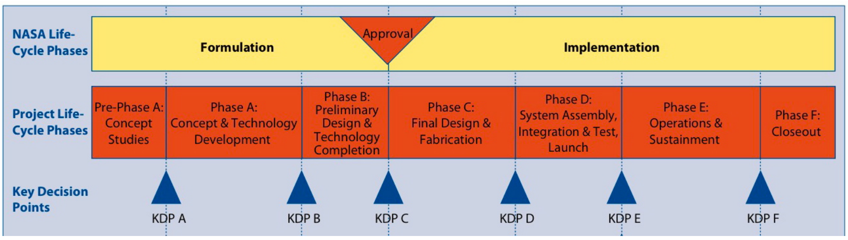

Figure 2.5: The NASA Project Life Cycle [65]

Pre-Phase A: Concept Studies In the concept phase several groups are assigned to continuously study various feasible concepts. The major outcome of this stage is a selection of suggested projects, based on the current needs and possible opportunities which are thought to contribute to the current strategies of NASA. Through the development of the different concepts users and other stakeholders are kept in the loop for their inputs, system requirements are identified, in addition to defining measures for effectiveness and performance.

A lot of ”base work” is conducted in this phase, which is good, because it reduces the amount of work necessary for a project that is actually selected.

Phase A: Concept and Technology Development The main goal of stage A is to develop a complete baseline mission concept and make assumptions about different roles and responsibilities for the work to be done. The mission concept is re-evaluated to make sure that the project can justify funding, the scope of work is determined, the WBS[1] is created, and different plans in terms of cost, risk, management etc. are established. Another major outcome of this phase is a functional baseline for the end products of the project.

Phase B: Preliminary Design and Technology Completion At stage B of the life cycle, the specifications handed over from phase A are reviewed and more detailed specifications are given. The plans are updated accordingly, and it should during this phase be possible to give plausible estimates for cost and schedule of the project. The changes during late phase A and early phase B are of such nature that one will have to revise the plans at this point of the project, but at the end of this stage the top level requirements should be complete. Additionally the baseline takes a more functional form in this phase than in the former, where mission goals and objectives could still be a bit vague.

Phase C: Final Design and Fabrication During phase C the activities to establish a complete system design are performed. The production of hardware starts, and eventual software is coded. The planning from phase A is implemented now. Schedules and technical specifications are closely tracked so that potential pitfalls are discovered in time to make corrective actions.

Phase D: System Assembly, Integration and Test, Launch At stage D the different activities (subprojects) are aligned so as to put the system altogether. This will be the preparation for testing, integration and eventual launch of the final product. Moreover one needs to train the users of the system at this stage, and the conclusion of the phase is the recognition of a system that is suited for its purpose. This is mainly a phase of execution, since the extensive planning of the process was conducted already in phase A.

Phase E: Operations and Sustainment Phase E encompasses the actions needed to achieve the intended goal of the systems, and the maintenance to support that need. Minor changes or adjustments could be applied to the system here, but if something of major importance occurs, if for example a need for upgrading is identified, the entire life cycle has to start all over.

Phase F: Closeout The closeout-phase occurs when the system has finished its mission or completed its purpose. It can be initiated as a result of the actual end of a project, such as a spacecraft returning to the earth as planned after a mission in space, it could be as a consequence of a failure which makes it impossible to continue, or even caused by technological developments making it

[1] Work Breakdown Structure

unviable to continue. This might be a long-lasting phase, as it takes into account actual dismantling of the system, documentation of lessons learned, making of final reports and proper archiving of the data.

Additional Comments

For the life cycle of NASA it has to be mentioned that all of the phases are subject to the systems engineering design method mentioned in chapter 2.1.3, although named SE engine in their book. That is, for each phase and for each subproject, there is an extensive use of the SE-method, and every subproject will have to go through these phases individually, before the major project can proceed. The scope of this paper limits a further elaboration, but the interested reader can find more on this in the works of Kossiakoff and Sweet, and NASA [41, 65].

2.4.4 Product Life Cycle

"A product is something sold by an enterprise to its customers" [64]. The development of a product is a process starting with the identification of a market opportunity and ending with the production, sale and delivery of the final product. As many projects (not all) are a result of market opportunities, and therefore have the development of a product as their final objective, a look on the product development life cycle of Ulrich and Eppinger [64] will be useful:

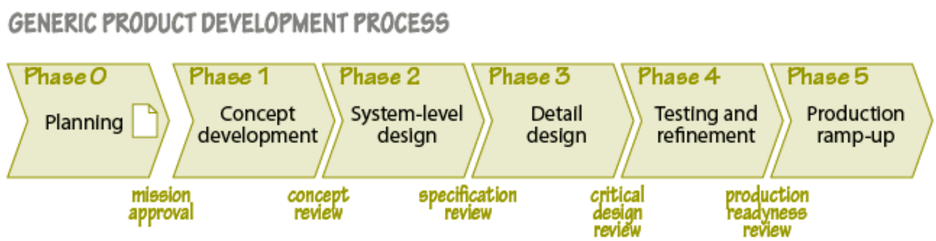

Figure 2.6: The Product Life Cycle [64]

Phase 0: Planning This phase takes place before the project is approved and the start of the development process for the project. How to align the potential project to the corporate strategy and to fit current market objectives are among the major contributions at this stage. These processes will eventually lead to the creation of the mission statement, which is a document encompassing the aspects of the product's target market, the business goals, key assumptions and constraints.

Phase 1: Concept Development The concept development phase is the first phase of the ”real project”, and where one identifies the actual needs of the target market. A group of different concept products are generated and evaluated, and decisions are being made about which concepts to develop and test further. The concept is a detailed evaluation about the product in terms of specifications, competitor analysis and economical feasibility.

Phase 2: System-Level Design At the third stage of the product development the division of the work into subsystems and components is undertaken. This is where the final assembly process is designed, and functional specifications for each subsystem are drafted. The main outcome of this tier is a solid manifestation of the architecture of the product.

Phase 3: Detail Design When the design at system level is over, the work on defining the complete specifications for all subsystems and in the end the final system takes place. Identification of all components that have to be purchased from suppliers are assumed to be complete when this phase closes, and a plan for how to develop each component within the production system is established. The major document output for this phase is the actual specifications describing all components of the system including the nature of each component and the planned interactions with other parts. Production cost and robust performance is solidly evaluated at this point.

Phase 4: Testing and Refinement In the second last phase the construction and evaluation of different pilot-products take place. The products go through different test-phases, and several prototypes are established. The beta-testing is usually the last of the test-phases, and voluntary customers often take part in this such as to discover eventual liabilities with regards to their needs.

Phase 5: Production Ramp-Up The last phase of the production cycle is entirely focused on the final production of the intended service or product. The work force is trained on the use of the product.

Additional Comments The product life cycle is project oriented in that it requires extensive planning in front of a product launch. This is well-achieved by using a project approach throughout the development life of a new product. Yet, the product development often has very narrow time windows, and combined with the common one-off nature of the products, there is no(t sufficient) focus on organizational learning and knowledge transfer in this model.

2.4.5 A Comparison of the Models

A selection of models for illustrating the life of a project has just been presented. This is not a complete list, as there also exist other approaches in literature (e.g. V-modell[34] or Stage-Gate[51]). However the selection is believed to be adequate to get an overview of the modeling process. Knowing some of the main ways to construct a project life cycle is believed to be beneficial when making a decision on how to design a life cycle for CERN. It is apparent that the chosen models share some elements, but each of them also has its set of distinct specifications so as to cope with its own uniqueness in the project. I will present some of the main findings here, see also Table 2.1. The aspects are chosen based on what is considered most important for the following discussion in chapter 2.6.3.

Attributes \ Model	PMI	HERMES	NASA	Product
Number of Phases	5	6	7	6
Pre-Phase	No	Yes	Yes	Yes
Overlapping	Yes	Yes	Yes	?
Needs Identification	Partly	Partly	Partly	Yes
Knowledge conservation	Yes	Yes	Yes	No

Table 2.1: A Comparison of Project Life Cycle Models

Phases The subdivision into phases is obviously present in all of the models, but it is emphasized in among others the PMBoK[52] that there are no clear borders between them. Thus, the phases are just a visualization tool to easier be able to handle the different aspects of the project life. Often there will occur overlapping of the phases, the execution of parts of the project may for example start even though not all of the planning is finished yet. This is the situation in the life cycle of NASA where some parts are executed although the project planning is not complete in its whole. The number of phases is not the same for the models. Some use 5 phases, whilst others extend to 6 or 7. Nevertheless it can be seen that they overall span the same information independent of the subdivision of phases.

Moreover three of the models utilize a pre-phase in which project planning upfront of the approval is described. These three focuses on feasibility studies for the project and ground work for projects that eventually will be approved. The PMI's life cycle starts with the actions necessary once the project already has received this approval, and does not as such focus on the work pre-approval.

Needs Identification To identify the exact needs is given an extensive focus in literature, and in particular it is seen in the product development model. This is rather obvious as its focus is to deliver an end product, or often several, to a customer and it is thus important that it satisfies their desire. This does not imply that explicitly stating the requirements is not important in the other models, and there exist also trails of this approach in all of them though not written out in specific.

Knowledge Conservation To keep record of experiences and lessons learned from projects, not having to do the same mistakes again it will be reasonable to have a way to conserve the knowledge. This aspect is present in the models of PMI, HERMES and NASA. The product development model justifies the lack of knowledge conservation by the fact that the products are unique and the market is rapidly changing. For the launch of a new product it will therefore be a liability to hesitate in the phase of knowledge documentation, rather than going on with the next product. The fast introduction of new products to the market is believed to offset the drawbacks of encountering similar mistakes again.

Terminology Issues There seems to be a different set of vocabulary used across the different frameworks. For example does the PMBoK talk about process groups where HERMES talks about phases. NASA does in a similar way as PMBoK divide their phases in process groups, but they do not use the same terminology. One could argue that the use of names, whether it is a phase, stage, tier, level or process group is not very important, but when the terms are used with different meanings depending on context it can create unnecessary confusion. This should be avoided.

The reason for presenting these models is mainly to give an overview of some different ways of designing a project. By comparing them it is possible to identify aspects that obviously has to be a part of a life cycle, but also to start thinking about how one can adapt this seemingly general approach to the characteristics of single projects.

2.5 Project Roles

The following section will give a description of some of the major roles within a project environment. The list is not complete, but it gives an overview of the major areas of responsibility that has to be covered to achieve a successful project. The systems engineering handbook of NASA does not provide any information on role definitions, so the used theory will mainly be based on the definitions of PMI [52] and HERMES [62]. The former is very brief on the responsibilities of the different project personnel, and put them all under a main heading named "stakeholders". The latter defines in a better way role responsibilities for the different positions. In all projects there are three main positions that has to be filled: the sponsor[2],

[2] "Auftraggeber" in HERMES

the project manager[3] and specialists[4] [60]:

2.5.1 Sponsor

The project sponsor is the person or entity that provides financial resources for the project. At initiation they make sure that the organization as a whole is convinced about the benefits of conducting the project, and they take part in the early scope development. They also have a significant role in the phase-end reviews and when changes are necessary to implement. [52, 60]

2.5.2 Project Manager

The responsibility of the project manager is to achieve the objectives of a project and they are assigned by the organization in charge of the project [52]. This role has different areas of responsibility depending on the size of a project.

Hellriegel et al. distinguish in their work between the role of a manager and a leader [33]. The former is mainly focused with the technical and managerial aspects, making sure that the work finishes on schedule, within budget and to the desired quality. The latter has a larger responsibility towards human resources and is a visionary or an inspiration rather than ”the boss”.

The delegation of work tasks is one of the most important roles of the project manager. This could often be difficult, especially for technicians, since they often have a strong interest in what is going on and want to follow it up in person. Other tasks include the coordination of resources, reporting to top management, and respecting deadlines.

2.5.3 Specialist

The roles of the specialists are several and can not be described in general for all projects. In HERMES these roles are described on an overall level so as to be utilized as a common understanding for projects [60].

2.5.4 Project Team

The project team consists of different roles and its size depends on the size of a project. In large scale projects you have roles for project engineers, technical coordinators, project planners, resource coordinators, safety officers and systems engineers, whilst in projects of a smaller size one person often fills several of these

[3] ”Projektleiter” in HERMES
[4] ”Fachspezialist” in HERMES

roles. For example is it not unusual that a project manager has the roles of technical coordinator, engineer, planner, resource coordinator and systems engineer.

2.5.5 Additional Comments

The highlighted roles are just a very brief selection of all the staff positions that have to be filled in a project work on a large scale. For a more extensive set of role descriptions it will be advantageous to read both HERMES and PMI. However also these do not give *the* solution of which roles are necessary for your project; many small projects barely have clearly defined roles at all, and for large projects it will be necessary to adapt the potential roles to the nature of the foreseen (and unforeseen) work.

2.6 Project Documentation

Documentation is an unavoidable and often invaluable asset to large organizations. When the number of people involved in a project becomes large, it is a challenge to keep everyone informed about everything all the time, so the use of documents is necessary. However, documentation is also an aspect that many workers have an ambivalent relationship to. Wulff et al. found that in large-scale development projects offshore the personnel raised their concern about unnecessary amounts of documentation [4]. Moreover Bayer and Muthig stated that workers often think their documents are unnecessary because they do not see the purpose of creating them [7].

This section covers some different outcomes that are expected throughout the different phases of a project in terms of documentation. The documents will be classified on two main levels:

Documentation	
Managerial	**Technical**
Project Proposal	Conceptual Design
Project Mandate	
Project Management Plan	
Quality Assurance Plan	Technical Design
Project Schedule Plan	
Risk Register	

Table 2.2: Some of the Major Documentation in a Project

In an optimal world and in an optimal project environment all major decisions and actions are documented so that they are traceable for later use. The HERMES methodology has results as the central focus [61]. Results are documents that are being designed on the basis of templates, or it can be a development of already existing results for example the activation of an IT-system. The documents are not always technical of nature, as there necessarily also exists a lot of organizational and managerial documents.

2.6.1 Managerial

Project Proposal The project proposal is a document stating the initial requirements of a project and its purpose. Why is the project needed and what is going to be the final outcome of the project period?

Project Mandate The project mandate[5] is a document that gives formal authorization to start a project, by documenting the initial requirements necessary to satisfy the stakeholders. The document consists of the statement of work, that is the business needs, the scope of the products and the strategic plan of the organization. Moreover the feasibility has to be justified on a business level. Additionally when the customer is external a contract is also necessary to have in place. Finally there should be a description of the organizational assets. [52].

Project Management Plan The project management plan defines the most important information to be able to define, prepare, integrate, conduct and coordinate the rest of the project. It includes the selected life cycle for the project, and detailed plans on how the work is going to be executed in order to achieve its objectives [52]. Among these are evidently plans for schedule, budget and resources.

Project Quality Assurance Plan The task of quality assurance (QA) in a project is to guarantee that the project results fulfill the desired level of quality [62]. The corresponding QA-plan is therefore a tool that among others guarantee adequate auditing methods.

The QA-plan is the central document for the planning and control of the quality assurance of a project, and is a supplement to the project management plan. It contains the general guidelines applicable to the project to achieve the required quality. For project of a small nature this document can be omitted if the necessary measures towards quality are included in the project management plan. [62]

Risk Register A risk register contains all the potential risks and opportunities that one can face throughout the life of a project. The risks are categorized based on likelihood and severeness, so as to in an easy way identify measures to cope

[5] Also named roadmap, charter or mission statement

with them all. The document is dynamic and is updated with new risks along the project life. [62]

2.6.2 Technical

In scientific projects the following two documents are among those commonly used:

Conceptual Design Before one can develop a system some design will be made. The conceptual design document does not specify the detailed design that the project team will follow. Rather it serves as input to the development plan and the business case. This document serves as a ”paper model” of the system to be developed and should be used as a guidance in when searching for agreements on what is proposed in advance of constructing the system. The set-up of the conceptual design varies, depending on both type of system, how one wants communication to be and the intended audience. For example, the conceptual design might consist of a narrative document; a storyboard of how the system is supposed to look, function and feel or a series of diagrams. Most likely, however, it may be combination of all of these elements. [55]

The document is mainly intended for the customer, and explains what the system does in simple terms without the use of technical jargon [20]. The document shows organizational hierarchy and functions of the software components, it shows data structures and flow, in addition to interfaces.

Technical Design The technical design is on the other hand the document that tells the builders how to construct the system. This document includes all the necessary specificities in terms of software and hardware specifications [20].

2.6.3 Additional Comments

When presenting a selection of documents like this, it is unavoidable that the reader will be left with questions as ”why these documents?” and ”why are other ones left out?”. My justification for this is on two levels:

1. The literature already provides a large selection of documents so I think it will be obsolete to recite it all just to cover all possible outcomes. The described documents are therefore those that seem to be most central to CERN as a research organization.

2. Specific documents and their contents have a slightly lower focus in the discussion so using a lot of space on it in the theory is also not considered feasible.

Strengths and Weaknesses With the Theory

This section will highlight my own thoughts on what are the advantages and liabilities with the theoretical best practices within systems engineering and project management, using the preceding theory as a point of departure.

+	−
Subdivision of Phases	Needs Representation
	Technical Documentation
Centralized Methodology	Knowledge Conservation
	Role Definitions

Table 2.3: Strengths and Weaknesses With the Theory

Centralized Methodology

The idea of a centralized methodology is kept outside of the three major headings of my discussion of literature, since the topic on an overall level covers the content of the thesis. The literature seems to unite about the fact that all organizations of a certain size should adapt a methodology to their business. The time when project management was just an optional asset to an organization is past and it is now often a necessity to create a centralized methodology for the organization to be competitive [52]. But even so, it is argued that it is not applicable to small companies because it is a huge and (resource-)demanding task. This makes it only an alternative for large companies [38].

2.7 Life Cycles

The comparison of the different life cycles in table 2.1 with the following descriptions, encompasses some major characteristics of the life cycle models. Some of the attributes are basic and absolutely necessary like the phases, while others in some cases do not have priority like the knowledge conservation in the product life cycle [64]. The selected aspects are chosen based on comparison of the models.

2.7.1 Representation of Needs

It turns out that one aspect that has been given limited focus in the life cycle models of the PMI [52] and HERMES [62] is the actual needs clarification in the initiation stages. If one does not have a clear view on what one really wants to obtain at this early stage of a project, the chances that major changes will occur are high. These models do not accurately provide a way to make sure that needs are clarified. NASA [65] does this to an extent with their approach, but it is not obvious how this is going to be preserved throughout the life or communicated effectively to all relevant participants in the project environment. The product development model of Ulrich and Eppinger accounts in a precise way for the necessity of a clear representation of needs [64]. However this model is focused more towards manufacturing business and highly dynamic markets, and not the nature of projects or scientific projects in particular. Scientific projects are often characterized by high uncertainty, as one of the main ideas by research is to discover something unknown, so it is apparent that it is not easy to define exactly what one needs to figure out. Thus I would argue that the needs representation in the models is an aspect that could be worth to further develop.

I believe that an early specification of requirements as specified in the product development model is beneficial also for projects in a scientific environment. Even though it is difficult to specify exactly what a design should look like at an early stage, it is possible to gradually develop the requirements as more information get available. This is an important contributor to avoiding never-ending and costly development of products [66].

2.7.2 Phases

For the phases of the life cycles there are two aspects that have to be kept in mind; the number and the sequencing of them:

The Number A life cycle should not have too many phases because it will make it difficult to structure the project at an overall level. Essentially a life cycle is just a model of the project life. Forrester states that a model shall organize, clarify and unify knowledge, and give people a more effective understanding about the relevant system [28]. Kerzner advocates that five main phases like stated in the PMBoK [52] should be sufficient for any project [38]. This view is also shared by at least one of the project engineers at CERN. I think the limitation of the life cycle to five phases makes it easier to identify decision points for major decisions, but each of the phases will naturally have to be subdivided to cope with the complexity of the individual projects. This is in line with the model of NASA [65], and I believe it is a reasonable and necessary action to manage activities on more specific levels.

The Sequencing The other aspect one has to be aware of when it comes to the life cycle is that even though we label and categorize stages of the project as phases, there are no clear borders that separates the different states of the project. I claim that the phases can be compared to that of a human being: First it is born, then comes a stage of infancy, before it enters the stage of a child at some point. Then comes the teenager, the official adult, the grown-up, the retired, and finally the death. At some points there are different borders for when the human is expected to enter the different stages (f.ex. in many cultures one is supposed to be an adult at 18), but this is not a blueprint; some enters the phases early other late, some re-enters them, and some never at all. This is also the case with projects. The phases are set up sequentially just to make it easier to visualize, but a project in the execution phase may have to reenter the phase of analysis if it turns out that it is necessary for the success of it. Moreover a project could go straight from the design phase to the closure, if it turns out that execution will not be possible. Interchanging between phases is therefore not unusual in projects, and one should treat the sequencing model as what it is: a model. This approach is also highlighted in the systems engineering engine of NASA [65].

But in addition to the possibility to skip or return to phases a project will often experience overlap in the phases, i.e. the execution may start even though all the planning is not finished yet. There are several reasons why this is beneficial and maybe most important that it gives increased efficiency. If an activity already is planned in detail it could make sense to start it even though other (seemingly) independent activities are not planned yet. As long as the activities really *are* independent this is the most effective way, but if it turns out that there was a dependency after all both resources and time may be wasted by this approach.

2.7.3 Knowledge Conservation

To retain knowledge and rely on the previous experience of others rather than doing the same mistakes over again is an invaluable asset to an organization, but it also demands good routines for tracking the competence. Three of the presented models emphasize the importance of conserving knowledge but the product model overlooks this aspect in its whole.

The uniqueness of projects is a good argument for not deciding to spend time on retaining knowledge and experience, since the probability of encountering similar situations in the future outweighs the efforts taken to conserve the experiences. However, despite the unique nature of projects, I would argue that all projects do have some similarities so there is always something to be learned from the processes.

For product development in an organization where several products are developed simultaneously, it is understandable that the explicit conservation of knowledge does not take place. The effort it would take to make efficient documentation will not be offset by the advantages of utilizing the experience on later times, so it is a tradeoff that has to be done. Sometimes it is better not to have the optimal solution and act quickly, rather than sticking to the normal routines.

Although conservation of knowledge seems to be an aspect that is difficult to treat it is beneficial as long as the experienced personnel stays in the organization. Maybe it would be a better solution to try to keep the experienced people as long as possible for them to teach new employees rather than writing documents on how things are supposed to be.

2.8 Roles

The literature does not provide a united understanding on the importance of role definitions, as this aspect is absent in the framework of NASA and only described to a limited extent in the standards of the Project Management Institute. In the HERMES methodology this is given considerable space, so I will spend some lines discussing the different responsibility areas. The project manager role tend to be vaguely defined on an overall level, rather than specific to the actual tasks they are in charge of. Statements like ”the project manager is accountable for all actions on an overall level and shall delegate responsibilities” are common. And in many cases this is a convenient way to state it. The role of the project manager is evidently different based on the nature of the project he is in charge of.

The lacking focus on roles in the NASA model, I believe to be that they mainly are considered with systems engineering and the lack of focus on soft systems. Similar for the product model the actual manifestation of a product and the corresponding processes is the central focus so also here roles are not given much attention. Moreover I think it is reasonable that since the PMBoK is a standard for project management it should per definition just provide an overview of all major roles, which it does, whilst the HERMES as a methodology is more specific towards the necessary roles in their project environment.

I think it is a weakness from the literature in general that roles and responsibilities are not given a larger focus. Lack of commitment is often a contributor to failure of projects [39], and this can come as a direct consequence of unclear responsibility areas. However, it is also not necessarily easy to specify the different roles, and especially not for projects on a smaller scale. In these environments there will not be enough personnel assigned to the projects for it to be reasonable to show a large distinct set of roles, as the available people will have to fill many of these roles. Nevertheless, I think literature for large scale projects in particular should have a higher focus on role responsibilities.

2.9 Documentation

The frameworks of both PMI and HERMES propose long lists of documents that have to be present in a successful project management methodology. The latter also describes how some of these documents can be omitted if their content is included in other documents, this particularly for the situation of small projects [62]. This is a part of adapting the documentation to the nature of the organization. The following paragraphs highlights some important findings from the literature:

Lean Thinking I think the intention of solid documentation is good, but it is important that the documents do not become too large. With the amount of documentation the literature represents it seems obvious that a lean approach is necessary; both in terms of limiting the number of documents (like for small projects) and with regards to limiting the size of the relevant documents. If the documents are not well-structured, preferably with templates used throughout the organization, documentation can prove more a weakness and a time thief, rather than useful. However if there exists clear routines on both the creation and use of documentation, it seems that it is a good and solid approach to use. The use of lean concepts is also highlighted as a necessity by Turner and Lane [63]. They argue that systems have developed radically since the introduction of systems engineering, and that the deliberate use of lean concepts is advantageous.

Quality Assurance The literature also gives focus to the quality assurance within projects and the project organization. The QA-plan is an effective document that helps the project manager to achieve the overall projects goals in terms of quality. The intention of the document is good, and when routines are clearly stated this is an effective document to use. However, often the quality assurance is a vague term which most people do not understand, and in this case developing a plan can be useless. When people use something they do not understand the utility of, it usually does not achieve its purpose.

2.10 Summary

The literature has given an overview of some existing best practices within systems engineering and project management. Moreover a selection of current life cycle models are presented and compared, to be able to identify pros and cons in the design of a life cycle for CERN.

In line with the three research questions also some of the main roles and responsibilities in a project environment are described. This is done to get an overview of the complexity of large-scale projects and to get an understanding on how literature defines the different responsibility areas of projects. Then some space is dedicated to the different documentation used in projects. The reason for this is well explained at the end of that section.

The third section of the literature has discussed the strengths and weaknesses with the general theoretical best practices. These have been explored with the selected focus areas previously mentioned in mind, i.e. the life cycle, the roles and the documentation.

This chapter lays the theoretical foundation for my research and will be used in alignment with my results to discuss the necessary aspects for developing a project management methodology at CERN.

Chapter 3

Methodology

> *"There is nothing like looking, if you want to find something. You certainly usually find something, if you look, but it is not always quite the something you were after."*
>
> —J.R.R. Tolkien

THIS section presents the rationale behind the selection of methods for the thesis.

3.1 Gathering the Background Information: A Literature Study

To get familiar with the current best practices of project management an extensive literature study has been undertaken. Books on systems engineering and project management have been studied, already existing standards within the field have been read, in addition to reviewing several articles on the different topics. Articles have been made available to me from CERN, but I have also used online search databases as Google Scholar and Sciencedirect, with search words as: "project management", "systems engineering", "lean management", "life cycle (management)" and "project management standards". Moreover the reference lists of the used literature have been investigated to find additional papers that could highlight the topics of interest. The literature study has been a continuous process throughout the working period. At first information was gathered so as to get an overview of the topics, whilst at later points both supporting and critical literature were collected as my understanding of the subject gradually developed.

3.2 Collecting the Research Data

Upon deciding what methodology to use for the data collection, it is important to know both what kind of data one wants (or *needs*[1]), and not least what one is going to use the data for, i.e. how to do the analysis. This is necessary to make sure that one does not waste a lot of time collecting useless information. It exists two main categories of research methods: quantitative and qualitative methods [70].

3.2.1 Quantitative Methods

The quantitative methods often encompass several statistical procedures, such as t-testing, regression, least squares and statistical predictions based on numeric data. These are appropriate to use when investigating a narrow area of data from a broad selection of resources, for example in analysing the stock-market, risk-analysis in terms of monte carlo simulations, or similar. Since the desired data for this paper is more of a qualitative nature, defining the best practices in terms of processes rather than quantitative deliverables, the use of quantitative methods is not well-suited. Further description of these methods is therefore not given.

3.2.2 Qualitative Methods

Using qualitative methods on the other hand, spanning actions like case study research, interviews and observation, is more suited to cases in which the material is one-of-a-kind, or where it is not possible to draw general conclusions based on a larger selection. According to Yin the use of a case-study is in particular useful to answer ”how”- and ”why”-questions [70]. The investigation of the current project management routines at CERN could be argued to be of such a nature, in line with the problem statement’s second question: ”How are projects at CERN currently managed?”. To collect the necessary data for the case study, and as a result be able to answer the preceding question, the following methods were considered:

Documentation The collection of documentation has been used to a limited extent and mainly to get an overview of the documentation that exists at CERN. The Large Hadron Collider Quality Assurance Plan is highlighted in the thesis for its importance in the largest project the organization has carried out until today. Documents can give valuable information to the research, but it is important to have a critical approach to the information stated within. The documents are (usually) written for a totally different purpose than to educate researchers, so one has to be aware of the intended audience of the information while reviewing it [70].

[1] See the analogy to the SE-method

Direct/Participative Observation Direct observation is a convenient method to use in research where one seeks to understand a process or the active use of different tools [70]. To get a complete understanding of the project management practices at CERN, both with focus on the entire life cycle of projects and the several measures taken throughout the project period, observation (active or passively) would be a very good method to use. Nevertheless this is far more time consuming than the actual scope of this paper, so the method is considered ineligible.

Survey A good way to acquire data from a large collection of people is by the use of surveys. Yet a challenge with this approach is to formulate the questions in an unambiguous way so that they reflect the actual nature of your problem. Unlike the situation with an interview you do not have the chance to give additional explanations of the questions, if it turns out that the respondent does not understand. Moreover it also requires a sufficient selection with corresponding response rate. Baruch found that the rate should be around 36 % with a deviation ± 12 % [6]. Additionally the questions have to be designed in a way making the analysis possible to overcome. The nature of my research problem is assumed to lie on a deeper level than what a survey would reveal, so this method is also omitted on purpose.

Interviews In many situations the only way to acquire the information needed is by conducting interviews. This is a very popular approach which, when used correctly, can give thorough data about the topic of interest. Many researchers regard this process as an easy one, but it is important to be aware of the many pitfalls [70]. Similar to the survey one has to design questions that will give the answers one needs, but this is not simple. As mentioned in chapter 2.1.1 social interactions are complex systems, and you cannot possibly tell how an interview would elapse in advance. One thing is to construct the correct questions, but your interview will probably not proceed as you have expected. Therefore you will have to be flexible and adapt to the behaviour of your interviewee.

Moreover while recording the results one should also pay attention to the context and the body language. These are aspects that the ”good listener” is able to identify, and that can give important information from the interview object [70]. One has to remember that the so-called ”hidden language” often can reveal more interesting facts than the actual words being spoken. Studies have shown that up to 70 % of communication is conveyed through body language [9]. Imagine asking your wife how she is doing; She will answer ”fine”, but you would use the interpretation of body language to tell whether that word means ”terrible” or ”fantastic”, would not you?

The use of interviews is my main method for gathering data, so it will be further described in section 3.2.3.

Triangulation Triangulation is a term describing the use of several methods for collecting data [70]. The combination of different methods for assessing the same phenomenon allows the researchers to be more confident in their results [37]. Another advantage is that the combined use of methods can be good from a critical point of view, testing the research against different theories [37]. This will be utilized also in this thesis to a limited extent by the use of both documentation, formal interview results, and content from informal conversations.

3.2.3 Execution

After omitting several of the possible qualitative methods the interview remains as the most relevant way to collect information. This is because I wanted to gather the experiences of project personnel in the organization. By talking to the people I would be able to steer the conversation towards the topics of interest, but even capture unforeseen topics that could be important for the research. This was considered an advantage. However, the disadvantage with interviews are as stated by among others Yin [70], that the answers could be both biased and inaccurate.

For the execution an interview guide was developed (see Appendix A). The questions were approved and further developed in collaboration with two experienced project engineers at CERN. The intention was to create a few basic questions that could be elaborated on as the process was going. When formulating the questions I have been conscious about the design, so as not to construct negatively biased questions. According to Yin, this can harm the results [70]. This was therefore also on my mind through the actual conduction. However the purpose of the questions was not to follow the guide entirely, but to get answers on the three main topics:

1. Reveal the different opinions on life cycles of CERN's projects.

2. Explore the responsibilities of key personnel.

3. Discover what kind of documentation the organization uses in its projects.

Through the interview processes I tried to behave as neutrally and naively as possible, so as to get my objects to explain the concepts with their own words. The initial plan was to conduct approximately 10 interviews. A list of 31 potential interviewees was made, so as to have redundancy in case some of them were not available. Due to the nature of my work I wanted to speak with employees that were familiar with project management, and that preferably had been in the organization for a long time. Based on these two criteria my supervisor assisted me with his experience and knowledge in the selection of respondents. Most of them have been at CERN for more than 10 years (many even their entire working career), so they should possess an extensive knowledge about the organization. It turned out that most of the people were positive to contribute to my work, so in the end a number of 17 interviews were conducted. The results of the interviews are presented in the next chapter (see 4.3).

The interviews lasted around 45 minutes, depending on the availability of the respondents, and were all conducted in their respective offices. The interviews can be divided into two groups (based on similarity in progress). In the first one it was hard to stick to the interview guide, because the interview objects were very talkative and gave a lot of information. This is one of the risks one accepts to take when making unstructured or even semi-structure interviews according to Yin [70]. I did not want to interrupt good points, so I tried to pay attention as good as I could. However, since some of the first interviews quickly became unstructured, I tried to adapt by stating more clearly at the beginning what outcomes I wanted from the interviews. This was an attempt to focus the conversation more towards my research questions, but it did not work well. Either because the respondents got confused and thus behaved like the second group (see below), or because it did not seem to make any difference. Therefore some of the interviews seemed less useful than others.

For the second group I experienced that I had to ”pull” information from the respondents. This was a challenge especially for the first interviews when I was not entirely sure about the information I wanted myself. Open-ended questions are good for discovering aspects that one has not anticipated, but it proved to be a difficult approach in these interviews since the interviewees were very focused on what exactly I wanted from them. In this group the interview guide was very convenient, since I could ask explicit questions from it when the conversations stagnated.

The use of a recorder was obviously considered, but I decided on an early stage not to take the advantage of this. First of all, if the conversation is recorded it may make me as an interviewer (unconsciously) pay less attention than I should during the conduction, so that I do not capture the essence of the interview; the content of a conversation is more than words, as stated in section 3.2.2. The other reason I did not choose this approach is that I wanted the respondents to speak freely, knowing that their statements could not be directly traced. This is often not the case if one records the conversation [43]. That said, the omitting of recordings made it more important for me to be focused all the time and to take several notes. The length of the interviews were also decided with this in mind. It is very hard to be as focused as necessary for a long period of time, so I decided to keep the interviews at a length of around 45 minutes.

The summaries of the interviews can found in Appendix B.

3.3 Validity and Reliability

All research will be object for the issues of validity and reliability. These terms are often confused with each other, but they do actually have clear borders and

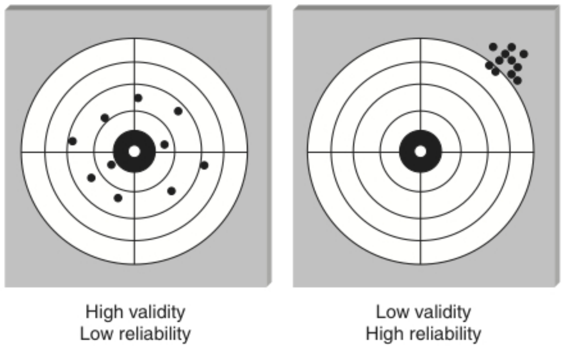

Figure 3.1: The Difference Between Validity and Reliability [56]

areas of relevance. Reliability is a term that reflects the actual precision of your research, i.e. if you (or somebody else) repeat(s) the exact same procedure as you have done, the results will be identical to what you have found. Compare this to a shooter: if he for each shot with the gun hits the same spot on (or off) the target, the gun is reliable (see Figure 3.1). Validity on the other hand states something about whether your methods are actually able to measure what they were supposed to measure. To the example of the shooter again, if all the shots hit the target, his shooting is valid. Thus it is apparent that the results of a research can be in either 1 of 3 states:

1. Valid and Reliable, it measures what you need *and* a replication would give the same results.
2. Not Valid but Reliable, its results can be replicated but they do not reflect the intended aspects.
3. Neither Valid nor Reliable: It does not measure what you want, and it is not replicable.

A research can per definition not be valid if it is not reliable.

For research like this, where interviews are used as a method, it is hard to preserve both validity and reliability. As mentioned in chapter 2.1.1 one could never know the progress of a conversation, and no two conversations are ever alike, i.e. the reliability will never be possible to preserve to a full extent. Moreover the interviewed candidates are made anonymous so it will not be possible (only with access to this thesis) to speak to the same people. In spite of the challenges related to reliability, measures can be taken to increase the precision of the research, and I have tried to do this by the development of an interview guide and by stating the adaptations I made during the interviews (see section 3.2.3). Additionally I also have given the background of the respondents in the interview summaries, so even if the exact same people can not be contacted, it should be possible to gather a similar selection.

The validity problem is of another nature. Yin defines three levels of validity: construct validity, internal validity and external validity [70]. Of these, the internal validity is only relevant to explanatory or causal studies, so I will not discuss it further. I consider my work to be more of a descriptive or exploratory nature since I am trying to describe the current project situation at CERN. Therefore the two other kinds of validity deserve a few lines:

Construct validity is related to whether the operational measures (in this case the results of the interviews) mirrors the reality in a realistic and objective way. So for a research to be testable against construct validity it is important that the measures one wants to explore are defined explicitly by specific concepts, and that measures that match the concepts are identified. I want to identify the best practices at CERN within systems engineering and project management. This term is too broad to be tested towards construct validity, so I have tried to define the best practices on the level of life cycles, roles and responsibilities and documentation. Moreover to increase the construct validity I have tried to use multiple sources, i.e. I have read some internal documentation in addition to the interviews. If findings are supported by more than one source the construct validity increases [70]. However the construct validity is probably not fully conserved in my research, since it spans such a broad area of investigation, so that is a weakness to keep in mind while reading the thesis.

External validity shows to what extent the findings are generalizable outside of the case study itself [70]. I.e. can the best practices found at CERN be generalized and applied also to other and similar organizations? One can argue that the environment at CERN is quite unique, so it will be hard to transfer the findings in general to other organizations. But also, there exist other organizations out there with similar challenges (e.g. Fermilab or GSI), so one can imagine that at least some of the findings can be utilized also for these.

3.4 Summary

I think the methods I have chosen to gather my research data are the only reasonable ones to use given the context of my work. As argued initially an observational phase across a longer period of time would probably have been better, but due to time constraints this was not possible.

To be able to understand the nature of project management at CERN, the interviews with experienced people in the field are seen as the most important source of information. But in addition to the formal interviews as a data source, also informal conversations during lunch or in the cafeteria have been taken into consideration. According to Binder these informal situations often give rise to the disclosure of the real problems [8]. This information is in general not explicitly used as data in the work, but it influences my reasoning in the discussion part.

The results of the interview rounds will be presented in the next chapter. With regards to my desired questions (see 3.2.3), it was a stronger focus on question 1 and 2 during the interviews than on the 3rd one. This impacts the following analysis in the way that there is a lower focus on documents in specific, although some space is devoted to documentation in general.

Chapter 4

Case Study

"It is a capital mistake to theorize before one has data. Insensibly one begins to twist facts to suit theories, instead of theories to suit facts."

—Sherlock Holmes

THE following sections present the results from my activities throughout the period, i.e. the review of documentation and the conduction of interviews.

4.1 Organization Background

CERN [1] is the European Organization for Nuclear Research, and is located at the French-Swiss border in the proximity of Geneva. The organization is a European collaboration initiative benefitting from the contribution of 20 member states with the purpose of investigating the fundamental Laws of Nature [15]. The organization has an annual budget around 1 billion CHF, and employs about 2 500 people. Moreover there are all the time a lot of part-time-employees and scientists hired by external partners working on site, so the amount of people effectively working at CERN is around 15 000 [11].

Among the projects of CERN most work is focused towards the Large Hadron Collider, either directly, or on all the different subprojects eventually contributing to the discovery of new physics and the search for the Higgs Boson.

Many people believe that CERN is a place only for physicists, but this is far away from the truth. To keep an organization like this running to its maximum it is necessary with a lot of supporting functions and administration. The overall

[1] Acronym comes from the French origin; Conseil Européen pour la Recherche Nucléaire - later changed to the current name.

structure showing the diversity of the organization is thus presented in the next section.

4.1.1 Organization Structure

From each of the 20 member states two official representatives constitutes the CERN Council. This is the highest authority of the organization and is responsible for all major decisions, among others the appointment of the CERN Director-General (DG) who manages the CERN laboratory. By assistance of the directorates the DG runs the facility through a structure of departments (see Figure 4.1).

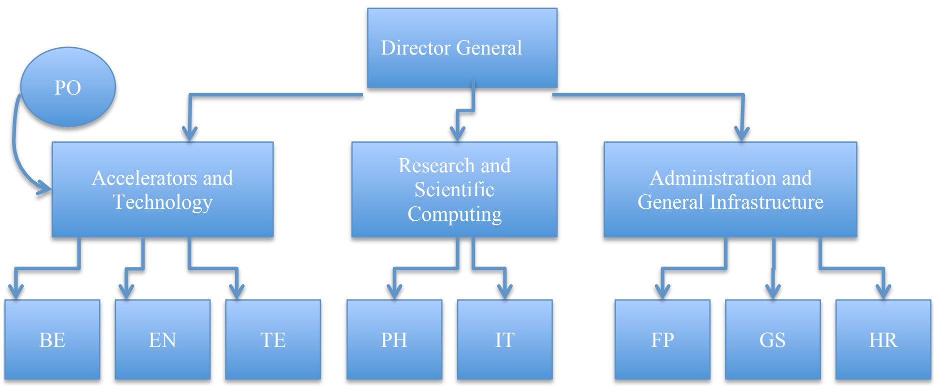

Figure 4.1: The Organizational Structure of CERN

Directorate for Research and Computing

Information Technology The overall goals for the IT-department are to provide the necessary information technology to achieve the mission of the laboratory in an effective way. This is pursued through the development of world-class competencies in all the phases of the life cycle of a project. [15]

Physics In the department of physics the basic research within theoretical and experimental particle physics is carried out. It educates a lot of young physics-students, and challenges the established Laws of Nature. [15]

Directorate for Accelerators and Technology

Beams The Beams Department's areas of responsibility are mostly related to the Large Hadron Collider. Optimizing the performance of the different accelerators is among the most important work areas of this department. Additionally the staff is also involved in R&D because of their expertise on beams. [15]

Engineering The Engineering Department provides CERN with the Engineering Competences, Infrastructure Systems and Technical Coordination required for the design, installation, operation, maintenance and dismantling phases of the CERN accelerator complex and its experimental facilities. [15]

Technology The Technology Department is responsible for technologies which are specific to existing particle accelerators, facilities and future projects. The main domains of activities cover: magnets (superconducting, normal conducting, fast pulsed magnets, electrostatic and magnetic septa), their machine integration and protection, power converters, cryogenics, high and ultra-high vacuum systems, coatings and surface treatments. [15]

The Projects Support Office (PO) The projects support office is an entity related to the directorate for accelerators and technology and the director general's office. The main function of this is to handle centralized aspects of project management. [15]

Directorate for Administration and General Infrastructure

Finance, Procurement and Knowledge Transfer This department is responsible for all the financial administration and the knowledge & technology transfer of the organization, by providing services covering accounting, procurement, payments, treasury and management of intellectual property. Another of the responsibility areas is the maintenance of strong relationships with external partners, among others universities and research institutes, the industry and member states. [15]

General Infrastructure Services (GIS) The GIS department is responsible for providing the support and infrastructure necessary to ensure a safe and healthy environment for any person working in or for the organization. This is done by among others maintenance of buildings and providing logistics services. Moreover support is given towards the technical and administrative information systems. [15]

Human Resources (HR) HR is mainly concerned with issues related to personnel, that be manpower planning, organizational development, employment conditions, recruitment, salary administration and other social challenges. [15]

4.2 Review of Documentation

In an organization the size of CERN's it is an unavoidable fact that documentation is necessary. The management of complex projects require a lot of effort in terms of coordination of resources, planning of work tasks and conservation of knowledge, so the proper use of documentation is very important.

CERN uses two systems for creating, storing and retrieving information: EDMS and EDH. The organization describes the systems as following on their websites:

CERN Engineering and Equipment Data Management Service (EDMS) The EDMS provides the organization with leading-edge engineering and equipment data management capabilities. The service provides a set of advanced information systems but it also develops and contributes to formalization of methodologies and procedures for the organization's engineering and equipment data management processes. The EDMS makes sure that these data, as well as documentation for projects and facilities are stored in an organized way, and remain retrievable on a long-term basis. In an organization like CERN with facility life cycles from 25-40 years it is important to maintain controlled quality documentation, because in many projects the people building machines and the people operating it belong to different generations. The EDMS has thus an important role as a knowledge transfer tool between the generations. This is only possible by imposing standards and methods of managing engineering and equipment information. [14]

Electronic Document Handling (EDH) EDH was developed with the purpose to provide cost effective user-friendly solutions to reduce administrative overheads in the organization. More than 100 different forms from leave requests to purchase requisitions, were filed manually, retyped, approved, signed and finally retyped again to fit the appropriate system. This was not a very efficient way of doing things, so the objective of the EDH was to replace the paper based procedures with streamlined electronic workflow, validating data against corporate databases and in an automatic way generate the end-results with the minimum use of human resources. The first version of the EDH was launch in 1992 and ran on CERN's central mainframe computer. Then EDH was replaced by a client-server version, making it available at the desktops of all users. [13]

The following section describes the content of some of the documents that CERN utilize in their projects. The layout of the concept design for the Large Hadron Collider project is presented, the technical design for the Linac4, and the quality assurance plan that was designed for the LHC.

4.2.1 Conceptual Design Report (CDR)

The CDR is CERNs naming convention for the conceptual design described in the literature. The CDR for the Large Hadron Collider is initiated by a short overview of the intended project, stating the overall goals, the central technologies and the main conclusions. This part is necessary to immediately give the reader an idea of what both the purpose and the overall content of the document are.

Thereafter follows a chapter that more thoroughly describes the technical aspects of the project. Here the different subtechnologies are described and the parameters and performances are all clearly stated.

The third and final part is dedicated to describing superconducting technology. [16]

4.2.2 Technical Design Report (TDR)

The technical design report follows the CDR and contains the major technical specifications in detail of how to construct a project. The size of the report varies between projects, from a document of 100 pages (f.ex. the Linac4 TDR) to several books (for the ATLAS).

For the Linac4 the TDR starts with an introduction describing linear accelerators in general at CERN, and how one has proceed from the early start-up and to where one is today. This is followed by a description of how the performance of the accelerator complex of CERN will be influenced by the Linac4, before the introduction finishes with a justification for the choice of parameters and layout.

The next chapter presents a detailed overview of the design with all the necessary specifications. The details of this are too technical for the purpose of the thesis so they will not be elaborated on further. Chapter three is even more detailed on the specific technology used for beams.

Then follows some chapters spanning necessary services and systems in general, how to treat radiation and safety, and how the civil engineering and infrastructure efforts are going to be handled.

The report concludes with a section describing the foreseen commissioning of the project and the expected project schedule in general. [18]

4.2.3 Large Hadron Collider Quality Assurance Plan

The Large Hadron Collider Quality Assurance Plan (LHC-QAP) is a manual that contains 6 chapters: policy, definitions, procedures, standards, templates and instructions addressing the various aspects of quality assurance at the LHC-project [17]. The purpose of the plan is not clearly stated initially, but it is apparent that the document was developed to cope with the challenges related to such a unique project as the LHC constitutes.

Policy The policy document includes the project organization and the quality assurance organization. The former includes the scope of work and the overall set-up of the project organization. The latter spans the distribution of responsibilities across all the components that are relevant in the project period, i.e. who is responsible for the quality of each part in the project. Moreover the policies regarding safety issues are part of this document. This document also states the purpose of designing a quality assurance plan, highlighting the complexity of the project with geographically distributed contributors, advanced technologies and the conservation of knowledge after the actual builders of the machine has left.

Definitions To provide guidelines for categorizing the LHC and its subsystems in terms of quality assurance this document was created. This is done by assessing the financial consequences of redesigning or replacing the item, and the unforeseen downtime resulting from a failure of the item. The systems are categorized at three levels: catastrophic, significant and minor.

Furthermore this document gives the types of documents that are used in the LHC project with corresponding naming conventions used throughout the work.

Subsequently technical terms, acronyms, abbreviations and related descriptions are given.

Procedures The procedure document describes the tools and methods that have to be used by institutes, contractors and suppliers in the planning and scheduling of activities related to the LHC-Project [17]. Moreover a detailed description is given of how documents are to be created, reviewed, validated and approved, followed by procedures on how to handle change processes as the project goes on. The latter presents in detail how the process on issuing a change shall develop. Additionally this section contains instructions on how to design drawings, both when they are made internally but also a section is dedicated to how to handle external drawings in the systems. The manufacturing and inspection of equipment is also given necessary attention in this document.

Standards The standards are established to show how all mechanical drawings, installation drawings and CAD 3D-models shall be prepared. Additionally the layout of official documents is defined.

Templates This chapter apparently contains the different templates that are relevant for the project in terms of documents. However it is not well developed, with a few exceptions.

Instructions The final chapter of the QA-plan includes the instructions on how the different templates are going to be created. This also gives guidelines to how to use the CAD-software for its intended purpose, and links to more elaborate information on the Internet.

4.2.4 Additional Comments

These documents were selected based on accessibility. There exist also other similar documents in the organization but they have not been explored due to both time and accessibility.

4.3 Interview Results

This section will present the major findings from the different interviews. I went through all the summaries of the interviews and tried to extract essential aspects from each of them. I looked at similarities and differences and made an overview of the frequency of the selected topics based on my understanding of the content (see Appendix C). The topics that are highlighted for further use are chosen based on three selection criteria:

1. The number of people highlighting a certain aspect during the interview (see Appendix C).

2. To which degree they answer the three research questions.

3. Relative importance as indicated by the interviewees.

The findings and how to utilize this information in a framework for project management will be further discussed in chapter 5.

Topics	**Number of Respondents Highlighting the Topic**
Life Cycle	12
Project Initiation	11
Necessity of Documentation	8
Proactiveness	8
Earned Value Management	6
Reliance on Experience	6

Table 4.1: The Most Highlighted Topics From the Interviews

4.3.1 Project Life Cycles

As one of the main topics of this thesis it is no surprise that the life cycle, with 12 mentions (see table 4.1), was the most commonly named aspect of my interviews. Among the respondents there were nevertheless different opinions about the nature of the life cycle and whether or not it existed a general description of the progress of a project:

Respondent 1 gave an explanation of the life cycle which seemed both unclear and unstructured, but he chose to divide the life cycle in two main parts: first a pre-project-part and then the main project. In the first part the initial design is created and the motivation for the work is described. Then follows a phase where experts consider it and give their approval. This gives the foundation for the eventual road map of the project, and a phase of clearly defined items follows. Then the second and main part comes. It starts with a functional specification phase, where the "how"s and "why"s of the project is stated more clearly in detail. This is followed by the detailed engineering specifications. When all this is in place the project takes one of two directions: Insourcing or outsourcing. For the former a procurement-phase is conducted and equipment is built. Then follows a design and implementation phase. If the project is outsourced this will usually be done through a tendering phase for a turnkey-contract. When either of these options come to an end there is the closure of the project. Here one tries to record lessons learned either from own experience (alternative 1) or in collaboration with the contractor (alternative 2). In either case this is supposed to give useful information for similar projects in the future.

Respondent 3 described the life cycle almost like defined in the PMBoK: He mentioned five main phases (See Figure 4.2): Conceptual design, Detailed design, Procurement, Implementation, Decommissioning.

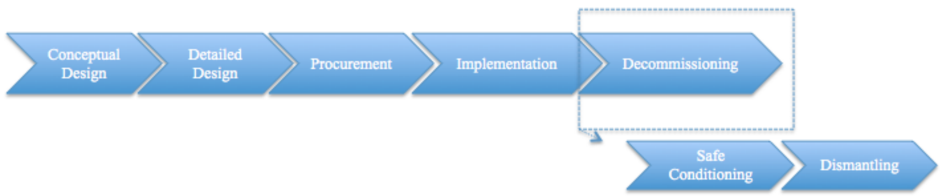

Figure 4.2: The Project Life Cycle Described by Respondent 3

In the first phase he chose to focus on the importance of defining the exact needs for the project and the functional specifications. When these are in place it will make sense to assemble a project team that subsequently will go on with the following phases. For the decommissioning he emphasized that it should be split in two focus areas, due to the radioactive nature of the environment at CERN: Safe conditioning and Dismantling. He pointed out the necessity of having space to store equipment whilst the radiation decreases, before one eventually can do the dismantling and scrutinizing of the systems.

Respondent 4 said that the life cycle of a project in his opinion would depend on the size of the project. For a large project he proposed the outline seen in Figure 4.3: The start-up would be a Letter of Intent describing the overall needs from the point of view of the physicists. Then the Conceptual Design Report (CDR) would follow, that contains the detailed overall specifications. At some point before the development of the Technical Design Report (TDR) it was suggested that the actual manifestations of requirements will take place, but he was not entirely sure about where exactly. The TDR includes all the details down to a component level, and is the predecessor of the technical specifications. Thereafter a tender-phase follows, directly succeeded by procurement and installation. After installation, what happens?

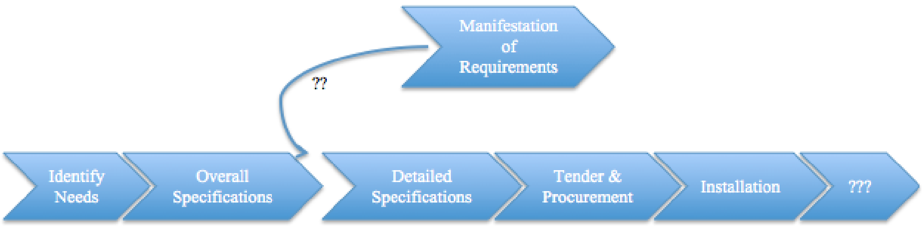

Figure 4.3: The Project Life Cycle Described by Respondent 4

> ”For these large projects I don’t think there are any clear procedures for what to do afterwards. The project will be finished after my career, so it is very abstract to talk about these things.”

I asked him to describe the end of a small project instead, by which he could not remember to have taken part in any. Nevertheless he mentioned that projects at CERN often are recycled, and that they therefore never will come to an end.

Respondent 8 chose to describe the project in terms of pre- and post-approval. The initiation will be the definition of the user requirements. Thereafter, but before the official approval of the project, the research and development phase begins.

> ”It is not feasible to let physicists go around doing nothing”,

so hoping for the approval this phase starts. When the project is approved the detailed design of a project management plan and a quality assurance plan follow. Afterwards there is a phase of design, where the technical specifications are manifested. Subsequently the procurement phase with its rigid procurement rules comes, before the project eventually transitions to the installation and integration phase.

Respondent 9 was only vaguely able to describe how a project elapses. He emphasized that a feasible project eventually would move into a tender phase followed by execution. But he did not mention anything about what was in between.

According to respondent 11 the start-up of the project is when the idea gets approval. Then a mandate will be given to the desired project manager, and they will assemble their project team. Subsequently a project management plan will be designed, before the monitoring phase starts. In this phase earned value management is an important tool. For the closure of the project it is important to create documentation and refer to already existing documents.

Respondent 12 was not entirely clear about what a life cycle is or how it is designed. She briefly mentioned the definition of parameters as a start-up followed by the CDR and the TDR.

The life cycle of respondent 14 was described over five main phases, and focused mainly on the technical aspects of the cycle. Initially the needs have to be clarified before the system or software design is defined. Then follows a stage where the schedules are being set, before one has to make priorities within these sets. Finally the technical documentation is put in place, so as to be able to track the project afterwards.

Respondent 15 described the start-up of the project to be the actual production phase. Afterwards he modified himself and mentioned the phases of feasibility-studies and tenders as a prerequisite before it starts, but to him a project would start with production. The feasibility studies were described as a mini-project spanning the well-known phases of the PMI. After the production phase there follows a phase of operation, and the project concludes eventually with a decommissioning phase.

In the opinion of respondent 16 the project life cycle has six phases. First it is crucial to understand the real need of the customer. Then a prototype will have to be designed and it will be put in a test environment. Subsequently the product will be tested in a real environment, before the phase of educating the end-users enters. Finally the projects moves into a stage of continuously supporting the users with eventual challenges they encounter during the daily routines.

Respondent 17 stated that a project life cycle always would consist of the five phases used by the PMBoK. He acknowledged the existence of different set-ups, but emphasized that they all share the phases from the PMBoK in the end.

Concluding Comments

These respondents have given some inputs on where the current knowledge level on project life cycles is at CERN, and there are both commonalities and discrepancies in the views of the managers. These are aspects that I will comment further on in section 5.1.

4.3.2 Project Initiation

The start-up of a project is another topic that emerged as interesting from the talks. It seems that there were three main views on the initiation process: Emerging needs, user requirements, and that there are no formal start-up procedures.

Emerging Needs The projects respondent 1 are in charge of usually emerge because the network is aging. Then they will have to do either consolidation projects, i.e. optimize the systems by replacing broken parts, or upgrade projects to extend the functionality. In both situations the project initiation is a direct consequence of the aging of the network. This is also how respondent 2's project started. There was a failure in a project showing that equipment was sensitive to radiation, so his project about coping with this issue was initiated because of this.

Respondent 12 highlights that if changes are made on an overall level of projects, the projects in her department will have to be upgraded accordingly. This gives rise to new projects which descend directly from the changes at f.ex. the LHC.

The projects that respondent 16 is dealing with are initiated either because someone needs to design and manufacture components for an injector, or because the quality documents states that they need to talk to his department. Then one has to identify the exact needs, which usually differs from what the user expect that he needs.

User Requirements Respondent 7 suggests that the user requirements should be explicitly stated and described at the start-up of a project. Very often he is given the responsibility of a project "in the middle of it", where the base-work already is supposed to be done. Unfortunately the requirements are not always (if ever) described unambiguously, so he needs to do a lot of reverse engineering to understand his work. Respondent 8 also states that the definition of user requirements is a natural start-up for the projects. The specification of needs from the physicists lays the foundation for the further work.

To respondent 9 a project starts with the request from a client. This is usually not feasible given the budget, so there is a procedure of formalizing and agreeing about what the absolute necessities are. This is an aspect also emphasized by respondent 10.

Respondent 11 states that the needs for a project start-up is based on the actual needs from the LHC. If it needs a higher intensity beam, there will be initiated a project to increase the intensity, i.e. projects start up as a function of project requirements.

According to respondent 14, the initiation of a project is when the user comes with a need of his. Then it is up to the project team to translate the need into a system able to manage it.

No Formal Start-up Procedures The lack of definite user requirements in projects as mentioned by respondent 7, is also seen as a missing standard procedure for initiation. Respondent 6 emphasized that it seems to be a lack of formal start-up procedures for projects at CERN. Since he is in charge of developing the EVM-tool (see later section 4.3.5) to suit all kinds of projects, this is an issue he often has encountered. There exists different reasons for why, when, and how projects start, so standardizing this process to be compatible with a project tool is a challenge.

4.3.3 Necessity of Documentation

About documentation respondent 3 stated that it is of crucial importance that one takes the time to document what is going on:

> ”If you talk about a man, he thinks. When you talk about organizations, they write. That means, an organization without documents does not think.”

Thus he argued that documents are the memory of an organization.

Respondent 4 said that:

> ”Documentation would definitely have been useful. Most knowledge transfer is done through transferring ”know-how” rather than official documents. That is a pity. On the other hand people do not like reading documents, so whether they actually would have been useful is a good question.”

Additionally he mentioned that for a project he took part in, one experienced manager suddenly died and the work was not documented. In this case he would have appreciated to have some guidelines to follow when he had to take over this job; after all he could not just go and ask for explanations anymore.

In the opinion of respondent 6 the documentation of processes is how things should be in an optimal world:

> ”Documenting things is optimal, but again, if one were going to document everything one would not have time to do any execution, so it is important to find a balance.”

Another aspect he emphasized was that physicists do not like to read a lot; they want to make experiments. So if they have to read a large manual of documentation, they will most likely just go on doing ”whatever they prefer”.

Respondent 7 prefers that all the steps of a project is documented through the EDMS-system, so that every action can be traced back to its initiation. This is regarded as an important point for the projects, because it will reduce the amount of reverse engineering required.

According to respondent 8 documentation is a natural part of an overall quality assurance plan. By using the EDMS-system one can keep documentation available to all relevant people, avoiding that documents are unavailable on local computers. However, he admits that the QA-plan for the LHC:

> ”contains too much documentation; Nobody has time to read it, and it would definitely not be feasible to read it.”

For this he was mainly talking about projects on a low-scale. ”In the situation of large projects however, it is a well-structured approach to use”.

The main focus of respondent 11 was on the possibility to track decisions by the use of documentation. Especially is this emphasized in the occasion of controversial decision making. Often a document can explain why a decision that in the present looks ridiculous was made in the past. And this is not uncommon, that a decision made today will look bad in 5 years time. However, despite the necessity for documentation, all documents should have an executive summary:

> ”...it is *really* important with an executive summary that shows the usefulness of the document. Nobody has time to read 50 pages, so it should be stated at the beginning what are the main points and one should be able to find the right paragraph quite easily.”

Respondent 14’s opinion is that documentation is very important, but that this is an opinion that unfortunately is not shared by all people in the organization. However he would not point out the people he was thinking about. He said:

> ”When I solve a problem, I do not want to have to solve it twice. That is, if I have spent two days by solving a problem, I do not want to spend another two days to solve it again in one year because I don’t remember how to do it. Therefore I always document how I have been doing things.”

Quite often the documentation made is not useful:

> ”...but although most of my documentation is not useful later on, the parts that are pay back for the time it takes to write it.”

The view of respondent 16 on documentation is that it is not used frequently enough. Changes are not always documented even if it would be nice to see it done:

> ”It is a nice thing to state in theory that we shall document everything, but I mean, there are a lot of stop signs on site, and speed limits are 50 km/h. People don’t always follow them, do they? Handling people is a great challenge as such, since you don’t know what to expect.”

He mentioned that one of the reasons for not documenting could be the nature of the work; documentation is less innovative than other work. Another reason could be the power of knowledge: if there is no documentation and you are the only one with the knowledge, you can not be replaced.

4.3.4 Proactiveness

The Oxford dictionary defines the term proactive as: ”creating or controlling a situation rather than just responding to it after it has happened” [59]. The attribute of proactiveness is important for anticipating events early on in the projects, and was highlighted by approximately $\frac{2}{5}$ of the respondents.

Respondent 3 stated that:

> ”...maintenance [personnel] and all other relevant personnel should be involved in the planning of the entire process. If a component is not radioactive, but becomes radioactive once object for power, it is important to make maintenance personnel aware of that.”

By using pro-active approaches his opinion is that one can reduce the focus on corrective maintenance and increase the preventive maintenance. This would be beneficial on a long-term basis.

One of the developers of the EVM-tool (see next section), respondent 6, emphasized that proactiveness is a key success factor for projects. ”If one is able to foresee eventual events early on, or at least try to make measures for doing it, it will be easier to monitor and manage the project.”

Respondent 8 chose to focus on that it would be an advantage to do a risk analysis as early as possible in the project:

> ”Nowadays the project starts up, and after 2-3 years someone wants to do a risk analysis. However, often one at this point is already in *deep shit*, so I would like to see this start earlier.”

In the initial design phase it is important to design for upgrades, based on the anticipation of new requirements. This will prevent bad surprises on the late stage of the project. ”No surprise” was emphasized as the ”key term of project management” by respondent 14. Based on his experience people would rather know if something can not be delivered as early as possible, than being kept out of the loop. Respondent 8 also claimed that the design for upgrades is a method that has been well utilized at the Schiphol airport in Amsterdam, unlike the situation at Heathrow in London.

For respondent 10 a very important point is not to forget about the maintenance and the operation phases in the planning. The total cost of ownership should be taken into account before decisions are being made, if not we risk designing solutions that are not sustainable. For this to be possible the project manager has to be aware of these phases, which means that there has to be an information exchange in the early stage of the project. He also emphasized the lack of a budget for preventive maintenance, leading to increased corrective maintenance, which again is costly in the long run.

4.3.5 Earned Value Management

The earned value management (EVM) tool is a project tool developed to keep track of the progress of a project, by comparing the current cost level and time frames with the expectations at the given time. The tools gives in a quick way an overview of whether or not the project is on track, and is an early indicator to top managers on the necessity of corrective actions. [49]

In the opinion of respondent 4, the EVM method is very good to keep track of the project progress, especially on the manager level. However he raised the concern that his employees probably would be hard to convince because it is difficult to see how it all fits together on the individual levels in the organization. Respondent 11 also uses EVM continuously throughout her projects, and is a supporter of the tool.

Respondent 5 described EVM as a tool that:

> ”...gives a centralization of the activities and that provides a good overview of the project.”

He also recognized the fact that although being a brilliant tool for the project manager, it does not always prove as useful from the point of view of the project engineers. Moreover he mentioned that the EVM-term is not always used properly in the organization. Sometimes managers tend to say that schedule prevails costs, and in this case the tool is not used as a true EVM-system. The application of EVM can not start until the execution phase; the quantification of planning activities (”plan the planning”) is not simple, so the tool is mainly useful for the monitoring once a plan is established.

Respondent 6 also mentioned the last argument of respondent 5. He said that the oscillations in numbers in the startup of a project is hard to extrapolate. I.e. in the beginning there will be very rough estimates for both schedule and time, so the standard deviations will be high. Later on this will decrease, and the EVM-tool is more useful. Because of the differing nature of projects, it is hard to develop the tool to suit all their needs, but this is an overall goal of the organization. One of the reasons not to use EVM was highlighted as ”the pride of the managers”. Revealing that you are behind schedule or over budget is not something people wants to do, so often they just wait and hope for the problem to solve itself. Usually it does not. It is hard to convince people to use the tool. The supporting managers often have discovered EVM on their own and then we give them the adequate support to implement it.

For respondent 8 EVM is mainly a tool for monitoring expenses. He utilizes his own Excel models to keep track of his projects, but in the end he makes reports to suit the EVM-templates. He is not completely convinced about the outreach of the tool:

> ”It is very difficult, in my opinion, to state anything about the future performance from the graphs of EVM; i.e. what are the real reasons for

> being behind schedule? For that you will have to go talk to the people, this method will not tell you that."

Respondent 17 highlighted the importance of an EVM system:

> "...is a very useful tool along the [approval] process, since it is the earliest indicator for a malfunction in your system."

Respondent 12 was not a supporter of the EVM-tool. She stated that the tool would be meaningless to use in an environment where changes are so high. New numbers and updates will come before the old ones are being updated, and as such she did not appear very fond of the system.

It seams that earned Value Management is in its early start-up phase at CERN. It has been introduced with success for large projects, but for the smaller projects it seems difficult to convince the managers.

4.3.6 Reliance on Experience

For one of the projects that respondent 2 is in charge of, a project where some equipment has to be relocated, the problem is not to move the equipment as such, but to identify all the supporting equipment that have to follow as a direct consequence, to make the equipment useable also in the new environment. This is not always a very easy task, so it is necessary to rely on the expertise of experienced personnel to make sure one does not overlook critical factors. In the same project there exists a working group consisting of approximately 50 people that possess key knowledge about all the different subprojects. Because of this there is not made much documentation, and one chooses to take the risk of relying on the competence of the personnel.

Respondent 6 emphasized the experience of the managers as a success factor for being able to keep a project within time schedule and on budget. Often projects are looked upon as something that is easy to conduct and a product of common sense, but it often shows that the experience of managers is crucial to keep the projects on track. These people know that everything is not necessarily exactly as it appears, based on their experience from earlier projects, and are therefore better to adapt than personnel with less experience.

The experience aspect was also mentioned as an important one by respondent 13. He meant that it is not possible to plan for or to document everything. For that reason experience is a crucial success factor for CERN's projects. Moreover he pointed out that not everything in a project can be taught, so it is sometimes necessary to learn your lessons by first-hand experience.

Additional Topics of Special Interest
Role of the Project Manager
Dealing with New technology
Desire for a Central Methodology
Quality Assurance
Project Closure: Radiation Issues

Table 4.2: Additional Topics of Special Interest

4.3.7 Dealing with New Technology

One of the major characteristics with the on-going work at CERN is that it is focused to the research and development-frontier. This necessarily gives rise to a set of challenges which pure manufacturing organizations do not have to deal with. One example is, according to respondent 13, when the cryostats were designed back in the days, they had to count on technology to be developed to serve their purpose some time in the future. Of course, there is often an idea on what is going to be developed and whether or not it will be possible, but still it is an aspect of uncertainty that one does not have to deal with in other kinds of organizations.

The emergence of new technologies is an unavoidable reality that the managers at large-scale scientific projects will have to deal with continuously. About the design and construction of the Large Hadron Collider (LHC) respondent 8 said:

> ”LHC was based on outdated technology when it was started up, because the design was made in the past. Thus it is important to remember to design for upgrades when an initial design is being made. Anticipation of new requirements is important.”

So coping with emerging technology seems to be another important characteristic within CERN’s environment.

4.3.8 Desire for a Central Methodology

The management of projects at CERN is usually done from a bottom-up perspective, based on the experience of the project manager for the respective project. Since the organization handles a lot of projects and many of them have different managers, this necessarily also gives root to several ways of carrying the projects out.

Respondent 10 said that:

> ”To me any work is a project, and I think it should be utilized one method for all things [projects], and not several different. This is based on my reflections after 14 years of field experience at CERN.”

The development of a central methodology adapted to CERN's projects is one of the desired future outcomes of this paper, and the experiences of different personnel in terms of this is therefore considered important for the work. The different interview processes have revealed that 4 of the respondents expresses an explicit desire towards a centralized methodology, a standard method, or a general guideline for how to conduct the projects. This especially seems to be important for personnel working in different project environments, or that have been assigned to a new project in the middle of it, and not been able to handle the existing methodology of this project in an optimal way.

Several of the respondents mentioned that the HERMES-methodology is used in their projects, and that it could wise to investigate this one further for developing a methodology for CERN.

4.3.9 Characteristics of the Project Roles

Initially the idea was to explore the different responsibilities different personnel have in a project environment. Surprisingly, this was a topic that the respondents put low focus to during the interviews. However it turned out that, if any, the role of the project manager was most commonly mentioned, whereas the rest of the team was not discussed a lot. This section will therefore highlight their opinions on what constitutes the responsibilities of the project manager.

Role of the Project Manager

When asking the respondents about what roles they considered the most important in a project environment the project manager was given as an answer. The follow-up questions trying to define the responsibilities of this role, revealed that although the respondents agreed about some aspects, there were also differences in what responsibilities were considered the project manager's and what was considered the role of top-managers or project personnel.

Respondent 1 claims that in every project the project engineer functions as a project manager for the project he is in charge of. This is illustrated by the three main responsibilities of the person:

- He is the project manager (coordinating the project).
- He is the equipment owner, i.e., he is an expert on the equipment that is necessary for the work.
- He does the advanced technical diagnostics.

For the actual responsibilities of the project manager he chose to highlight the functional specifications, the management of the "iron triangle"[2], the general coordination and in the end the safety aspects.

[2] cost, time and quality

Respondent 3 described that he usually did all the design-work of a project on his own: ”I want to solve a problem when it is there, so I design a solution.”

Respondent 6 mentioned briefly the different ambitions of the program and the project manager. The latter is more focused on the completion of the ”actual project”[3], and does not focus enough on benefits of the outcome. A more united view between the two of these positions would have been nice.

According to respondent 8 the project manager has two important roles in a project environment: The technical coordination, i.e. getting the right teams to talk together; and providing the means for achieving the work, i.e. providing the money and the people.

Respondent 9 states that his role as a project manager is ”easy” to describe: To deliver within the borders of cost, time and quality.

Respondent 10 emphasized that a large problem is that the project leaders do not know their projects. It is thus important that they early on talk to the technicians so that project definitions are well defined for their purpose.

4.3.10 Quality Assurance

The creation of a quality assurance (QA) plan for the organization was an aspect that a few of the respondents highlighted, but it was one that was emphasized as important by those who did. Apparently it does not exist one at CERN today so the one that is used is the one that was developed specifically for the LHC-project, see 4.2.3. Respondent 8 said that this one could not be utilized on an overall level for the organization, but that the approach probably is good and structured for large-scale projects. Respondent 7 also emphasized that a QA-plan should be in place, although without specifying the content of such a document.

To respondent 16 quality assurance is very important. Designing a QA-plan is a necessity to have united definitions on how to manage and work in detail. The current plan for the LHC is ok, but it does not specify enough details on how to proceed in the project when it exits the detail-phase, i.e. how to cope with procurement, installations, etc. is not sufficiently covered.

4.3.11 Project Closure: Radiation Issues

One of the main *challenges* that several of the interview objects emphasized is how to handle the closure phase of projects in an organization like CERN. The main problem at CERN in this phase is that they are working with radioactive material. Whilst one in a regular manufacturing company can shut down a machine, do maintenance, and then start it again, it is not as simple as that for them. Materials that are not radioactive in their current condition, might start radiating as soon

[3]within the borders of the iron triangle

as they are connected to a power source. To maintain this kind of equipment it is therefore obvious that they can not just stop the machine and go on with maintenance. They might have to wait for weeks or even months before the doses are so low that humans can interfere with the equipment.

This is also an issue for the closeout phase, when the projects are coming to an end. Equipment would be radioactive and cannot just be dismantled straight away; in many cases it would have to be stored at a safe location whilst it deteriorates. It is very important that this is taken into account early on in the project phase. In the same way it is important that one keeps maintenance personnel into the loop all the way, so that one has measures for how to keep systems that are becoming radioactive up to date during the lifetime of the project.

With this in mind, respondent 3 suggested that the closeout phase is divided into two separate phases: ”Safe conditioning” and ”Dismantling” (see Figure 4.2). The former would be making sure that the equipment is safe to dismantle, i.e. storing it long enough at a secure location for it not to radiate anymore, and the former would be the actual dismantling and scrutinizing of the system.

4.4 Summary

This chapter has given an overview of the current project management perception at CERN. The organizational structure has been briefly described, and some of the different documents in use in the organization are presented in short. Moreover the interview results show some of the major concerns that experienced practitioners within the organization express. My views on the current routines, use of documentation and the experiences of the personnel will be presented in the next chapter in section 5.1.

Chapter 5

Analysis

In this chapter I will initially discuss the findings on the project management routines at CERN with documents and interviews as a point of departure. I will argue for pros and cons with the current situation by using relevant theory to underline my points. In the second part I try to identify some main elements from the theory (chapter 2) and the empirical findings (chapter 4), that are necessary for CERN to develop their project management methodology.

5.1 Strengths and Weaknesses with CERN's PM-Approaches

<table>
<tr><th>+</th><th>−</th><th>?</th></tr>
<tr><td>Proactiveness</td><td>Lack of Life Cycle</td><td rowspan="4">New technology</td></tr>
<tr><td>Utilization of Experience</td><td>Lack of Documentation</td></tr>
<tr><td rowspan="2">Earned Value Management</td><td>Unclear Roles</td></tr>
<tr><td>Centralized Methodology</td></tr>
</table>

Table 5.1: Strengths and Weaknesses at CERN

This section presents my thoughts on the pros and cons with the project management routines at CERN, as revealed from my results in chapter 4.

5.1.1 Lack of Life Cycle

The interviews show that there is no united view among the managers at CERN on how the life cycle should be designed. Also, it is not evident that there is a desire among them for a more clearly stated life cycle orientation. Ambiguity in the view on initiation procedures is another sign of the absence of a centralized life cycle approach for this research facility. Moreover, one would expect that on direct question about the life cycle of a project, and even on an indirect request as "could you explain the process from the start to the end of a project", the managers would all have something to say. If you have taken part in a project you should for sure be able to explain at least on a very general level how the different phases will elapse. It is therefore quite surprising that there was not a 100 % recognition of this topic among the candidates. It could be several reasons for this, for example the formulation of questions or maybe even lack of attention from the interviewer when making notes, but it still does not eliminate the aspect of surprise with regards to this topic.

Based on the theory stating that an overall life cycle is advantageous for project environments [41, 52, 65], I would argue that it is a weakness for CERN as an organization that it does not exist a standard within the company for how the projects are going to elapse. A centralized life cycle will help managers recognize projects and a comparison of experiences between projects is possible. I would also claim that it is easier for personnel to transfer between projects and work in different environments when the processes are similar, as it reduces the amount of time necessary to spend learning in a new setting. This is also supported by Crawford [22]. Finally I believe a generalized life cycle for the projects of the organization will lead to less administration on the top-level since there is less uniqueness to consider between different projects when making decisions.

Among the cons of a rigid life cycle structure for the organization is the collaboration with external stakeholders that may have different approaches on how they do things. It will not necessarily be easy to fit external routines to the standard. Block and Davidson claim that the best way to make a project management standard work for all key stakeholders is to involve them in the design process [10]. Moreover there will always be managers that want to do things their own way, so it can be hard to convince them on adhering to *the one* life cycle when designing their projects. Both these are aspects to bear in mind when a life cycle is designed, and it could thus be reasonable to have some flexibility in the final layout.

5.1.2 Documentation

Lack of Documentation Missing documentation is an issue that has given many a manager grey hair. And the projects at CERN are (unfortunately) no exception. It seems to me that there are several reasons for why documentation is not used sufficiently throughout the organization, and I will present my arguments here:

1. Many projects have an unclear nature at the start-up phase, and documenting a project that is not yet started may not seem reasonable. Thereafter the transition often happens fast, and the project is suddenly ongoing without

the appropriate documentation. Trying to document what has happened after it actually happened is difficult, so the vague initiation procedures of the projects is probably a contributing factor to the missing or incomplete documents.

2. Workers like to work. Often ”work” is a term that to most people means ”creating a product, or a result”, and not ”writing the story about how this happened” (exception for authors). So the lack of inspiration to write the necessary documentation because it is boring, and not something that gives a visible deliverable in terms of (immediate) value is another aspect that can be influential.

3. In the same line as for the second argument, there is a question to whether or not the documentation is actually necessary. In most cases it can be hard to motivate oneself to write in detail about the work processes when one knows that these documents (probably) will never be of any use. This is the situation with a lot of information; On a normal day of work it is obsolete, but when there is a problem it would have been indispensable for the organization. It is therefore crucial to be clear about the usefulness of the documentation where one can. This is also reflected in the findings of Bayer and Muthig, who state that the quality of documentation is directly related to the use of documentation [7].

4. Finally there is the aspect of opportunism, or the pursuit of your own benefits from the organization. CERN is an organization in which most people work on short-term and temporary contracts, and where the terms for the employees are very good. Thus it is no surprise that many of the employees want to extend their contracts and eventually hope to receive a permanent position in the end. One way of doing this could be *not* to document any of their work, especially for those who work as a software developer. If you are the only one that knows how a specific (and important) system works, and there exists no documentation that can help other people grasp the functionality, well you can easily add up one and one; you have made yourself indispensable to the organization. Accordingly, the lack of documentation could also be a consequence of deliberate actions in the pursuit of own success or career goals.

Technical Documentation I believe that the use of technical documentation as the CDR and the TDR is a benefit for the projects, because they seem to span important aspects with regards to specifications and design of projects. Nevertheless the candidates, when mentioned, did not elaborate on the content of the documents, so either they are not familiar with it at all, or the content is seemed to be ”common knowledge” within the organization. The fact that the documents where brought up however supports the latter argument. There also exists several versions of these in the online databases of the organization, so it seems that the documents are relevant to the work at CERN.

5.1.3 Utilization of Experience

Although the documentation of experience is not done well in CERN's projects, this does not mean that experience is not taken into account, rather the opposite. It seems that it is often more convenient to rely on the knowledge of experienced personnel, such that one avoids to read several pages of documentation when decisions have to be made. This increases the reactivity of the managers.

Moreover it is often more effective to learn by doing and not by reading manuals. There exists a Chinese proverb stating:

> *"Tell me and I will forget;*
> *show me and I may remember;*
> *involve me and I will understand."*
>
> — Chinese proverb

and in many cases this is the most effective approach. By acknowledging experience in an organization, and learning by doing rather than reading manuals, the likelihood of succeeding with knowledge transfer increases (given that there is enough time and resources for it). It appears that CERN is particularly good in using the existing experience to educate their employees, as the interviewees were not too excited about the alternative which is documentation. Nevertheless it constitutes a challenge when the "teachers" all of a sudden leave the organization for different reasons.

5.1.4 Clarity of the Roles

The responses from the interviews show signs of what I would call unclear role definitions. It seems that it too often is the project manager that is seen as responsible for all the work in the project, and that parts that obviously could have been delegated to other positions tend to stick in his office. For example several of the specification work could be delegated to other people. The candidates mostly described the work of the project manager as a direct response on what the main roles of a project are, albeit many of these tasks according to theory belongs to other kinds of personnel.

The reasons for these discrepancies from the theory can be several, but I will argue for two main directions:

1. Many of the project managers are working on and are directly related to projects of a smaller scale. In these kinds of projects it does not make sense to have an entire staff of personnel since the amount of work does not justify the request for additional people. If you have a staff of 3 persons assigned to a project, it is obvious that some (or even all) of them have to fill several of the "standard roles" of the project team (see section 2.5).

2. On the other hand, the manager's reluctance to delegate work can also be a reason for the all-covering description of the responsibility areas of the project manager. A strong project manager knows when to delegate and when not to, and in projects of a certain size it will definitely be an advantage to divide the work into smaller positions handled by individuals. It seems to me that this can often be a problem in research projects at CERN because the person in charge often has technical expertise and is very excited about the work they are doing, and that they fear losing control if work is delegated.

That roles are unclear is also what Goold and Campbell found in their study of matrix organizations. They claim that by defining explicitly how the different business units are supposed to operate, the unit can get sufficient information to define the internal roles [29].

5.1.5 Proactiveness

The idea of a proactive mindset is a valuable asset to any organization. The earlier one is able to start planning, the better time one has to get an overview over all relevant factors that can have an impact for the project. For CERN it is definitely an advantage that almost half of the interviewed managers explicitly show this attitude, and that they acknowledge the necessity of proper front-end planning in projects. However, despite the expressed desire for improved early-phase planning, it appears to me that it is an area that has a long way to go to be part of the organizational culture.

Several of the candidates chose to highlight the high amount of changes in the projects, and the lack of proper requirement-definitions in the first place. This is not surprising, all the way CERN is a research organization and one does not necessarily know what to expect at this early stage of the projects. Einstein said:

> ”If we knew what it was we were doing, it would not be called research, would it?”

However, blaming the nature of the work could also be an easy solution not to specify the initial requirements sufficiently. Adapting a proactive mindset, specifying requirements as early as possible, and when this proves difficult at least informing of changes as soon as one knows they will occur, will in my opinion still improve the overall efficiency in the projects.

Yet a drawback with this mindset is that there are several reasons for not wanting to make reports in this way. Similar to the fourth argument on bad documentation, poorly specified requirements can be made on purpose so as to extend the work assignment for the involved people. Most of the personnel are on short-term contracts and in a very temporary environment, so if uncertainty about own future exists, one way of coping with this could be to make sure that you will still have sufficient work to do. This opportunistic way of acting is also in line with the findings of Williamson [67].

5.1.6 Quality Assurance

From the interviews the focus on quality assurance was not highlighted too often, but there were three people mentioning the importance of it, and they emphasized it strongly. It emerges as a weakness that a plan specifically designed for a single project (albeit the largest ever in the organization) is used at an overall level for the organization. Especially I would argue that the plan is not able to grasp the diversity of projects and then in particular for projects on a lower scale.

The read-through of the Large Hadron Collider Quality Assurance Plan also leaves me with some questions that need further analysis:

1. It is not well stated what the actual purpose of the QA-plan is. The chapters describe a lot about what it contains and to some extent how to use the documents, but there is nowhere stated why a QA-plan is designed in the first place. If workers are going to adhere to a plan I claim it would make sense to in an understandable way state the reasons why in a more explicit way. My experience is that when people understand the connections in the work they are doing it is usually easier to get them to collaborate. This is also supported by the findings of Churchill [21].

2. The plan is supposed to focus on the LHC-project. The overall organization needs something that is more tailored to all projects. One could argue due to the unique nature of this project, involving almost all personnel at CERN at a point during the project life, it is a good start-up point for a centralized QA-plan, and that can in fact be true. Several people emphasized that reinvention of the wheel is unnecessary. I agree that it will make sense to learn from the experiences from the LHC, but it is also important not to get too stuck in old habits limiting the perspective with focus to a broader selection of projects.

5.1.7 Handling New Technology and Radiation Issues

The handling of new technology at CERN is a unique feature of this research facility (as compared to manufacturing). Working on the research-border, many of their projects rely on technology to be developed and the challenges that this aspect brings. The use of new technology itself I would argue is neither an advantage nor a disadvantage for the organization; it is rather an attribute of the working procedures in the organization. Thus it is categorized in the unclear (?) category in table 5.1.

To me the development of technology shall not be seen as a liability since it is usually a necessity to be able to cope with many of the challenges, not only at CERN, but in the society in general. On the other hand it is not purely an advantage either, since technological progress may make current routines obsolete. Since it is obvious that one cannot go around new technology, I would argue that the topic shall not be given extensive focus in a standardized methodology. It is important to know that technological development will happen, and that this can give rise to other challenges or consequences that is currently foreseen, but as long as one cannot foresee the future I claim it is reasonable to live with this risk.

5.1.8 Earned Value Management

Earned value management is a tool that is useful to keep track of large projects and of groups of projects. The unique features combining indexes of cost and schedules make the tool valuable for the planning of processes and to handle changes. The impressions I am left with after the interviews is that most of the candidates think it is a valid and useful approach in a project environment, but that it will have to be utilized on a higher level. The reasoning behind this was firstly that it is hard to convince the engineers about the usefulness of the tool since the tool does not provide immediate results at their level. Secondly the tool is not believed to be effective in the start-up phase of a project because of the higher relative uncertainty compared to the later stages where more information is available.

I believe that it for a standardized project management methodology will be useful to have some standard methods or tools to stick to, and I would argue that earned value management should be among them. The tool seems to be accepted by the candidates of the organization that already know about its usefulness, who state that it is a good tool for tracking the project progress. That it among the rest is not (yet) a discussed topic I think is a consequence of unawareness rather then deliberate ignorance. Thus I argue that for the tool to be successfully applied in the organization some kind of education will have to be given.

Additionally if one accepts the idea of using this tool, the questions of when to use it, how to use it and who shall use it arise. This will have to be discussed for the implementation, but I initially argue that it mainly should be a tool at the manager level. Subsequently a project will have to be clearly described for it to benefit from earned value management.

5.1.9 Lack of Central Methodology

A final topic to discuss from the interviews is the desire for a central methodology. It is good to see this topic being brought up because it acknowledges the fact that practitioners believe adapting best practices to CERN-projects will be beneficial. Yet, since this topic was only highlighted by a very limited number of respondents, it also seems it is a topic that is not widely recognized. This ignorance can show lack of knowledge, but it can also be due to lack of faith in the possibility and/or benefits of introducing a centralized standard.

Based on the interviews it seems to me that the organization lacks some maturity to be ready for introducing a standardized methodology. Too few of the interviewed candidates seem interested in the topic, although the ones that showed interest were really encouraging about the idea. I would argue that this mirrors a need for education of personnel on the benefits of centralizing the project management methods. However, this is probably not so easy since physicists and computer scientists often are interested in their own fields more than in making administrative procedures effective. This could possibly be overcome by explicitly informing about the advantages a methodology gives, rather than forcing the use of standards and methods to the organization. If it is obvious where people, even at the ground level, will benefit it should be easier to convince them.

5.2 Conceptualizing a Framework for Large Scale Projects

So far the thesis has presented some of the best practices of project management and systems engineering within literature, followed by the experiences of a selection of project personnel at CERN working in different project environments. The empirical findings have been discussed in the previous section, so the intention of the last section of this chapter is to highlight the topics I think would be reasonable to proceed with for designing a centralized project management methodology at CERN.

5.2.1 Organizational Culture

Implementing changes in an organization is usually difficult because of the existing organizational culture. Lawrence states that this is one of the largest challenges a leader can face, because of human's resistance to change [42]. This will also be the case for introducing a new and centralized project management methodology. If CERN is going to be successful with this, it is important to convince the members of the organization about the benefits of utilizing a methodology.

One start-up point can be the use of a ”project champion”, i.e. a person that is convinced about its usefulness and able to motivate also other people [32]. Then it is important to state clearly some of the benefits a methodology will give, not only on an overall level for the organization, but also how each individual worker can benefit from this.

Changing the culture of an organization is a slow and difficult process, but I believe it is a necessary action if CERN shall succeed reaching their goal.

5.2.2 Life Cycle

The life cycle design should be short and concise but should at the same time encompass all the major aspects in a project. This thesis has explored four life cycles from the theory, and in addition some have been suggested by the respondents. I propose to divide a life cycle for CERN in five main phases, not very different from what is proposed from the PMBoK, and with flexible borders. This to make the model simple as suggested by Forrester [28]. At the same time I believe the approach from NASA, where each phase is divided into similar subphases, is reasonable to be able to clarify the different work packages necessary in each of them. Then I think one should use the steps of the systems engineering method, either as stated by Kossiakoff and Sweet or the adapted version that NASA is using. This will provide an organized management of the project life cycle. By subdividing phases, the suggestion from one of the project engineers about subdividing the closeout phase to take into account radiation issues is also covered. Moreover I think there should be, despite the flexible borders, some clear decisions points along the life cycle, similar to those found between the phases of HERMES. This will make the decision processes more organized. Finally I will devote some space to two other aspects I also think should be part of this design: identification of needs and clear routines for dismantling.

Identification of Needs To identify the needs is important at an early part of the initiation phase. Both the literature and the practitioners express a real concern for a statement of what often is obvious: What is it exactly that you need? Apparently it is not very easy to clarify what the real needs are due to the many possibilities of interpretation. Therefore one has to make some effort already in the opening phase of a project to try to state the needs in an understandable and united way [66]. This can be a challenge and it is a problem that will differ in nature whether one is working in a manufacturing company or within research.

For a research organization like CERN the overall goal is to explore and discover new physics, but this as such is not a clear enough statement to call it a need. It is more a goal or a vision than a manifested need that one can pursue through regular methods and actions. Not to be misunderstood, there are a lot of regular methods one can adhere to within physics, methods that often also are being used, but the overall objective of discovering new physics is too general. A better description would for example be to state that the need is to ”collide beam energy of $500GeV$ by the use of superconducting radiofrequency structures” [19].

However, in spite of the evident challenge of identifying the real needs in an organization like CERN, there are some measures that can be taken to increase the probability of developing the right things. Most of all: Communication. People need to talk together, and they need to speak the same language. This is an aspect that the people at CERN seems to agree about. It will be useful to question the proposals, and to ask the users to be more explicit about what they want. Because the organization relies on technology that is not yet developed, one can of course not be exactly sure about how one would want things to be made nor what the costs of it will be in terms of money or time. Therefore it is important that at least the information that is present is shared so that the risk of miscommunication can be minimized.

The early identification of needs will also make it less likely to implement major changes later in the project. This is beneficial because it usually is more expensive to do changes later on. After 20 % of the project has elapsed, 80% of the resources are committed, so the first fifth of the work is crucial for the success [38].

Clear Routines for Dismantling The establishment of clear dismantling routines is another important aspect that CERN should have in mind for their methodology. Because of the unique radioactive nature of their projects it is necessary to think about how to treat the equipment once it is radiating already before it becomes radioactive. Thus I argue that maintenance personnel and those that eventually will be responsible for decommissioning should be included in an early phase along with technical experts within the field. It may already be the case, but the impression I got from the interviews is that it is not done well enough. Taking this into account will contribute to securing an appropriate planning of the closure phase.

5.2.3 Roles

With regards to project roles and responsibilities I think CERN should do an assessment of the current positions across their projects to identify all the roles they are currently using. The identification of responsibilities will make it possible to remove obsolete positions and by comparing to literature one could also discover whether some crucial roles are left out.

Clarity When all the roles are identified I argue that it is important to state clearly the responsibility areas for each of them. If all the roles are explicitly described, it will be easier to follow up on the work, and engineers taking on a new role can immediately identify with their work tasks. This will be a benefit for people that often change positions. For projects on a smaller scale where all the positions do not necessarily apply, it is equally important to know which responsibilities to merge.

Project Manager The role of the project manager is especially important to define clearly for the large scale projects, and for the project manager themselves it is important that the other responsibilities are transparent too. This will make it easier to delegate work to the right instances, so that it does not pile up at their table increasing the likelihood for delays. As mentioned in section 5.1.4 the technical expertise of the project manager could often be a liability to work delegation. One way to overcome this could be to appoint a project manager with strong knowledge of project management, but who is not an expert on the technologies, i.e maybe it would be a good idea to appoint a systems engineer as the project manager.

Utilizing the Responsibility Assignment Matrix A responsibility assignment matrix (RAM) is used to illustrate the responsibility areas of the different project team members [52]. The tool can be used both on unit-level and individual levels within the organization and I argue that it can be a good way to help clarifying the roles and responsibilities for the different team members.

5.2.4 Documentation

As stated in the methodology chapter, the specific documentation unfortunately got a lower focus than I wanted, but since the topic on a general level seems to be important, I will still try to suggest two measures based on the information I found.

Lean The documentation used in the projects should made through lean approaches. The general opinion in the organization as revealed both through interviews, but maybe more important through informal conversations, is that there is too much unnecessary documentation. This takes up a lot of time so one should do a review of the procedures for documentation. This is also reflected in the study of Wulff et al. on large-scale development projects offshore [4]. Documents are important especially to keep track of what has been done, but also to reflect the future plans. Hence I argue it is reasonable to try to keep them, but then keep the information at a low level. If one explicitly states why the documents are needed, it is easier to quickly identify whether or not it is relevant to the current project.

Quality Assurance Plan Using a quality assurance plan for the organization will be advantageous, but I think it is important that the purpose of the plan is stated at an early stage. This will make it easier to understand the real use of it, and the intention of the subsequent sections will be easier to grasp. According to Churchill an early planning of the quality assurance can contribute to reduction of costs [21]. Then one can discuss whether there should be one overall plan for the organization, or if the methodology shall demand a quality assurance plan for each project. I think this is an issue that will have to be further investigated; an overall plan may lack the flexibility and specificity needed for individual projects.

5.2.5 Earned Value Management

The section of earned value management is included because the interviews point out this tool as a very valuable one to the organization. The tool should be applied for monitoring the progress of projects, but before this applies the organization has to convince all relevant personnel about the usefulness and the outreach of the tool. The benefits of the EVM-tool has already been demonstrated in many situations

[49], so one could use real-life examples as a point of departure when trying to convince the members of the personnel.

Chapter 6

Conclusions

THE final chapter presents the main findings of my study and some suggestions for how one can base future research on the content.

6.1 Summary

This thesis has tried to investigate to what extent it is possible to develop a centralized methodology for project management at CERN based on the best practices within the field, within the subset of systems engineering and based on the experiences and attitudes of personnel at CERN. My work shows that the organization still has some way to go if it is going to successfully implement a centralized project management methodology. With respect to the research questions from section 1.1 my conclusions are the following (similar numbering):

1. The literature advocates that the best practices of project management depend on the organization. The standard provided by e.g. the PMI is a collection of all the methods or procedures that are or have been optimal for a project once, so the theory states that a project management methodology shall be adapted locally to the organization. Yet, some central aspects are emphasized like the utilization of lean thinking or organizational aspects like the establishment of a local project office. Moreover best practices could be defined on several levels as seen in this thesis, where the focus is on project life cycles, roles and responsibilities and documentation. Although centralizing project management in the design of a methodology for an organization generally is seen as an advantage (or even a necessity), it is claimed that the approach is not reasonable for small organizations or projects [38].
2. The projects at CERN are not currently managed with the use of a standard methodology, but it emerges that the personnel at CERN (at least the

people involved in project management) want to use one. The existing HERMES-methodology seems to be the preferred choice as a point of departure. Among the issues within the projects at CERN is the lack of sufficient documentation. Managers often rely more on the experience of each other than on written documents. Moreover, it appears that the front-end phase is often not well developed, i.e. projects face several changes because of bad planning. A strength is their implementation of the earned value management tool. It helps to keep track of the schedule and budgets, so that corrective actions can be taken early when projects go off track. The tool is at the time only used for some projects, but the intention is to expand it to the entire organization.

3. Based on the theory and my empirical findings I would suggest some measures that CERN could take to introduce a methodology for the organization:

   – To incorporate the idea in the organization culture is the first action I would suggest. This is not done over night, but is a long-lasting process of gradually adapting. The people working for the organization will have to understand and agree about the necessity of using a centralized approach. It will be beneficial if it is possible to do this all the way to the bottom-level, but as a minimum it has to be generally agreed about at the level of the project managers. Even the best methodology in the world will not work if people do not agree to use it.

   – Involving the stakeholders at an early phase is another important aspect. This will make it easier to cooperate across organizations. However, it will be difficult to account for all possible (future) stakeholders when a methodology design is made, so I think it is important to keep some flexibility still.

   (a) As seen from the analysis a centralized life cycle approach is necessary, and I believe it would be optimal to divide the cycle in 5 phases. This should be necessary to cover all the main points and at the same time it should not be too much in terms of details. The life cycle proposed from NASA where each phase is subdivided in a similar way as the overall cycle seems to be a sound start-up point. Moreover I argue that the use of their corresponding SE-engine will make it easier to organize the project life cycle.

   (b) For projects on a large scale the identification of roles and responsibilities is very important. When people have clear responsibilities they feel more committed, and if these are delegated to the appropriate roles, it will ease the work of the project manager who can spend more time on his role of coordinating the project. It seems that the role definitions at CERN are somewhat ambiguous, so I have not been able to extract the different roles' contribution to the best practices within the limited timeframe of the work. However, the literature has put an emphasis on the role of the project manager and their capabilities, so this is an obvious role to explore further. Moreover the roles of the other members of the project team should be identified to see if it can improve the performance of the organization.

(c) Concerning the necessary documentation it appears to me that the explicit formulation of needs and requirements upfront in projects is an important contributor for developing a methodology at CERN. To clarify the usefulness of the documentation also improves its quality, according to Bayer and Muthig, so that is an aspect one should keep in mind for the documentation [7]. The tracking of work is also believed important from a perspective of quality assurance, and the use of quality assurance documents should also be present. This is supported by Churchill, who also emphasizes the importance of clarification of necessities [21]. The use of conceptual (CDR) and technical (TDR) designs seems to be relevant for identifying the needs and requirements even though they can be improved for the organization, but they are also utilized to trace why decisions were made in earlier phases. Other specific documents that are necessary for the organization were due to constraints of time and accessibility unfortunately not sufficiently explored.

6.2 Further work

This thesis lays an early foundation for what can be used as a basis for the development of a project management methodology for CERN. In its current form, the thesis does not alone provide a clearly defined path for how to continue so I will suggest some main directions:

1. The organization can use the studies of the life cycles to design an overall life cycle for the projects they are dealing with. It will probably be beneficial to have a look also on other relevant standards or methodologies like the acknowledged PRINCE2 and the recently developed ISO21500 from September 2012. This to make sure that important aspects from the literature that I have not covered are not ignored. Nevertheless CERN should make sure that the chosen approach is adapted to and fits the organization.

2. As for any organizational change the rigidity of the organizational culture may be a problem. Parts from this work can be used to motivate people and to explain why it is important with a centralized methodology for the organization. An idea could be to explore further what f.ex. an organization like NASA did to get approval for their methodology within the organization, or whether they actually did.

3. A more thorough investigation of documentation should be performed. The practitioners have explicitly voiced their opinions on the shortcomings of the current documentation procedures, so since this thesis only vaguely pins the surface of the specific documents that are used by the organization, I would

claim that it could be an important aspect to follow up on for the design of a methodology. This is also important with regards to identifying whether there are unrevealed reasons for why the personnel rather rely on experience than on documentation.

4. As stated at the end of section 1.1 the thesis has solely been looking on the "hard systems" part of project management, so there lies an obvious potential in investigating how to treat soft systems as a part of a methodology. I am touching only the tip of the iceberg of this when suggesting to define responsibilities of personnel more clearly, but for the development of a project management methodology it would be both interesting and even a necessity to do research on the social aspects of an organization.

Finally the conclusions are mainly based on theoretical considerations. Thus there is no guarantee that the suggestions are possible to implement in the proposed way. How the findings can be utilized in practice is also an aspect that can be explored further.

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Appendix A

Interview Guide

Life Cycles

1. Could you describe the life cycle of one of your projects at CERN?
2. Do you think this life cycle can be seen as general for projects at CERN?
3. What would you like to change about it?

Project Roles

1. What do you think are the most important roles in a project?
2. What is usually your role?
3. Could you in short describe how the influence of this role develops throughout the life cycle?

Deliverables

1. What are the major deliverables in terms of documents throughout the life cycle?
2. How are these documents useful?
3. How can they be developed to better serve their purpose?

Appendix B

Summary of Interviews

The individual summaries of the interviews are to be found on the following pages.

Candidate 1 - Section leader High Voltage.(EN/EL/HT). 15 years at CERN. 10 years constructing the LHC.

1. The role of our section is to construct the power network at CERN, maintain it and diagnose problems.
2. We have quite a few large projects, ranging in the scale of ~10M CHF.
3. There are mainly two categories of projects within our department:
    a. Consolidation projects: i.e. projects to optimize performance of the system; If one part is degrading due to age, we replace this part with a new one to preserve current performance.
    b. Upgrade projects: We add extensions (new parts) to the existing grid to either increase performance or to extend the performance spectrum.
4. The naming of the project categories is a question of terminology.
5. In our department each engineer is project manager for the project he is responsible of.
    a. He is a project manager.
    b. He is an equipment owner, that is, he is an expert on the equipment that's going to be used in his work.
    c. He does advanced diagnostics.
6. My role: First I propose the work to be done to the existing network to keep it able to deliver the necessary 7 TeV for the LHC. Then this is discussed at a higher level, and budgets are estimated.
7. The initiation of our projects often emerges because of the aging of the network.
8. Then we assemble a working group that will discuss the future network at CERN.
9. Documents for the consolidation projects are:
    a. Drawings, status reports, estimates, minutes.
10. Phases: Initial design (motivation) → Expert report → Own designed roadmap → Define clearly by items.
11. Items
    a. Network analysis – specifications.
    b. Detailed study
    c. Inventory of safety equipment
    d. Communication with CERN stakeholders.
12. It is the first time we do a full-scale network analysis at CERN.
13. We rely a lot on the experience of our engineers.
14. Life cycle: Functional specs (why and how) → Engineering specs (Detailed description) →
    a. In sourcing: Buy equipment. Design and implement.
    b. Outsourcing: Turnkey project → Tenders
        i. Impose self supply on equipment.
15. Knowledge conservation
    a. Documentation
        i. We want to introduce a meeting with the contractor at the closure phase, to record lessons learned and to keep trace of potential errors.
        ii. This is supposed to document what has happened, so that the information does not get lost.
        iii. Contractor also wants feedback.

b. Defined templates (independent of projects)
    i. To-do-list upon closure.
    ii. Minutes
    iii. Drawings.
c. Optimize the design phase
    i. Too often we have to do redesign, for minor changes. This is ok as long as the number of changes is low.
    ii. As-built-construction design should be provided.
    iii. Cable parameters
        1. Better visualized in 3D than 2D. You can check all the parameters. Try to impose models on subcontractors.
d. Contractor standards are not always applicable

16. PM Responsibilities
    a. Functional specifications
    b. Iron triangle
    c. Coordination
    d. Safety
17. Engineers are good to and like to design equipment. A challenge is to get them to explain why they make their decisions.
18. We sometimes show them other projects where lack of specs has been an issue, to highlight the importance for documentation.

Candidate 2– Project leader for the R2E-project.
16 years at CERN, been through all stages.

1. The need for our project was discovered with the failure of the CNGS. It turned out that radiation had negative impact on our equipment, so we had to try to identify measures to solve this.
2. A lot of options were considered and in the end we ended up using a mixture of relocation, shielding and new environment.
3. Civil engineering was one of the aspects that was discarded because of lack of time.
4. We have been able to reduce the number of failures dramatically the last years, from several hundred, to eleven two years ago, three last year, and we hope for 0.5 this year.
5. The major problem with a relocation is not the moving of the equipment itself. It is to identify all the supporting equipment that follows as a consequence, and take this into account, such that the equipment can operate as usual in its new environment. This is not always easy, and requires the expertise of experience personnel.
6. What we figured was that there was no database covering all the inventory of the company, so it was very hard to tell what we had, the sensitivity of it and whether there were any constraints related. We had to fight a lot of scepticism in the process of identifying this.
7. Luckily the nature of the equipment differs so we could do the upgrades in phases. First was to take care of the things that were immediate. Now we are in the middle of the medium-term phase, whilst we by the end of 2018 (before LS2) will finish the long term phase.
8. In the procurement phase we have a very strict procedure for how things work. We identify a selection of qualified suppliers, and then the cheapest one wins the tender. This can create problems, f.ex. for us we experienced a lock-in for the Romanian supplier of iron when the bank went bankrupt. Luckily we were able to 1) get out of it and 2) get the second best option to deliver on the same premises.
9. We have a working group in the project, consisting of approx. 50 people, that possess the key knowledge about all our different projects. The information is there for not necessarily documented as such. This is a risk one has decided to take, consciously or not, but it is often necessary due to the lack of resources. “Give me 2 men to do it, and I will give you documentation”.
10. Another bad thing about documentation is that it limits the reactivity. If you have a long document to follow, you can not take quick decisions. Therefore I am not sure whether it is the way to go, although in theory it is a very good idea.

Candidate 3 – Project Engineer / Project Leader. About 10 years at CERN.
No academic background in project management, but he wants to learn a lot about it.

1. There are two kinds of deliverables, services and components. The processing of these is different.
2. The life cycle of a project can be described like this:
    a. Conceptual design phase:
        i. Needs ⇔ Functional specifications.
            1. Requirements
            2. Assumptions
            3. Constraints
        ii. Project team is assembled
            1. Technical specifications are designed.
    b. Detailed design
    c. Procurement
    d. …
    e. …
    f. Decommissioning.
        i. This is a phase that has two parts at CERN: Safe conditioning and dismantling. Radioactive material needs to be stored for a while, until it can be dismantled.
3. "If you talk about a man, he thinks. When you talk about organizations, they write. That means, an organization without document does not think."
4. Mandate → Project Management Plan → TDR
5. He suggests to move the technical design report to the end of the development phase.
6. Merely influenced by his experience within research, as he has no experience from industry.
7. Lessons learnt: Maintenance and all other relevant personnel should be involved in the planning of the entire process. If a component is not radioactive, but becomes radioactive once object for power, it is important to make maintenance personnel aware of that.
8. If changes occur in projects, they are usually imposed through engineering request documents. This gives rise to other sub-projects for implementing the change in the overall project.
9. Finally he has never come into a project "in the middle of it"; he has always been there from the start. This influences his perspectives of project management.
10. Another important aspect is the focus on corrective vs preventive maintenance. The former is done way too often, and could be reduced by proper planning.
11. Responsibilities: I have done most design on my own. Proposals, concepts, etc. Because when I discover a problem, I want to solve it, so I design a solution.

Candidate 4 – EN/MEF, Project manager, Mechanical Engineer, Technical coordinator.

EN/MAF: Engineering department – Machines and Experimental Facilities.

- Planning and coordinating maintenance and installation activities
- Supporting experiments using accelerators.

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1. To define a life cycle for a project you first would have to define the scale of it. For example ATLAS has 2000 people, 20years lifetime – it means we have not started to think about how to close it down yet. The challenges with research projects are among others that we don't know what we are looking for. Planning a closure and dismantling, and then suddenly discover something that makes us want to keep the project still going will be stupid. That would just be a waste of both time and resources
2. However, the life cycle could be described as following, in terms of documents:
    a. Letter of Intent (LoI): This is a document developed by the physicists describing what kind of physics they want to perform. Here the overall goals are stated.
    b. Concept Design Report (CDR): This is developed by the engineers that take on the challenges from the LoT. The document specifies in detail how the engineering should be made on an overall level, to be in line with laws of nature. Includes the WBS and the Functional specifications.
    c. Somewhere before the TDR the actual requirements of the system is defined. This is not totally clear.
    d. The TDR is a set of documents which goes further in detail on each component of the total system and the corresponding subsystems.
    e. Then we have the technical specifications
    f. Followed by a call for tender phase.
    g. Procurement, with the corresponding acceptance of equipment from the suppliers (if not another round including contractual issues has to be conducted)
    h. Installation, with corresponding acceptance.
    i. Then what? For these large projects I don't think there are any clear procedures for what to do afterwards. The project will be finished after my career, so it is very abstract to talk about these things.
3. How would you describe the end for a small-project then?
    a. Uhm, I can't think of any small projects I have been in charge of.
4. In the AD project, and other projects, whose purpose is to discover new things the planning of a dismantling phase is obsolete. Documents might not be used if it turns out one doesn't want to close down the work as planned. The PS(???**check**) for example has been running for 60 years, so a planned closure of this, and allocation of corresponding funds, would have lost its value today as a consequence of inflation.
5. The NA62 (combination of NA60 and NA48) was a short project ~3 months. It does not make sense to use project management methods for such a short time period.

6. The planning of a new control room. Had to convince four different departments. Started with the most positive ones, and moved them gradually. Made adaptions so as to satisfy the different users. A radiation problem was discovered and solved at stage (subproject, comment added) 1 – this made us available to take it into account for stage 2, and so on. Project is assumed completed by the end of 2014.
7. Many projects at CERN are never finished, but rather recycled. It seems we learn as we go.
8. Documentation would definitely have been useful. Most knowledge transfer is done through transferring “know-how” rather than official documents. This is a pity. On the other hand, people don’t like reading documents, so whether they would have been used if existing is a good question.
9. The safety coordinators play a very important role in all projects. They are making approval of different designs once installed, and are one of the necessary actors to make the project proceed.

Candidate 5 – 5 years at CERN.

1. Mainly working outside of projects as a support when people are in need of our tools. I am a software engineer that is learning project management.
2. APT (Application Planning Tool?) is used by the group responsible for the budget and for the mid-term-planning.
3. EVM should be used for projects that are larger than 50M CHF.
4. The WBS is usually in place when a project wants us to come help them with the EVM-tools.
5. However the nomenclature used is not standard, and that can be a challenge. For example are the terms wbs and work units used interchangeably.
6. Our tool only takes into account material resources for the time being. The problem with people is that
    a. They are managed on a department level, and not the project.
    b. They don't want to report their own errors and performance.
    c. No reporting of work → It will not work.
7. There is a difference in the use of the term for projects and for billing. Time sheets are never filed at CERN, unless it is for the billing of a customer or on governmental purpose.
8. EVM is used from the start-up of a project, i.e., from the beginning of the execution phase.
9. NN is the responsible person for the EVM-follow up on the R2E-project.
10. I have the impression that [Candidate 2] is not interested in EVM, but implements it because he is imposed to do so.
11. [Candidate 11] on the other hand is very positive towards the tool.
12. So the process starts with how to model your project; what have you defined? This is usually an easy part.
13. Thereafter you have to break the project down into sub-structures. That can be more difficult.
14. EVM is a tool that gives a centralization of the activities and that provides good overview of the project.
15. The problem about EVM is that even though it is a brilliant tool for the project manager, it is not always seen as good from the engineer point of view.
16. We should also be careful with what we call EVM here at CERN. Often managers say that schedule prevail costs, and in case it is not a true EVM-system.
17. The tracking is done by defining deliverables in terms of work units, and tracking the progress of the different ones. There is this 90%-rule and also the 20%-80% rule.
18. Documents
    a. Data quality → WBS, Work units, etc..
    b. S-curves
19. It is hard to plan the planning. That's why EVM doesn't apply before the execution phase.
20. Project Costing Tool.

Candidate 6 – GS/AIS

- Deputy of the AIS-department.
    - Advanced Information Systems: Corporate Information systems.
- Manager of the PM
    - Project Management and resource planning

1. My work is mainly on developing tools for monitoring the progress of projects, and the EVM is an important part of this. The tool is mainly useful from the execution phase because the oscillations in number in the startup of a project is hard to extrapolate.
2. Often we are contacted too late by people who wants to use this tool, so that projects are really going bad. We try to convince people to early on monitor their projects and let us know whenever they are behind on schedule.
3. Projects are very different, so it is hard to tell a general way of managing them, also for this EVM tool. We do want to develop it so that it can be used for all scales of projects, but as of know it is mainly useful for management to keep track of their portfolio of projects and how this is progressing.
4. The Medium Term Planner, is where the start-up of projects is decided, but of course smaller projects may be initiated at lower levels of the organization within department budgets. Especially for these it is hard to impose the EVM methodology, unless the managers themselves already see the use for it.
5. My department is mainly supporting the projects, and it seems there are no formal start-up procedures for the different projects. There exist different reasons for why, when and how they start, so that's in particular a challenge when developing a standard tool for the execution of projects.
6. In many organizations there exist thresholds for when one has to use EVM.
7. Projects are often seen as something that is common sense, and easy to conduct, but it is the **experience** of managers that make them able to keep it on track. They know that everything is not exactly as it appears based on earlier projects, and are therefore better able to adapt.
8. Why would people not use the EVM? One major reason I think, is the pride of the different managers. You would not want to reveal that you are behind schedule or above cost for a project, and rather wait and hope it will solve itselves. Very often it does not, and the actual problems are brought to the surface at the end of the day. We are trying to convince managers to disclose the problems earlier for then to be able to solve them at an earlier stage.
9. Another reason why the actual quantification and use of EVM can be hard is because it is impossible to know the nature of the technology. At the start-up of the LHC one had to rely on the fact that the appropriate technologies would be developed throughout the lifetime of the accelerator. This would of course be hard to take into account in this kind, or any kind of, tool.
10. EVM is usually given as ad-hoc-training. People see the need to use the tool, and we then provide them with necessary education as to fulfil their needs. To educate them in the means of large manuals is useless, because then a physicist will just go on doing whatever he prefers; physicist don't like to read a lot (don't ask too much of the people).
11. The proactiveness is a key successfactor for projects. If one is able to foresee eventual events early on, or at least try to take measures for doing it, it will be easier to monitor and manage the project.

12. For Linac4 it was an advantage to separate the civil engineering from other disciplines in the EVM. It revealed that the CE was actually lower on costs, which made us able to make the appropriate adjustments.
13. I don't think that EVM would be useful before we actually get to the construction phase of a projects. It is very hard to quantify planning (when is a document finished, when it is uploaded, verified or printed and signed?), compared to the actual manifestation of 1 km of cupper cable. These are some issues with the EVM. If we compare to the definition of the PMBoK it is quite ok to put the WBS into the tool, but it is much more difficult with the PBS (**check**).
14. Other tools are also being used as the Project costing tool (**Consult** Bonnal)
15. An issue at CERN is the Project Management-Knot. We have not been able to unveil this one yet, because there are a lot of contradicting forces.
16. One reason that it is hard to generalize a framework is the dynamic nature of the world. The continuous change makes it important to adapt, and this could be very hard in a project setting with rigid plans. But this is also important for commercial projects, not merely the scientific ones. **Check** the book "Fast Strategy" by among others the CEO of Nokia: "Methods don't work anymore.."
17. Another point to emphasize is the different roles of the project leader and the program leader. The former is more focused to completing his actual project, and does not worry too much about the use or benefits of the outcome. This is the responsibility area of the program manager. A more united view between managers would be nice.
18. Finally, I am very interested in the work you are doing. Don't hesitate to contact me again ; If I don't answer immediately give me a call.
19. Documenting things is optimal, but again, if one were going to document everything one would not have time to do any execution, so it is important to find a balance.

Candidate 7 (EN/HE – HT)

- Handling Engineering
  - Provides transport and handles services for infrastructure.
  - High risk → respect of procedures and operation manuals.
- Handling Technologies
  - Multidisciplinary
    - Design studies, equipment development, in-house built or specification and procurement to optimise procedures for remote inspection, measurements and handling equipment, custom built transport and handling equipment.

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1. Check EDMS-Document: 1209438.
2. For the camera train in the ceiling, the HERMES-methodology is used (**check** name of project). This is a light version of the official methods used, and the one referred to in the small handbook of HERMES.

3. Status reports are mainly made as minutes. He prefers to document all the steps of a project through the EDMS-system, so as to be able to trace every action back to its initiation. This is regarded an important point for the projects, because it will reduce the amount of reverse engineering regarded.

4. Apparently my quest of the interview was regarded too ambitious. One could not answer all these topics within one hour.

5. One challenge with the management of projects: Managers enjoy autonomy and freedom. When some framework or actions are imposed to them from above, they are usually reluctant to adhere to them. They want to do the things in their own ways, and do not like to be told how to do things all the time.

6. Restriction of documents. He generally wants all documents to be open, and to be used. However under certain circumstances, f.ex. when collaborating with external contractors or consultants, it may be necessary to restrict their access to keep some secrets.

7. The specification documents are seen as the most important ones. It appears that it in this project is developed a document that states the actual needs and requirements of the user, based on the project team's interpretations of the descriptions given by the user.

8. The steering committee is constituted of the program manager [candidate 7] and the different group leaders, and is responsible for making the different decisions at the points throughout the project life time. These could be to choose between concepts of action, when there is no obvious solution for what would be the best choice.

9. One major disadvantage in the projects at CERN is the lack of a Quality Assurance Plan.

10. He has never seen a mandate document. His projects are usually given to him in the middle of the process, so that they already have a basis. This basis is

often poorly documented and he has to spend a lot of time on reverse engineering, i.e. reviewing and understanding what has already been done up to this point, and why the different actions have been chosen. The project therefore often starts with the proposal, which the manager in charge has been responsible of developing.

11. Reverse engineering seems to be a major issue throughout the conversation.

12. His current role is to be the program manager of a selection of projects. However, because of few resources he often takes the role both as project manager and project participant. Thus it seems that in these small projects one person has to fill several roles.

13. He suggests that the creation of ownership to projects, i.e. letting people feel how and that they actually contribute in the process is of major importance to be able to process a project effectively. One large issue is that people seems to act as if there were no constraints on time nor money, so they don't care to much about the actually execution of projects.

14. Suggested process: Project engineering
    i. Define user requirements
    ii. Write functional specification
        i. Run integration study with CAD.
    iii. Write technical specification
        i. Run tests
    iv. Build or procure equipment.
        i. Build prototype
    v. Operate or handover to client.
15. Recommends to talk to [Candidate 17]

Candidate 8 – EN/HDO, at CERN since 1993.

1. The project starts with the user requirements. That is, the physicists provides us what they need: Either new machines or upgrades to existing equipment.
2. Then the process is the establishment of two documents: Scientific motivation and technical options for the project. This is presented for the research board, which will go through the information and decide whether the project should be pursued or not. If the board accepts it, the project will be transmitted to the top management, where it will get approval as soon as there is room for it in the budget.
3. A technical coordinator will be put in place, which is responsible to design the structure of the project, work packages, product packages, schedule plans, cost plans, whatever. And then at some point in time there will be an approval from the top management.
4. Before this there is a research and development phase; it usually starts when the research board states it is a good project. We cannot let physicists go around doing nothing. This phase is partly funded externally.
5. Then when the budget is approved the organizing of the project takes place, and a quality assurance plan is established. The QA for the LHC is being used, but it is not adaptable to the small-scale projects. We don't have the same amount of resources, often only 2-3 people, so we cannot assign on person full time to do naming conventions f.ex.
6. The work of the project leader is mainly the technical coordination and getting the right teams to talk together. The expertise is here, but it doesn't always show up at the right place when needed.
7. The QA-plan of the LHC contains too much documentation. Nobody has time to read it, and it would definitely not be feasible to read it. However we do rely on some aspects of it. For large projects however it is a good structured approach to use.
8. A major issue at CERN is that there are a few people in the project office that has a lot of knowledge. For a huge project that is not a problem, since the people would be able to coordinate this quite well, but to get this knowledge to use on the several small projects is not very easy; obviously one person cannot be at 50 projects at the same time. My project does so far not have the priority in the PO, so it means I will have to just try my best, and see how it goes.
9. I think it would be advantageous to do the risk analysis early on. This is not the situation nowadays, where the projects start; after 2-3 years someone wants to do a risk analysis, and then we see that the project is in deep shit. I would therefore like to see this starting earlier.
10. So when the project gets its approval the design phase and the technical specifications are developed. These are detailed versions of the technical options provided initially. Then follow the procurement with the purchase rules, which are really well structured. Actually these are some of the procedures at CERN that are very well worked-through. There are of course executed technical reviews throughout the period to make sure that the design is possible – this is often done by external experts.
11. The project office often handles the technical specifications.
12. Then follows the integration and installation phases. This is quite fast, but the time it takes to acquire the equipment is usually of a slow nature.

13. Documentation is a natural part of the QA-plan. We used the EDMS-system a lot, and try to encourage people not to store documents locally. We have templates for how to structure the different documents so as to make it easier to understand the information within.
14. Do we always need best practices? That is an interesting question, and I am not sure about that. I would say that to a minimum there should be a tool for monitoring expenses, and we would usually use EVM. Personally I use excel and my own models for monitoring, but I report my results by the EVM-system. It is very difficult, in my opinion, to state anything about the future performance from the graphs of EVM; i.e. what are the real reasons for being behind schedule? For that you will have to go talk to the people, this method will not tell you that.
15. People usually don't like to change their habits. This is f.ex. an issue in terms of storing information locally.
16. The role of the project manager is to provide the means for achieving the work; i.e. providing the money and the people.
17. LHC was based on outdated technology when it was started up, because the design was made in the past. Therefore it is important to remember to design for upgrades when an initial design is being made. Anticipation of new requirements is therefore important.
18. By participating in experiments one learns a lot.

Candidate 9 - GS/SE
2,5 years at CERN. Previous experience in Africa, as a part of a public development project in Congo, and briefly within the private sector.

1. My work is mainly on planning activities, making an urban masterplan, and taking part in engineering projects for civil engineering.
2. I mostly spend my time coordinating resources.
3. At CERN the technical expertise is already present, no question about that, but this makes it even more challenging to get the right people to talk to eachother at the right times.
4. Priorities are not given from the top management, and the decision making is well-distributed at all levels of the organization. This is also a consequence of the strong organizational culture of the company.
5. Pre-feasibility →Feasibility →?? → tender → execution.
6. Initially a client provides a request. We give a rough estimate, and the client provides his budget. Usually they want more than the budget can give, so we will have to find a compromise and agree upon what is actually necessary.
7. Making estimates is hard, because we don't have the time to do proper research.
8. Communication is important, but we rely a lot on informal procedures. If we have to build the fundament around a concrete block in the soil, we might do it without registering it in documents.
9. There should be a fine balance between informal and formal routines. Documenting is very time-consuming.
10. It is hard to keep track of all changes in a project. Many of them are minor, so it will take too much time.
11. Often things are floating around a bit, but they get assembled upon the time we reach milestones.
12. People are the core of our business, and the management of relations is especially essential.
13. We don't use much documents. We constructed a flow chart for the PM-practices of Civil Engineering, similar to the one for procurement that Pierre made, and this is good for newcomers.
14. As a project manager my task is easy: Deliver within the borders of the iron triangle.
15. In our organisation where money is not the driving factor, it is hard to tell when we are off-track because this is a subtle topic. For a private company negative income means something is wrong, but that does not work for us.
16. I would like to see your final report when it is established.

Candidate 10 – SE/HV-HE

1. To me any work is a project, and I think it should be utilized one method for all things, and not several different. This is based on my reflections after 14 years at CERN.
2. Lack of resources is a common issue, which means that it is important to prioritize.
3. Too much of the work is outsourced. It means that we risk losing the information when the contractor is finished.
4. A very important point for me is that we should not forget about the maintenance and the operation phases in the planning. The total cost of ownership should be taken into account before decisions are being made – if not we risk designing solutions that are not sustainable.
5. This is also in the same approach as LEAN and TPM (total production maintenance).
6. The project manager has to be aware of the phases of operation and maintenance. It means there has to be an information exchange in the early phases of the project.
7. Too often the projects are focusing on the first investment cost, ignoring the total cost of ownership.
8. One of the main problems with the users is that they want everything, but they won't pay for anything. That is of course not possible.
9. Another issue is that project leaders do not know their projects. The definitions are not well-prepared for their purpose, so the leaders should discuss this early on with the technicians to make sure that things will be as planned.
10. In my department the budget for maintenance is continuously decreasing. We don't get sufficient money to do our job.
11. There is an issue with information flow, and this leads to safety issues. When the right people do not speak together, we cannot disclose obvious things that should be very simple to detect. This is something that has to be improved.
12. Safety personnel should be involved early in any project, so as to help calculate the total costs of the project with all important safety measures taken into account.
13. There is no budget for preventive maintenance; it means all we do is corrective maintenance. That is costly in the long run.

Candidate 11 – Deputy.
Currently working on the LIU (**check**) project, which is estimated to come to an end in 2035.

1. A project starts with the approval of an idea. Then the mandate is given, before a project team is assembled.
2. Furthermore the different project management categories are established as WBS, PBS and the defined Working Units.
3. Then EVM would continuously be used throughout the project life to monitor and reveal necessity for changes.
4. The project has weekly update meetings and EDMS-documents are created, in alignment with the current standards, so as to be able to track decision later on.
5. The actual needs and requirements of the project is stated as parameters from the LHC. The purpose of the(/all) project(s) is to deliver a high-quality beam at the entrance of the LHC, so our project starts up with the desire from the LHC. Then we take a look on what and where we have to do changes to cope with the new issues. Often in these kinds of projects we rely on technology to be developed, while other times we have to change current plans because of the emergence of new technology.
6. For decision making these usually made based on consensus. In the end it is the project manager who makes the decision, but usually there is needed so much technical expertise that it at the end of the day will have to be a unambiguous decision.
7. The project does make use of both informal reviews and informal discussions over coffee. However, when we make decisions in this setting I make sure to type an email afterwards, to get it clarified before it is uploaded officially in an EDMS-document. It is very important to track changes, and I try to adhere to good PM-practices as best as I can.
8. How does changes work? An ECR (engineering change request) is filed, if the part is already existing and we want to do an upgrade or another change. If it is a new project, i.e. adding a component upfront for example, we would have to justify in terms of cost/benefits.
9. When controversial choices are made it is VERY important to make documents. This to be able to understand why this (seemingly) ridiculous decision was made back in the past, when one currently can't seem to remember why.
10. Closure
    a. A good finishing of the project should adhere to solid PM-practices. It is important to involve people from the field, and the CDR and the TDR would be extensively used as a reference for the parameters, i.e. we consult the documents to understand why things are as they are.
11. A decision made today is not necessarily good in 5 years, due to the change of technology and the world in general. That is also a reason why we have to make documents. A document can explain the current situation, so that a seemingly bad decision is justified based on the knowledge level at the time.
12. Baseline-definitions: Choice of equipment, are in the start of the projects.
13. Re-baselineing is made annually. This is too often, as it seems one cannot…
14. My unit is mainly working on coordinating projects, getting the right people to speak together, and making sure that the right information is at the right place

at the right time. This is a very time consuming effort, and we also do have support from your office by NN and NN.

15. For the documents it is REALLY important to have an executive summary that shows the usefulness of the document. Nobody has time to read 50 pages, so it should be stated at the beginning what is the main points, and one should be able to find the right paragraph quite easily.
16. Another project I did was the CMGS (**check**)**.** The closure of this project focused on closing the books, making the final documentation, and achieving the deliverables. This was a project where different project management tools where used quite to an extent, so in the aftermath we also gave seminars on the use of these to other stakeholders.

Candidate 12, BE/OP – Deputy
Operation of accelerators and monitoring technical infrastructure.

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1. The introduction of a new injector for the LHC from top management, has led to the necessity to upgrade the projects of our department.
2. The project life cycle starts with the definition of parameters. These will eventually be gathered and lead to the assembly of a conceptual design. During this phase it is also tested how things work.
3. Then it is the technical design report, containing all the detailed specifications.
4. Earned value management is used in the process, but I don't see the need for it when there are so many changes. << A lot of frustration is emerging because of the (lack of) routines of top management in imposing changes to projects >>. It is hard to motivate one self when there are so many changes.
5. Documentation:
    a. TDR
    b. EDMS-documents
        i. Descriptions of equipment
        ii. Specifications
        iii. Minutes.
6. Suggests to contact **[Candidate 2]**
7. **Check** the **R2E.**

Candidate 13 – Section leader at CMI

1. My work has mainly been on design and construction of the LHC, that is the cryostats for the magnets.
2. These need a precision on 0,1mm. The length is 15m, so you can see this is very accurate.
3. The one word that describes our projects is **integration**. It is the most important thing of all, to see how the cryostats can be integrated with the other equipment.
4. Design -> Procure -> Assemble
5. Among the decision taken are:
    a. Define the cross-sectional needs. This could be difficult.
    b. In addition the supporting tools and infrastructure that follows the needs from a has to be developed and planned for.
6. We know the exact position of each object.
7. At the start-up of a project a working group is assembled that consists of technical expertise from the different disciplines.
8. We do not work with standard equipment, so it's sound to say we work in the R&D-frontier.
9. Experience is vital. You cannot plan for everything and you can not document everything, thus experience is crucial for our projects.
10. Challenges
    a. Non-conventional equipment (NCE) with known technology. How to assemble things.
    b. Reduce the price – NCE is very expensive.
11. Large productions are being sourced, while we try to do small stuff ourselves.
12. Documentation
    a. Preserving competence.
    b. Not done in a perfect way yet.
    c. Challenge: We work on projects with a long time-scale; Will the information still be useful in 20 years?
    d. We should only document things that there is a direct use for.
        i. Example, for the LHC we have a documentation of every parts that are in the tunnel, so that we know this when it is going to be dismantled in 20 years time.
13. Managerial challenge: Training engineers that are inexperienced, and thereafter see them leave the company because we don't have work for them.
    a. So the know-how of technicians and the keeping of core competencies is particularly difficult.
14. Learning by experience is important – not everything can be taught.

Candidate 14 – GS/ASE
Section leader. Has been at CERN for 18 years, worked also as project manager.

1. His section is mainly developing different systems for the users; EDMS, ADAMS (a system providing access to the different doors at LHC, by assembling information from different documents to check the permissions.)
2. His department is mainly constituted of IT-professionals.
3. The start-up of a typical project for us is that a user comes to us with a need of his. Then we will try to translate this need into a system that can handle his problem.
4. There is difference between the functional needs and the technical needs of the users.
    a. The technical need could be that the user states needing a database for storing several kinds of information.
    b. The functional need… … … (no answer..)
5. We use a system called BPMN (Business Process Management Notation) to represent processes. (**check**)
6. If it is possible, we avoid to re-invent systems that users require. If we have a system that is 90% compatible with the demand of the users, we usually try to ask whether the last 10% is really important. Often it is not, and it makes us able to use already existing systems.
7. We do provide different engineering tools, and do not work that much (if at all) with the physicists.
8. We also do not deal with different planning tools, since we merely have interest in the technical data of each project.
9. For the communication we follow a handbook that is called ITIL (**check**). This is mainly concerned with service management and the idea of having one center of communication that could direct you to whoever you need to get in touch with. The guide was developed as a response from the British need for adding bombs to planes during the war against Argentina, when bombs and airline personnel did not talk together.
10. It is important to emphasize that there is a difference between the users and the customers. Now we usually have a "customer" in between our department and the user. The client often has to pay for what he wants, and will as such be able to prioritize his needs, unlike a user that will just ask for everything. When there is a customer-joint in between, we save a lot of time trying to convince the users of the need of priorities, and additionally the users have easier to understand someone speaking their own language rather than some "computer geeks".
11. We do prioritize a lot, and it all depends on the users. Safety and maintenance of operations usually have higher rank than the creation of new equipment. People have been able to cope so far, so they can wait a bit more.
12. Documentation is very important, but not everyone is very interested in this. We do have black and white lists of users, but I am not going to provide you any names here.
13. Some users tell us that they will not make a specification of their needs before we can tell them whether the project is feasible or not. But how to tell if a project is feasible without specifications? This creates an evil loop.
14. So the cycle starts with the user needs →software specifications →Planning schedule →Priorities → Technical Documents.

15. It is of major importance to follow the rules of documentation. When I solve a problem I do not want to solve it twice. That is, if I have solved it once, I would not want to spend another two days to solve it again in one year because I do not remember. That is, I always document how I have been doing things.
16. Miscommunication is a very common issue in our work. That is why meetings are important, and to clearly state what has been decided on the different occasions. If two parts both think that it's the move of the other part, nothing would happen.
17. My experience is that even though most of my documentation does not prove useful later on, the parts of it that actually does pays back for the time it takes to file it.
18. The key sentence of project management is "no surprise". My experience is that people would rather know if something is not delivered on time as early as possible, than being kept out of the loop.
19. One major issue at CERN is to get people to speak the same language. If for example an elevator is named AA00, h-? or 123 depending on who is speaking, how would we know that we are talking about the same thing? Reviewing the standards would therefore be beneficial.
20. Having one "quality office" is something that should be investigated; keeping all information for all necessary actors in all projects.
21. There should be a standard methodology for the execution of projects.

Candidate 15
Position: Different ones, currently section leader at RF; 20 years at CERN.

1. The projects usually start with a feasibility study. That is a concept document is being designed, prototypes are being made, and they are sent to the sponsors for approval.
2. For me the project actually starts with the production.
3. But before that there is a tendering phase, with certain purchase rules etc, and it is important to follow up on what is being done additionally.
4. Then there is an acceptance of the components that are being procured, before the operations phase (with all that brings) follows.
5. For the decommissioning there exist certain problems related to radioactive facilities. Many parts cannot just be scrapped; they need to be stored until the point where this can be done. For small projects this is usually not a problem, but for very large equipment it is not very easy to find space to store it whilst it decommissions.
6. Concept report: Contains the different parameters that are based on the needs of the actual physicists. Then the engineers make the design more in detail, before the actual construction of the prototypes starts.
7. The size of the project does not necessarily give rise to major technical issues, but the coordinating of personnel and especially handling of knowledge loss is a major issue.
8. Among the major documents that are useful in the project are the MTF (**check**) and the purchase rules. There are very strict ways for how to handle procurement in terms of tendering process, and price is usually the decisive factor.

Candidate 16 - (GS/ASE)

1. We are providing tools for processes. Mainly CAD.
2. People come to us for two reasons:
    a. They want to design and manufacture something for an injector.
    b. The quality documents tell them to come to our department.
3. Mainly the LHC-QA-plan is used.
4. We use our existing tools as much as possible, so as to avoid starting all from scratch in designing the work. It is important to try to have some overall tools, so that all systems can speak to each other.
5. Trying to understand the need is the first phase; People usually need something totally different from what they believe that they need. → Designing a prototype and testing it in a project environment. → Implement IRL. → Give the necessary user training → Support the users throughout the life of the system.
6. We are not using the TDR but we have a supporting role in the development of it.
7. Documentation: Changes are not always documented. It depends a lot on the nature of the change. It is a nice thing to state in theory that we shall document everything, but I mean – there are a lot of stop signs on site and speed limits are 50km/h. People don't always follow them. Handling people is a great challenge, since you never know what to expect.
8. A quick-fix should be avoided. If you don't have the proper time to fix it now, you will not get more time in the future. Do the work well the first time. One of the lessons learned is that a "temporary" solution often becomes a permanent or at least a medium-to-long-term solution.
9. Natural resistance to change is a problem when it goes for planning the duration of some kinds of projects. You never know how smooth it will go.
10. People do not do sufficient documentation, because they don't like to document things. This could be because it is less innovative, but also as a response to eventually being replaced.
11. At the small projects it is important with:
    a. Technical expertise → to a detailed level. No helicopter-planning.
    b. Motivation.
    c. Delegation.
    d. Planning & Delivery.
12. Quality Assurance is very important.
    a. How to manage and how to work in detail.
13. There is no plan for CERN so the one of LHC is used, however it is not detailed enough for the phases after the design. I.e. it does not take into account installations or procurement f.ex.
14. There should be a plan.

Candidate 17 – Engineering group; Head of Department Office.
15 years at CERN. Certified in HERMES and PRINCE2; now working on the PMP-Certification.

1. The main difference between the PRINCE and the HERMES is the structure. For the former the project leader has the responsibility for the entire project process; human resources organization, financial organization and organizational resources.
2. In HERMES there is a steering committee above the project manager, which the pm is part of, that gives the project management a set of resources, and the pm is then responsible for making a plan on how to reach the targets of the work within the frames of these resources.
3. So the process goes as following: Needs are identified, and a project plan is evaluated. This is then taken back to the steering committee for quality assurance. The EVM is a very useful tool along the process, since it is the earliest indicator for a malfunction in your system.
4. The initialisation phase is where the project is specified in some kind of detail, and the decision about a (no) go is made in the first place.
5. Define the activities in more detail: What is going to be done? Who is going to be in charge? When is it going to be finished? How much would it cost?
6. This will in detail eventually lead to a proposal.
7. At CERN there are strict purchase rules, where the lowest bid usually wins, and this can create issues with subcontractors/–suppliers.
8. In the finalisation phase there is usually a wrap up, i.e. quality assurance is being made to make sure the product fulfils the conditions, all documentation is assembled, and making sure that operations can go on as requested.
9. The lifecycle could thus be stated in terms of documents: Proposal→ Mandate/Roadmap → Project management plan → Quality Assurance Plan.
10. The major difference and the major challenge of the CERN projects compared to private companies is that it is handling radioactive material. A stop in production to do maintenance can usually be done quickly in the privat sector, but for these kinds of projects, the equipment cannot be touched until a couple of weeks or even months, because of the radioactive nature of the material.
11. It is important to keep a fine balance between different parts.
12. For the lifecycles they are all the same to me in one or the other way. The PMI-Lifecycle is always there as a foundation, although your supervisor would adhere to the HERMES-method. To me they are all the same, with only minor modifications. However the HERMES-method is probably more suited for the CERN-projects, whereas the PRINCE2-method would be more applicable in a private company.
13. He concretized the lifecycle with exemplifying how to build a major air balloon to fly over CERN to show the site from above to visitors. First it is decided that there is a need for it. Then the intended project manager will get a certain amount of resources. The PM will have to go through the detailed design, and see if it is possible to fulfil this within the constraints of the iron triangle. Then he will give feedback to the steering committee if it is not possible, with his modifications. Then some negotiations occur, before the startup of the project. Contracts are being signed, making it difficult to proceed. When 20% of the project is done, 80% of the resources are COMMITTED.

14. Additionally we discussed some business strategy, among other the strategy of Apple and luxury products. They create a need that is not there already; people can wait outside a store for week for the latest product. Good marketing.

Appendix C

Selection of Topics

The following three pages show the method I used to figure the frequency of topics in the interviews. If a topic was present in an interview I marked it with a 1 in the table. Each new topic was introduced downwards. In the end formulas were used to calculate the total frequency and topics where chosen accordingly.

Candidate	Summary	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	Summary							
	New topic proposed																			12	11	10	9	8	7	6
1	Several project types.	1									1								2							
	Terminology.	1				1					1				1		1		5							
	Project engineer is a project manager.	1																	1							
	Life cycle.	1		1	1			1	1	1		1	1		1	1	1	1	12	Life cycle.						
	Relying on experience		1		1		1			1	1			1					6							Relying on experience
	Knowledge conservation.	1					1												2							
	PM-responsibilities.	1								1		1							3							
	Project initiation	1	1				1	1	1	1	1	1	1		1		1		11		Project initiation					
2	Procurement rules are rigid.		1						1							1		1	4							
	Documentation limits reactivity.		1							1									2							
3	Documentation necessary.		1	1	1		1	1	1						1		1		8					Documentation necessary.		
	Changes lead to sub-projects.			1															1							
4	Challenges with research projects				1									1					2							
	Planning for closure of large projects obsolete				1														1							
	PM methods not suited for small projects.				1														1							
	EVM is a good tool.				1	1	1		1			1						1	6							EVM is a good tool.
6	No formal startup procedures for projects.						1	1											2							
	Proactiveness			1			1		1		1			1	1			1	7						Proactiveness	
	New technology.						1		1			1		1					4							
	No united methodology.						1	1			1								3							
	Project leader vs program leader.						1		1										2							
7	HERMES-methodology.							1											1							
	Reduce reverse engineering.							1											1							
	Lack of QA-plan							1	1								1		3							
8	Project starts with user requirements								1	1	1	1			1			1	6							Project starts with user requirements
	Centralized knowledge / lack of resources.								1		1								2							
	Early risk analysis								1										1							
9	Resource coordination									1	1	1							3							
	Strong organizational culture									1									1							
10	Centralized methodology										1	1			1		1		4							
	Lack of information flow										1								1							
11	Documentation is very important											1		1	1				3							
12	EVM useless when change frequency is high												1						1							
13	Integration													1					1							
	Learning by experience													1					1							
14	ITIL- handbook														1				1							
	Difference between user and customer														1				1							
	Prioritization														1				1							
	Reduce miscommunication														1				1							
15	Project starts with production															1			1							
	Hard to close-down radioactive projects															1		1	2							
16	Hard to get people to document.																1		1							
	Avoid temporary solutions																1		1							
	Resistance to change																1		1							
17	Project manager role in different methodologies																	1	1							
	--																									
	Summary of aspects from each candidate	7	5	4	7	2	10	8	12	8	11	9	3	7	12	4	9	7								

Candidate	Summary	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	Summary			
	New topic proposed																		**0**	5	4	3
1	Several project types.	1									1								**2**			
	Terminology.	1				1					1				1		1		**5**	Terminology.		
	Project engineer is a project manager.	1																	**1**			
	Life cycle.	1		1	1			1	1	1		1	1		1	1	1	1	**12**			
	Relying on experience		1		1		1			1	1			1					**6**			
	Knowledge conservation.	1					1												**2**			
	PM-responsibilities.	1								1		1							**3**			PM-responsibilities.
	Project initiation	1	1				1	1	1	1	1	1	1		1		1		**11**			
2	Procurement rules are rigid.		1						1							1		1	**4**		Procurement rules are rigid.	
	Documentation limits reactivity.		1							1									**2**			
3	Documentation necessary.		1	1	1		1	1	1						1		1		**8**			
	Changes lead to sub-projects.			1															**1**			
4	Challenges with research projects				1									1					**2**			
	Planning for closure of large projects obsolete				1														**1**			
	PM methods not suited for small projects.				1														**1**			
	EVM is a good tool.				1	1	1		1			1						1	**6**			
6	No formal startup procedures for projects.						1	1											**2**			
	Proactiveness			1			1		1		1			1	1			1	**7**			
	New technology.						1		1			1		1					**4**		New technology.	
	No united methodology.						1	1			1								**3**			No united methodology.
	Project leader vs program leader.						1		1										**2**			
7	HERMES-methodology.							1											**1**			
	Reduce reverse engineering.							1											**1**			
	Lack of QA-plan							1	1								1		**3**			Lack of QA-plan
8	Project starts with user requirements								1	1	1	1			1			1	**6**			
	Centralized knowledge / lack of resources.								1		1								**2**			
	Early risk analysis								1										**1**			
9	Resource coordination									1	1	1							**3**			Resource coordination
	Strong organizational culture									1									**1**			
10	Centralized methodology										1	1			1		1		**4**		Centralized methodology	
	Lack of information flow										1								**1**			
11	Documentation is very important											1		1	1				**3**			Documentation is very important
12	EVM useless when change frequency is high												1						**1**			
13	Integration													1					**1**			
	Learning by experience													1					**1**			
14	ITIL- handbook														1				**1**			
	Difference between user and customer														1				**1**			
	Prioritization														1				**1**			
	Reduce miscommunication														1				**1**			
15	Project starts with production															1			**1**			
	Hard to close-down radioactive projects															1		1	**2**			
16	Hard to get people to document.																1		**1**			
	Avoid temporary solutions																1		**1**			
	Resistance to change																1		**1**			
17	Project manager role in different methodologies																	1	**1**			
	--																		**0**			
	Summary of aspects from each candidate	**7**	**5**	**4**	**7**	**2**	**10**	**8**	**12**	**8**	**11**	**9**	**3**	**7**	**12**	**4**	**9**	**7**	**0**			

Candidate	Summary	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	Summary		
	New topic proposed																		**0**	2	1
1	Several project types.	1									1								**2**	Several project types.	
	Terminology.	1				1					1				1		1		**5**		
	Project engineer is a project manager.	1																	**1**		Project engineer is a project manager.
	Life cycle.	1		1	1			1	1	1		1	1		1	1	1	1	**12**		
	Relying on experience		1		1		1			1	1			1					**6**		
	Knowledge conservation.	1					1												**2**	Knowledge conservation.	
	PM-responsibilities.	1								1		1							**3**		
	Project initiation	1	1				1	1	1	1	1	1	1		1		1		**11**		
2	Procurement rules are rigid.		1						1							1		1	**4**		
	Documentation limits reactivity.		1							1									**2**	Documentation limits reactivity.	
3	Documentation necessary.		1	1	1		1	1	1						1		1		**8**		
	Changes lead to sub-projects.			1															**1**		Changes lead to sub-projects.
4	Challenges with research projects				1									1					**2**	Challenges with research projects	
	Planning for closure of large projects obsolete				1														**1**		Planning for closure of large projects obsolete
	PM methods not suited for small projects.				1														**1**		PM methods not suited for small projects.
	EVM is a good tool.				1	1	1		1			1						1	**6**		
6	No formal startup procedures for projects.						1	1											**2**	No formal startup procedures for projects.	
	Proactiveness			1			1		1		1			1	1			1	**7**		
	New technology.						1		1			1		1					**4**		
	No united methodology.						1	1			1								**3**		
	Project leader vs program leader.						1		1										**2**	Project leader vs program leader.	
7	HERMES-methodology.							1											**1**		HERMES-methodology.
	Reduce reverse engineering.							1											**1**		Reduce reverse engineering.
	Lack of QA-plan							1	1								1		**3**		
8	Project starts with user requirements								1	1	1	1			1			1	**6**		
	Centralized knowledge / lack of resources.								1		1								**2**	Centralized knowledge / lack of resources.	
	Early risk analysis								1										**1**		Early risk analysis
9	Resource coordination									1	1	1							**3**		
	Strong organizational culture									1									**1**		Strong organizational culture
10	Centralized methodology										1	1			1		1		**4**		
	Lack of information flow										1								**1**		Lack of information flow
11	Documentation is very important											1		1	1				**3**		
12	EVM useless when change frequency is high												1						**1**		EVM useless when change frequency is high
13	Integration													1					**1**		Integration
	Learning by experience													1					**1**		Learning by experience
14	ITIL- handbook														1				**1**		ITIL- handbook
	Difference between user and customer														1				**1**		Difference between user and customer
	Prioritization														1				**1**		Prioritization
	Reduce miscommunication														1				**1**		Reduce miscommunication
15	Project starts with production															1			**1**		Project starts with production
	Hard to close-down radioactive projects															1		1	**2**	Hard to close-down radioactive projects	
16	Hard to get people to document.																1		**1**		Hard to get people to document.
	Avoid temporary solutions																1		**1**		Avoid temporary solutions
	Resistance to change																1		**1**		Resistance to change
17	Project manager role in different methodologies																	1	**1**		Project manager role in different methodologies
	--																		**0**		
	Summary of aspects from each candidate	**7**	**5**	**4**	**7**	**2**	**10**	**8**	**12**	**8**	**11**	**9**	**3**	**7**	**12**	**4**	**9**	**7**	**0**		