# Optimization regarding the system engineering process of mechatronic systems, in consideration of the transparency and the development efficiency

## Master Thesis

For obtaining the
academic degree,

Master of Science,
Diplom Ingenieur

Master study: Product science of Management

Submitted at the

## Technical University of Graz

Supervisor

Univ. Prof. Dr. Stefan Vorbach

Institut für
Unternehmen
sführung und
Organisation

Werfen, April 2017

## Acknowledgement

Firstly, the completion of this thesis could not have been possible without Palfinger Europe GmbH, who gave me continuous support and guidance through the course of this thesis. Their contribution is sincerely appreciated and gratefully acknowledged.

Furthermore, I would like to take this opportunity to thank my supervisors: Mr. Sebastian Schinwald and Mr. Bernhard Wielder for their expert knowledge and understanding spirit. I would also like to convey my sincere gratitude to Mr. Uni. Prof. Dr. Stefan Vorbach for supporting me in literary and comparative studies.

Moreover, I would like to thank my fiancé Michaela Rainer, who always supported me through thick and thin.

Lastly, great thanks to my family for their unconditional support, without which this thesis was not possible.

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# I. List of abbreviations

AD Degree of Difficulty Assessment

CAN Controller Area Network
CIT Crane Innovation Team
CON R&D Construction
CS *Corporate Service*

DIN Deutsches Institut für Normung
DOMM Degree of maturity model
DP Development Phase

EC External Consultant
EIRMA European Industrial Research Management Association, European Industrial Research Management Association
EMEA *Europe Middle East Asia*

FMEA Failure Methods and Effects Analysis
FSD Functional Specification Document, *Siehe* Functional Specification Document
FSP Functional Specification Phase

HoQ House of Quality
HW Hardware

INCOSE International Council of System Engineering

LU Lead User:

M Montage
MCC Mounting Control Center
MD Managing Director
MEC R&D Mechatronic and Patent Management, *Siehe* Mechatronic department and Patent Management
MV Markt Vorteil

NASA National Aeronautics and Space Act

PDP Pre-Development Phase
PE Product Engineering
PEP Product Engineering Process
PLO Project Lean Office
PM Product Management
PS Prestudy

QA Quality Assurance
QFD Quality Function Deployment

R&D Research and Development
RM Requirement Management
ROI Return On Invest

RSD  Requirement Specification Document, *Siehe* Requirement Specification Document
RSP  Requirement Specification Phase

SE  Systems Engineering
SEMP  system engineering management plan
SLP  Series Launch Phase
SP  Strategic Purchasing
SV  Strategischer Vorteil
SW  Software
SysEP  System Engineering Process

TP  Testphase
TRL  Technology Readiness Level
TU  Technische Umsetzbarkeit
TÜV  Technischer Überwachungsverein

VDI  Verein Deutscher Ingenieure

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# IV. Abstract

Driven by the globalization and the dynamic market demands for the development of systems as well as the reduction of complaints after the serial launch of a product, the mechatronic department and patent management of the Business Unit Crane within the Palfinger Business Area EMEA, caused the necessity for the increase of the development efficiency regarding the time to market and the sufficient use of resources through the development of systems and innovations within the Business Unit Crane. Therefore the evaluation of the actual system engineering process of the mechatronic department was analyzed and through the discussion within Stakeholder surveys and workshops the project potentials and their related process specific criteria were determined. The stakeholders who are involved into the development and management of systems within the company were first in surveys and later in workshops interviewed. Based on their opinion regarding the optimization possibilities the process specific criteria, which involve the requirements a system engineering process, should have and the considerations about the transparency regarding the measurability of the development maturity of a system and the necessity of increasing the development efficiency were discussed. The overall goal should be the increase of competitiveness and the maintenance of the high standard of the development of investment- or premium goods. This requires beside the collection of the Stakeholder-process related criteria the discussion of the topic with the literature as well as the evaluation of the overall system engineering process and the determination of a new hybrid process model. The first step within this thesis is to gather a basic overview about the systems engineering theme. The topic of systems engineering according to Arthur Hall and INCOSE will provide the basic understanding and nomenclature. The importance of the development of products and the related systems should build on the discussion of the process model of Mr. Kohnhauser which provides the idea of the product engineering process which is very similar with the actual situation of the Palfinger Case Study. The question what makes an engineering process efficient is discussed on the basis of this product engineering approach. From the literature there exist several definitions of key performance indicators which are enhancing the development efficiency. The following the crucial potential for the development and valuation through the approach of requirements management is discussed which shows that there are several methods for the assessment of requirements which provides further possibilities for the prioritization and validation of requirements through the system engineering process. The management of requirements is a very important and successful tool for the creation of efficiency and transparency within a development process. Because the problems which arose during the development of systems were always enhanced through the change or the implementation of functions or requirements within later development stages when the system should already be at a point of robustness. The point of robustness determines the development maturity state of a system which defines the concreteness in terms of requirements, functions or the system architecture etc. to ensure the development efficiency through the rest of the process. The theoretical part closes with the topic of technology-management which provides a clear definition of different development stages within the development of technologies which could be further assessment possibilities to increase the transparency regarding the measurability as well as the definition of one coherent process understanding of all involved Stakeholders.

# 1 Introduction

## 1.1 Problem

Business enterprises face many challenges in the industry such as rapidly changing market requirements, constantly increasing cost pressures and demands for innovative solutions for high quality products. In addition, constantly changing competitive conditions and increasing globalization are also adding to these challenges. (Rummel, 2014 p. 21)

In order to cope with international competition, it is essential to use technical knowledge and entrepreneurial resources optimally. (Spath, et al., 2008 p. 10) The development of technical systems is faced with major challenges. According to (Michels, 2013), the traditional development methods are often no longer sufficient to react to the high technical and market-related requirements. A differentiation can only be achieved if the company succeeds at an early stage in the development phase of new products or technologies and thereby bringing technological systems with promising innovations to new markets. (Ganz, et al., 2012 p. 58)
Shorter development time and product lifecycle as well as a higher expectation of the customer in terms of quality and costs are the primary reasons of the global competition. To strengthen the role of the company in the competition field the organization should be able to shorten the development time of products. (VDI 2206, 2004 p. 3)

The described challenges make it clear that the development of technical systems increases the scope of competences and thus also the number of resources required for development. A structured methodological approach is necessary to take all relevant aspects into consideration while at the same time effectively and efficiently achieving a market-ready solution. At the same time, it is necessary to create a common foundation for the cooperation of all parties involved, as well as to create a common understanding so that it can be developed with united forces. (Michels, 2013 p. 172)
Even during the early phase of the product development, in which the operational capability of technological developments can be determined only to a limited extent, the need for methodological approaches for the development of these systems must already be available. (Spath, et al., 2011 p. 32)
Driven by new technologies in microelectronics and software technology, the dynamics in the development of technical systems are growing rapidly. It is clear that machines are becoming more and more intelligent and can adapt themselves to new environmental conditions and requirements. At the same time, their range of functions, their reliability and their efficiency are growing at great pace. Therefore, there is a need to methodically support the development process for technical systems in order to be launched quickly and efficiently. In many cases, the early phases are crucial during a development process. (Michels, 2013 p. 171) In addition to the methodical development of technical systems and innovations, standardized development processes as well as their validation by the management of technologies and requirements form the basis for the successful development. In addition to system engineering, these topics form the basis for the consideration of the development quality of a system development process.
The increase of complexity and the fast change of the market regarding to the development of systems made it clear that a defined and a well-structured system engineering approach is essential. A serious issue is to invent a standardized system engineering approach that can effectively cope with lack of planning, which lead to difficulties in performance, design and also expensive modification of the system. Moreover, these “last-minute-modifications” introduces a high impact in schedule and costs. Therefore, the detailed planning of a problem solution with the system engineering approach was necessary to reduce this high cost impact by the reduction of those modifications. (Azimi, et al., 2011 p. 9) Based on the importance of the efficient development regarding systems engineering processes the company Palfinger was evaluating the system engineering process of the Mechatronic

department. The companies target was to generate an actual point of view of the current system development situation with respect to the synchronization scenario of the SysEP into the product engineering process and further to evaluate via stakeholder surveys and workshops the process specific criteria and the project potentials regarding the optimization of the SysEP. The result of the Case Study should be a hybrid system engineering approach to fit the requirements of the company.

## 1.2 Objective

The R&D BU Crane department of Mechatronic and Patent Management started with the evaluation and analysis of the actual system engineering process. The existing process was not fitting anymore to the expectations of the company. Therefore it was necessary to conduct a detailed investigation into the whole process.. For the evaluation of the work, the major process specific criteria of the whole process should have been discovered, in all important divisions and with the survey of all involved stakeholders within the development of a system. That means every important step of the process should be proved on its necessity and purpose. Another Task is the evaluation, regarding to the development efficiency of the SysEP and the setting of the right measurements for the future to increase the efficiency as well as the development quality. A further investigation is necessary for a detailed discussion of the actual synchronization scenario of the SysEP and its integration into the product engineering process. For instance the department of the Business Unit Crane is developing a new generation of a control system, which should be integrated after a specific process time into the product development process. The question is how far the development maturity of the system should be, to guarantee the crossover, from the SysEP into The PEP seamlessly. Furthermore, regarding to the Optimization of the SE-process, agile Models as well as hybrid process development models should be considered for the solution finding. The specification of flexibility through development of System engineering is a crucial issue of the Company. That means how long, is it possible to stay high flexible and when is the point of return reached. It is necessary to figure out when the stage is where the pros and cons of the agile approaches cross, so the linear modus operandi can be initiated. The implementation of flexible approaches, in the early stage of the SE, is one of the major requirements of the organization, which must be figured out.
Based on the objective of the master thesis there are three research questions carried out which represent the guideline for this thesis. These questions are mentioned as follows:

- **How can the development efficiency regarding to the time to market be ensured?**
- **How could the topic of agility be implemented in the SysEP?**
- **What affects the successful integration of the engineered system into the Product Engineering?**

These questions build up the basis for the master thesis, since the master thesis is divided in a theoretical and a practical part, the first half of the thesis is related to the literature which is important for the basic understanding of the practical part and which allows to determine the theoretical point of view on the optimization regarding the System Engineering Process. The theoretical part is followed by the case study which will be discussed in the second half of the thesis. For a better overview of the course of action the next chapter provides a detailed overview of the master thesis.

## 1.3 Course of action

The course of action of this master thesis is basically divided in two parts. The first part is dealing with the theoretical point of view and starts with the basic understanding of the theme systems engineering. In the first chapter the basic principles of the systems engineering based on the literature of (Hall, 1962) are discussed. The basis for the understanding of the topic of systems engineering which is mostly related to the approaches and definitions of (Haberfellner, et al., 2012) and INCOSE were compared with each other and discussed on the basis of (Schäppi, et al., 2005) and (Ehrlenspiel, 2006) on the part of the PEP. For the basic understanding of the Palfinger specific definitions for the later discussed case study, the traditional product engineering process is represented in chapter 3, which is the main part of the theoretical part. Chapter 3 comprises two important subchapters which are related to the topics of requirement management and one of the key success phases of the Product Engineering Process, the Requirements Specification Phase. These two subchapters are important, regarding the later discussion of development efficiency of the system engineering process in the practical part. The theory finishes with, the Technology Management. Chapter 4 answers the question regarding the validation of technologies which will be synchronized after the development into a product and the process specific measurability with suitable assessment methods. The second part is related to the Case Study within the Company Palfinger and focuses on the determination process from the initial situation of the engineering of systems in the mechatronics department and carries out through the stakeholder surveys and workshops which optimization measures will be implemented. The practical part will start with a brief introduction of the company and the determination of the field of research. The field of research provides basically the overview of how the system engineering process is integrated into the process landscape of Palfinger. Based on the field of research the procedural method of the case study is explained with more detail and deals with the actual system engineering situation and closes with the output of the stakeholder surveys.

# 2 Systems Engineering

Under the concept of system engineering, defined for the first time by (Hall, 1962) at the beginning of 1960, a framework is summed up which has emerged from these challenges and contributes to their solution. Systems engineering is a concept that is perceived as more and more important. Until now, there is neither a clear definition of the concept nor a clear naming of the individual steps up to the solution. It is only a basic understanding of how complex and interdisciplinary development projects are to be tackled. Systems engineering puts the holistic and integrative approach as well as the synchronization of all aspects of the system into the forefront. In addition, the SE provides a set of different methods and approaches to efficiently manage characteristic tasks for the structuring and elaboration of a technical system. (INCOSE, 2006)

This chapter provides a brief overview about the discipline of Systems Engineering (SE), divided in 4 parts and beginning with the first part, which comprises an overview about the basic terms and definitions in Systems Engineering. The second part deals with the basic idea and the structure of the SE approach. The third part focuses on different characterizations of system types. The target is the basic understanding of how an approach could be implemented properly. This chapter finishes with the fourth and last part which is focusing on the example of a process model.

## 2.1 Systems Engineering Overview

This section will basically discuss the history and the evolution of SE regarding to the increase of complexity as it is today. System Engineering still evolves within a fast speed. This section will also give a brief overview about the definition of all SE terms. The basic tasks of Engineers will also be outlined. (INCOSE, 2004 p. 9)

Back in the late 1950s, extreme pressure was placed on the military services and their civilian contractors for developing nuclear tipped missiles and orbiting satellites. Therefore the engineers developed techniques and tools for support systems and project management. (INCOSE, 2004 p. 9)

Engineering has always been characterized by the development of new facilities and technical equipment. In the course of interplay, task analyzes and syntheses of new structures are carried out to complete the tasks, these are called in general systems. (Bruns, 1991 p. 1) Beginning with the computer age, the detailed structure of system elements became also very important due to the fact that systems became more complex. Over the decades a lot of lessons were learned out of the evolution of SE. (INCOSE, 2004 p. 9)

System Engineering was published in the early 1960s by Arthur Hall. System Engineering was evolved and standardized more and more for the specification of requirements, interface and control documents, design reviews and more. (INCOSE, 2004 p. 9) The systems were formerly of a simple technical type (e.g., tools). As the demands grew, the systems quickly grew through the construction of larger systems, the involvement of people, the development of computing systems, etc. Early on, questions about the description of the systems and the delineation of the systems to the system environment emerged. With increasing system size, the complexity of the systems grew because, first they became more complex and, second the system development process became more uncertain. (Bruns, 1991 p. 1)

As a result of globalization, competition between the organizations has increased, which has pushed the companies to reduce costs and shorten development times. The lack of clarity in the determination of requirements and the lack of planning are the main factors for the development of SE. (Azimi, et al., 2011 p. 3) A crucial issue out of those lessons where the implementation of the reliability of a system. Over the years SE includes all phases of engineering, technology product development, procurement, manufacturing, testing and quality control. (INCOSE, 2004 p. 9)

For many years important aspects of project management were integrated into SE. SE became more detailed and complex. The integrated elements came out of many disciplines, for instance, system modeling, requirement development, decision analysis, project management, industrial engineering, risk management, cost estimation and many more. The SE became an overall discipline for the development of products and services. A crucial issue is further the integration between system elements. The quantitative approach of SE comprises, involving trade-off, optimization, selection and integration of products of many engineering disciplines. (INCOSE, 2004 p. 10) Also the controlling and integration includes tasks such as project management, configuration management and cross-project requirements management. System management also considers change management and traceability as important tasks of requirements management. (Schienmann, 2004 p. 23) The requirements management will be discussed, within this thesis, in more detail.

Also the questions of task fulfilment and the responsibility for it came into the forefront. From this situation, the system engineering, which engages in the engineering sciences and the neighboring disciplines, developed in the sense of coherence. System technology provides a common formal language that allows engineering methods to be transferred to neighboring areas and vice versa, thus providing a viable foundation for interdisciplinary problem solving. The main focus of system engineering is to bring development projects to the realization and to the successful operation. (Bruns, 1991 p. 1) In the last decade the purpose of SE spread in terms of covering more activities and to handle the creation of complex systems, including hardware and software. It covers all activities of the planning, development, implementation and operation of a system over its entire life cycle. (Schienmann, 2004 p. 22)

**Definition of System Engineering:**

For the definition of system engineering there exist in the literature many versions. An accurate formulation exists from (Eisner, 2002): “Systems engineering is an iterative process of top-down synthesis, development and operation of real-world systems that satisfies, in a near optimal manner, the full range of requirements for the system.” (INCOSE, 2004) Defines SE “as an approach for the successful development and realization of systems.”

The Basic idea of SE is a concept which is representing a methodology for the development of problem solutions. This differs between an existing situation and a wanted situation. SE describes the way of problem solving, between these two situations. How efficient a solution of a problem could be identified depends on different factors. Some of those factors are for instance, specialized knowledge, experience, method of procedure, knowledge of the current situation and many more. (Haberfellner, et al., 2012 p. 27)

In the literature SE is discussed as a guideline for the successful system realization which was enabled due to the reason that in the last decades the complexity and the standard of technical developments were increasing. Thus the need for a standardized process for the engineering of systems was given. Therefore procedural methods were defined by famous scientists like (Hall, 1962) in the 1960s. These methods were developed over the years and modified. A leading book for the basic understanding and development of such methods were written by (Haberfellner, et al., 2012). In the latest version the basic idea of SE and different procedural methods and also what purpose those methods have, are described.

The method of the SE is to identify critical factors, examples are shown in Figure 2-1, and to relate them in a proper way. Important for the problem solution finding is that this process will be not interrupted or constricted by the method itself, because the method is not the only way to solve a problem. (Haberfellner, et al., 2012 p. 27) The methodology of SE must be seen as a guideline through the problem lifecycle and this method and its structure will be discussed in chapter 3, the System Engineering Process. In the following subchapter, Basic Definitions, the terms and the needed basic knowledge about System Engineering will be discussed.

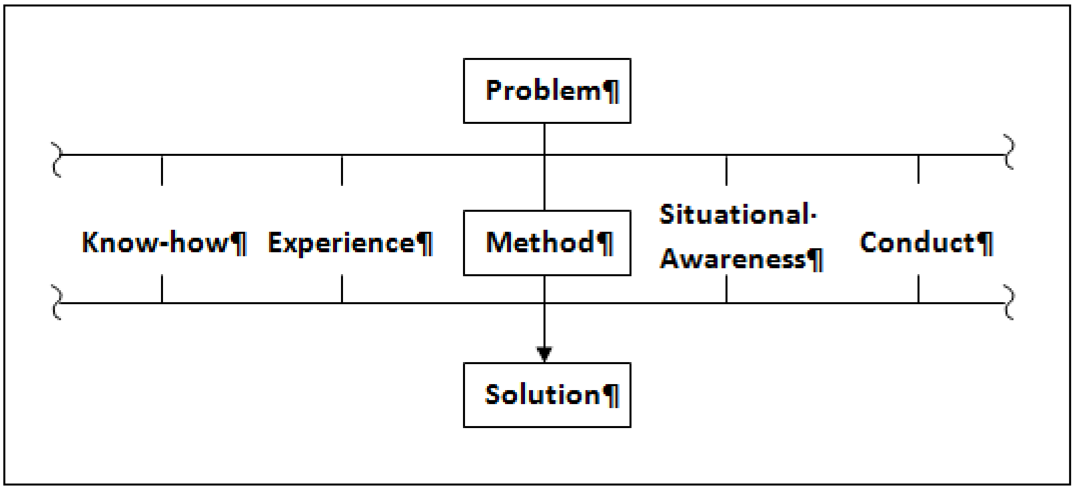


**Figure 2-1: SE as a procedural method for the problem solution: (Haberfellner, et al., 2012 p. 28)**

(Azimi, et al., 2011 p. 6) determines another version for the SE problem solving. This approach is considered by the SE as follows:

- Locate the Requirements and identify the problem and possible solutions
- Develop a conceptual model
- Design and formulate a physical or virtual model based on the requirements and available resources
- Create attesting procedure with knowledge interference
- A options to procedure with knowledge interference
- Analyze the various available options to resolve the current issue
- Pay attention to feasibility in relation to technicality, cost and time constraints

This is a standardized process for the problem solution development of a system and is used for the project management as a guideline for SE. The base of a successful system realization is built on appropriate know-how, proper project coordination and the right strategic approach to handle the development method. (Azimi, et al., 2011 p. 6)

### 2.1.1 Basic Definitions

The term system is rooted to the Greek word "systema" which means "an organized whole". A system defines after (Hall, 1962) a set of elements and their relationships regarding to their specific attributes. All these elements are part of the system. Every element outside the system comprises the systems environment. The complexity if a system is strongly depending of the components (Kauffman, 1980).These components are linked to each other and perform many functions which provide the desired purpose of the system. According to (Magee, et al., 2002) a system could be characterized by several different categories. Including natural, man-made, static, dynamic, simple, complex, reactive, passive, precedented, unprecedented, safety-critical, non-safety-critical, highly reliable, non-highly reliable, high-precision, non-high-precision, human-centric, nonhuman-centric, high-durability and non-high-durability systems. (Azimi, et al., 2011 p. 2)
What is a System? "A system can be broadly defined as an integrated set of elements that accomplish a defined objective". (INCOSE, 2004 p. 10) The definition of the term "System" is driven by the perspective of the person from the different engineering disciplines. Therefore a software engineer could refer a system to a computer program as a system. The electrical engineer would define complex interface which is solving a specific problem. (INCOSE, 2004 p. 10)
(Beer, 1985) defines the system as a word that stands for connectivity. This means the accumulation with each other in related parts. A system includes a whole system with related parts and forms with them a whole.
A system therefore consists of elements that are related to one another. At the beginning, the problem formulation and its solution is important in system development. It is important to keep the

development risk as low as possible. An essential task of the system engineer is the identification and measurement of such risks. A system can be essentially distinguished between a new development and a modification. The stakeholders of a system are all persons who are involved in an SE that can directly or indirectly influence them. (Azimi, et al., 2011 p. 3)

The aim of an SE is to solve a problem based on the requirements of stakeholders. Stakeholders can have internal and external influence on the project. Among stakeholders, for example, the owner, the customer, the vendor as well as the developers of a system can be counted. (Azimi, et al., 2011 p. 3)

The fulfilment of the requirements is also essential for the target fulfilment based on the defined requirements. The earlier an error is discovered in the development of a system, the less are the resources that are used to correct this error. The resulting costs are borne by R&D, development, service and support. The main indicators for characterization are availability, reliability, maintainability, quality, disposability and supportability. (Azimi, et al., 2011 p. 3)

Azimi divides the SE-process into four phases, conceptual design, preliminary design, detailed design and development and operation and management. (Azimi, et al., 2011 p. 3)

If the resources in the first two phases, the concept design and the preliminary architect, are focused at the beginning of a system development, the development effort can be clearly reduced in the following phases. This is done indirectly through the use of more sophisticated design studies or developments to increase the quality, as well as the reduction of errors and the development time (Azimi, et al., 2011 p. 4). Thus a system developer has to find a balance between performance and costs. (Gonzalez, 2002)

Frequent problems of SE are exceeding development time and costs. Therefore, the clear definition of design and requirements should be a priority. Important factors for a system engineer are the identification of requirements and the associated risks and uncertainties. An important tool for the analysis of requirements is the House of Quality (HoQ) or Quality Function Deployment. Since this analysis method has already been described in detail in many specialist books and articles, for example (Jakoby, 2015 p. 285ff), this master thesis does not elaborate on this in more detail. (Azimi, et al., 2011 p. 4)

(Gonzalez, 2002) distinguishes between three different phases in system development. The first phase is the identification phase, which deals with the design process and the compromise. The second phase analyzes the results of the first phase and selects a method to deal with the compromise. The final phase decides on the feasibility of the project. This base on three aspects: (Azimi, et al., 2011 p. 4)

The first aspect focuses on the technical feasibility of a system or project. This is based on two or more variants. From this, the feasibility is determined for certain criteria. The criteria can, for example, be availability, ability, etc., of a variant. The decision should be based on the usability and the capacity efficiency. (Azimi, et al., 2011 p. 4)

(INCOSE, 2004) describes a system furthermore as a combination of elements which are accomplishing a defined objective. These elements could consist of processes, people, techniques, facilities, services, information’s, hardware, software as well as other many other support elements.

A system as a framework (structure, complex, composition) of certain objects (components, components, objects) between which relationships (connections, couplings) with certain characteristics exist. (Bruns, 1991 p. 31)

**Basic Definitions of the System and components:**

The basic definitions play an important role for the later understanding of the complex problem lifecycles of different SE approaches. Therefore a basic understanding with a short overview of the structure and the different elements comprising a system is necessary. An important task of a system engineer is the definition of the basic elements and their connections to each other. This should happen in a clear and coherent manner that every individual who is part of the development process understands equally what is meant by those definitions. (INCOSE, 2004 p. 12) It is also very important to define the system from the top to the bottom that means to begin with the definition of the whole system and further the subsystems, assemblies and so forth. (Haberfellner, et al., 2012 p. 59) How the definition of a system and the further activities should look like is defined in chapter

The Systems Engineering by (Haberfellner, et al., 2012) describes the basic structure of a system as follows:

**System**

Systems consist, therefore, of elements (parts, components), which means in a general sense the building blocks of the system. (Haberfellner, et al., 2012 p. 34f)

(INCOSE, 2004 p. 12f) Describe a system as an arrangement of elements as an air transportation system.

**Elements**

Elements have properties and functions: for physical elements the properties would be the dimensions and the color. The function usually corresponds to the purpose of an element within a particular system context. ( (Haberfellner, et al., 2012 p. 34f)

(INCOSE, 2004 p. 12f) Describe elements or segments as a major product, service or facility of the system. If we stick to the case of the air transportation system it would be an aircraft element also subsystems could be used instead of elements. Elements can in turn be referred as systems (Haberfellner, et al., 2012 p. 34f). The elements are connected by relationships. Also the conceptual relationship is very general. It can be material flow relations. Information relations, position relationships and so forth. (Haberfellner, et al., 2012 p. 34f)

**Subsystem**

(INCOSE, 2004 p. 12f) Describe the subsystem as a component of assemblies and parts which is clearly separating single functions or involving technical skills. This could be an air port control tower as a part of the before mentioned air transportation system.

**Assembly**

The assembly consists of components or subassemblies which are a defined part of a subsystem. An example would be the pilot’s radar display.

**Subassembly**

The subassemblies comprise the set of components for the assembly. This could be a video display with its related integrated circuitry.

**Component**

Consists of multiple parts, all of those are clearly defined. An example would be a cathode ray tube of the pilot’s radio headset.

**Part**

These are the smallest separable items of a system; this could be a bolt for a console. (INCOSE, 2004 p. 12f) in Figure 2-2: Hierarchy of a System

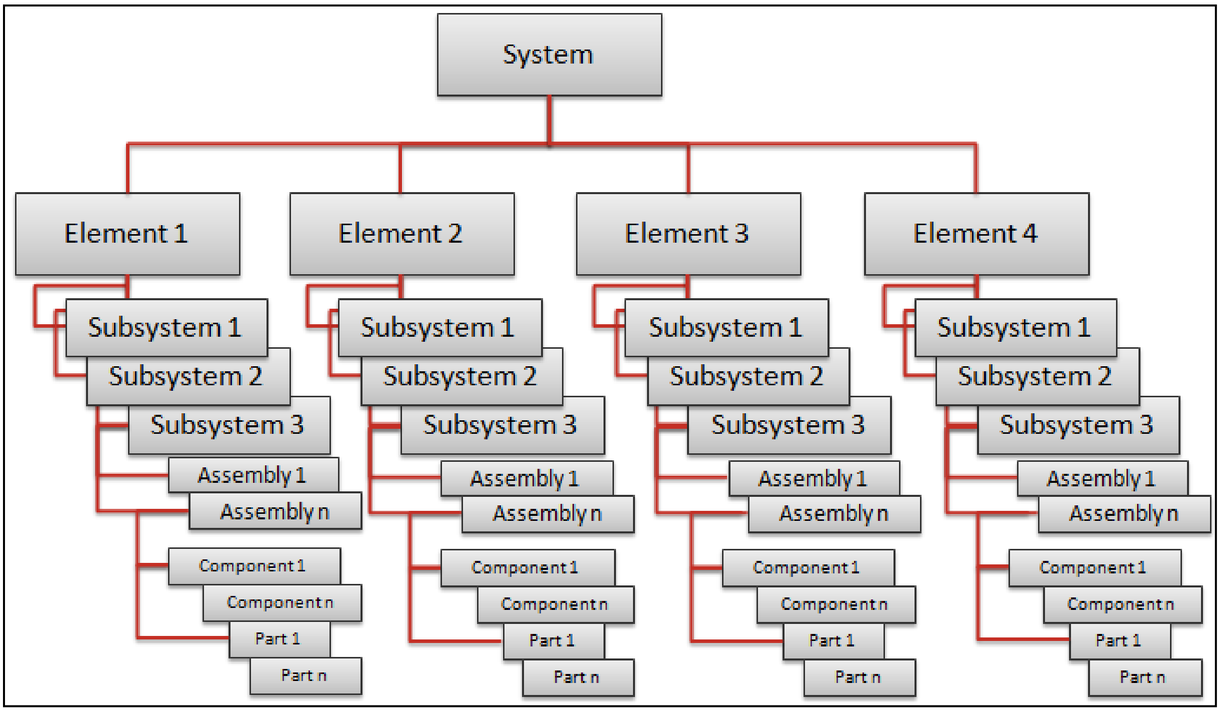


**Figure 2-2: Hierarchy of a System (INCOSE, 2004 p. 12)**

The lifecycle of a system could be defined after (Azimi, et al., 2011 p. 10) in five different steps:
The first step deals with the identification and analysis of the stakeholder requirements. The second step further analyses the defined requirements and categorizes them into elements and discusses the system functions. Third a design of the generic system based on the primary requirements is defined. The fourth step the generic system gets divided into specific subsystems. Regarding to the subsystems the important interfaces must be defined. The fifth and last step deals with the implementation or integration of the system

One crucial issue, after (INCOSE, 2004), in the development of a System is to define a coherent language with a nomenclature and a terminology which every stakeholder in the company understands in the same way. Because only if a basic understanding of every individual exists a basis for the development of a system is given. Also a clear structure for an easier understanding of the system components and its functions is necessary. Therefore a numerous types and versions of different step by step approaches were formed in the recent decades.

At the beginning of every new project the field of research has to be differentiated, for a closer and more detailed investigation. Furthermore important factors of the problem field must be identified and those factors should be defined and presented with their dependencies. Moreover the environment elements of the system should also be considered and putted in relation to the investigated system. Not before the problem field is defined and the structured is clear enough, it is not useful to start with a closer investigation of the system. The basic thought is to plan from the top to the bottom which means to start from the rough to the fine detail. This is essentially the basic idea of the first approach, the "Top-Down-Method". (Haberfellner, et al., 2012 p. 59)

The traditional top-down systems engineering approach is after (Azimi, et al., 2011) a basic approach which begins with the analysis of the problem and the determination of the system of interest. This approach is layered which means that every layer is a step into a more detailed version of the determined system and its requirements. The last layer which is called the bottom layer addresses the configuration items which the engineers have to design. After the configuration items are defined the next step of this procedural method are the integration and validation. (Buede, 2009)

**Uncertainty & Risks in System Engineering:**

One of the key indicators used to measure a system and its degree of maturity, which can be used in an engineering project, is the ability to analyze and manage risks and uncertainties. A system engineering project could be validated, after Azimi, through four specific aspects: (Azimi, et al., 2011 p. 14)

- **Complexity:** The complexity of a system depends primarily on the number of components. On closer examination, it turns out that in essence the uncertainty in the system is due to two aspects. The first aspect relates to the difficulty of presenting and understanding a complex system. The higher the complexity, the more difficult is the structure and function definition. The second aspect is the difficulty in the definition of systematic interfaces. A change in a complex system would lead to unforeseen changes.
- **Processing capacity/ communication bandwidth:** The process capacity can lead to uncertainty in system development. This uncertainty can arise from an over determination of the capacity; the consequence would be a problem with the data processing if it would be a software engineering project. Another possibility of the capacity problem is an underestimation of the capacity requirement. This would create a problem for the system when processing the data volume. This capacity can be applied to both software development and hardware development.
- **Rate of technological change:** In the case of software development, constant changes in the field of technology have become normal. Because of these rapid changes, uncertainties may occur during system development. Even at the beginning of a system development, the insecurity is high due to the choice of the appropriate technology to be implemented in the system. This requires the ability to adapt to rapid changes in technical requirements.
- **Information imperfections:** Deficits in the use of information can be based on both qualitative and quantitative information. This also applies to the development of the decision-making process, since if the information is not adequately or incorrectly formulated, there is no adequate basis for the handling of any kind of decision-making. The aim here is to clarify and improve those misunderstandings. (Azimi, et al., 2011 p. 15)

**Fuzzy Front End:**

According to (Herstatt, et al., 2001) the early stages ("Fuzzy Front End") are crucial for the successful development of an innovation and have the highest influence within the overall development process. The importance of the "Fuzzy Front End" approach, for the development of a product as well as the assessment of the innovation project, is huge.

The early stages within an innovative process are stages which effect the overall development the most. Therefore it is crucial to invest more resources and time into the early phases of an innovation process. (Lynn, et al., 1998)

According to (Hausschildt, et al., 1999), innovation can be understood as innovation, reintroduction, renewal or even novelty. Before innovation, the process of the invention is developed, developed and marketed for product maturity. (Hausschildt, et al., 1999 p. 4)

In an extremely catchy structuring, (Thom, 1980) breaks down the innovation process into the generation of ideas, conceptualization and realization of ideas. In the second and third phases, ideas are examined and specified using re-sizing plans. After the decision about the implementation, the concrete realization of the new idea is carried out until the success control. If one considers the first phase of the idea generation more precisely, it is noticeable that a search-field determination has preceded the idea-finding and the associated idea-proving. In the context of the search field determination, the framework under consideration is to be defined, for which creative ideas are generated in the subsequent idea-finding phase. (Thom, 1980 p. 53f)

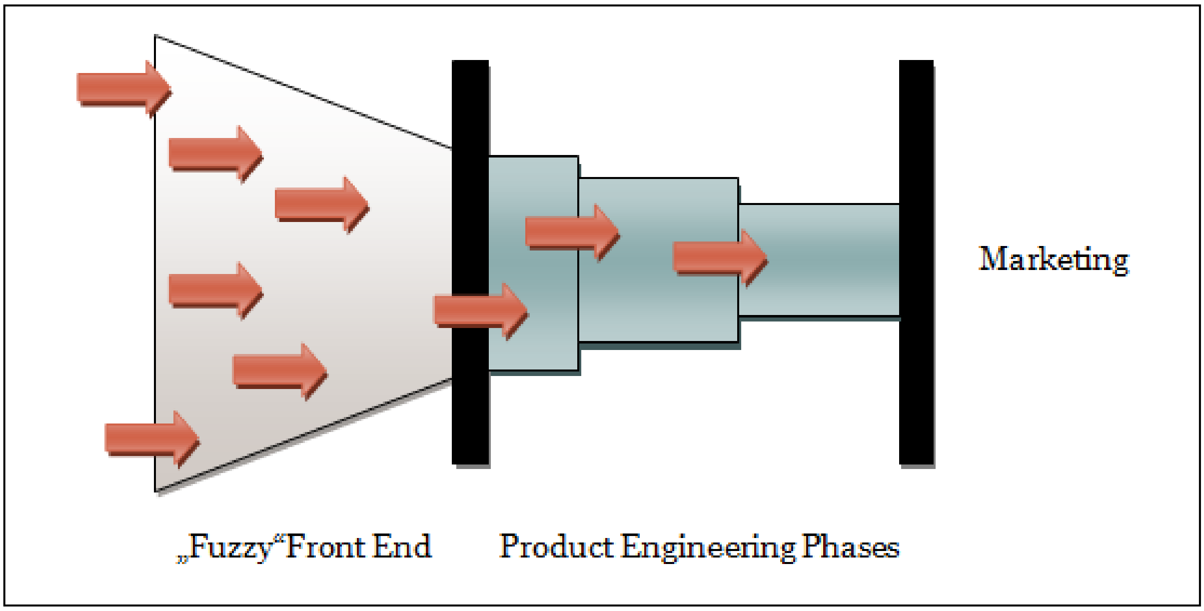

**Figure 2-3: Overview of Innovation processes (Abele, 2013 p. 3)**

Today, a large number of companies have a defined milestone process (see product development process Kohnhauser). The number of necessary assessments in the early stages of the innovation process alone poses significant challenges. (Christensen, 2006)
In the fuzzy front end approach, a distinction is made between the product development process and the upstream innovation or idea generation process. Fuzzy expresses the fact that the first phases cannot be precisely controlled in the innovation process because the project ideas differ strongly in their maturity, their degree of innovation, etc. At the very beginning of the innovation process, both the technical as well as the market-side uncertainties are greatest. According to (Herstatt, et al., 2003 p. 11), the market uncertainty is that if customer requirements are generally not available, the potential of a development cannot be estimated. Furthermore, there is also a lack of knowledge about the context of use. On the other hand, the technical uncertainty is due to the lack of specifications and the lack of specifications as well as the difficulty of estimating the potential for use and the technical feasibility. (Abele, 2013 p. 4)
For the practical part the determination of the term Fuzziness which is defined for the characterization of different project types for the development of systems. Thus the basic understanding of the Fuzzy Front End could give an idea of an generic point of view to the characterization of an innovative project.

**System Integration:**
NASA defines the integration plan as the basis for the definition of the implementation strategy of systems in the products intended for this purpose. Here, the definition of appropriate interfaces is relevant. The integration plan is intended to enable a structured assembly of subsystems and elements. The goal is the integration of these components into the finished system / product. An important point is the description of the costs of the integration strategy. Furthermore, the requirements for system integration as well as the resources required for stakeholders are to be defined. (NASA, 2007 S. 299) The core process of system integration is used for the assembly and quality assurance of components. Here, a continuous check is carried out to determine whether interim results meet the defined requirements. (Schienmann, 2004 p. 23)
According to the VDI the system integration, the functions of the subsystems, which are set up in the design, are combined to form a superior product. Various integration types can be selected according to (VDI 2206, 2004):

- Integration of distributed components
- Modular integration

- Spatial integration

When integrating distributed components, connections are made between components, such as actuators and sensors. The connections themselves are realized by CAN buses, cabling and through plug connections. In modular integration, the entire system consists of module-defined functionality and standardized dimensions. In spatial integration, the components are spatially integrated and form a complex functional unit. For example, all components of a drive system are integrated in housing. This reduces the installation space and the number of interfaces.

**Types of Systems and System aspects:**
The previous versions have been made in a general way without special systems. In the consideration of system properties, on the other hand, the systems in the forefront are concerned with the systems technology. According to (Platzak, 1982), the following four systematically distinct system types can be distinguished:

- **Target systems** (also called demand systems) are abstract. They describe the goal of a development process, without knowing the path exactly. Typical manifestations are the requirement specification document, as the functional specification document and the requirement description.
- **Program systems** (also called task systems) are also abstract. They indicate in which steps a given goal can be achieved. Projects, programs and plans are typical programs.
- **Active systems** (also called operating systems or work systems) are specific. They are the bearers of the actions required to achieve a given goal. Typical effective systems are organization, materials, equipment and tools.
- **Object systems** (also called results systems) can be concrete or abstract. They are the work object, product, produce, benefit or profit. In addition, the term object system is used for the considered system but without considering the nature of the system.

The determination of a system could be defined via different angles, but the definition and the detailed structure of the system elements as well as the internal relations between those elements is crucial for the definition of system aspects. System aspects could be described as different point of views for the investigation of a System. That means that for instance a complex system could be considered through different filters which are focusing on certain relations. These relations could be for instance, material flow, information flow, energy flow, characteristics of elements and their relation and many more. So the benefit of focusing on certain aspects is that the complexity could be reduced and the structuring more efficient. (Haberfellner, et al., 2012 p. 39)

### 2.1.2 Development of mechatronic Systems

Mechatronics has developed into a very attractive field of engineering sciences worldwide. It combines the classic engineering disciplines, such as mechanical engineering, electrical engineering and information technology, which ultimately lead to completely new products. Mechatronics is an interdisciplinary area, which requires the cooperation of experts in different areas. This requires a new approach because of both research, cooperation and, last but not least, education. Examples of mechatronic systems are robots, digitally controlled combustion engines, so-called drive-by-wire systems, airbags, machine tools with self-adapting tools, safety-related assistance systems, etc. As realistic as possible, system models are a prerequisite for realizing mechatronic systems and optimizing them. This applies to all system components, such as mechanical components, sensors, actuators, power and control electronics, as well as suitable control strategies. (Ulbrich, 2004 S. 2)
Mechatronics is an interdisciplinary field of engineering science. It can already be concluded from the description that mechanical and electronic components are interlinked. In addition to these two classic engineering disciplines, information technology is now playing a major role. The concept of mechatronics originated in 1969 and has its origin in fine mechanics. The first among these name-based products were merely mechanical systems, supplemented by electronic components to meet new functions and requirements. Today, the concept of mechatronics is much more important,

however, that a uniform definition has developed. According to (VDI 2206, 2004), mechatronics is defined as follows: "Mechatronics is the synergetic interaction of the specialized disciplines of mechanical engineering, electrical engineering and information technology in the design and manufacture of industrial products as well as in process design". (Bertsche, et al., 2009 p. 2)

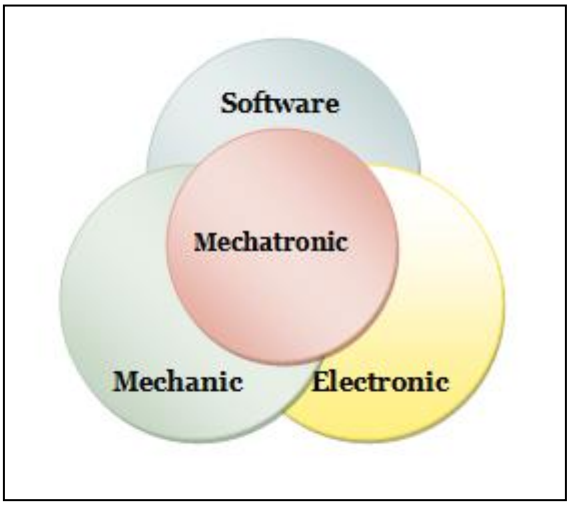


**Figure 2-4: The synergetic interaction of mechatronic (VDI 2206, 2004)**

The breakthrough of the automotive industry succeeded in mechatronics with the introduction of the first generation of electronic antiblocking systems in 1979. Due to the great potential of mechatronic systems, ever more partial systems have been replaced by mechatronic solutions and thus improved in functionality and efficiency. The main focus of mechatronics is to meet the ever-increasing requirements of the customer. This is achieved by a tight interaction of domain mechanics, electronics and software products. Mechatronics makes it possible to design technical products which are not possible with previous solutions through a single discipline of engineering. (Bertsche, et al., 2009 p. 3)
Mechatronic systems are characterized by a complexity that results from the large number of coupled elements. In addition to the complexity of the mechatronic product, the development is impaired by reduced product and development costs. Despite these aspects, however, the reliability of these product developments should be maintained and even increased. (Bertsche, et al., 2009 p. 4)

# 3 The System Engineering Process

According to (Michels, 2013), a business process model of a company is primarily derived from the corporate strategy and therefore individually defined. There are, of course, a number of reference process models which, in the sense of a benchmark, are a starting point for the further development of company-specific process models. For the development methodology of systems there are various established approaches. In this chapter we will discuss the most important models in view of the practical part. (Michels, 2013 p. 176)
In this chapter the basic approach of the System Engineering Process will be mapped. This will reveal the activities within the process as well as the purpose of those activities. Further the relations between those process steps will be discussed in more detail. The target of this chapter is the generation of an overview of the whole system Engineering Process topic and to prepare initially for the main chapters of the thesis. This will include the product engineering process (PEP), the tailoring of the process as well as the system development phases. The chapter will be closed with the subchapter of the product realization.
The system engineering process has evolved from the experience of engineering and practical work. Due to the further development of systems into increasingly complex constructs, the need for a method of proceeding has emerged, which is an iterative problem solving process. The basis of a system engineering process consists of three important approaches. Firstly, the problem to be addressed must be understood before it is worked on to solve it. Secondly, on the basis of the

problem, solutions must be developed, thirdly, and finally, the developed solutions must be verified and proofed on their correctness. (INCOSE, 2004 p. 27)
In the System Engineering Handbook of (INCOSE, 2004) several tasks regarding the SE-process are described:

- Definition of the System Objectives (Customer Needs)
- Definition of the System Functionality (Functional Analysis)
- Performance requirements of the system (Requirement Analysis)
- Concept of the design and the system operation (System Architecture)
- Baseline Selection (Cost/Benefit Analysis)
- Verification of if the Baseline meets the Requirements (Customer Needs)
- Baseline Validation for customer satisfaction (Customer Needs)
- Process Iteration through the Lower-Level-Analysis (Decomposition)

The system engineering process also involves a requirement specification of performance requirements and functional requirements. (Azimi, et al., 2011)
The SE process is an iterative approach and is based on the continuous improvement process. The purpose of an SE process is to define the relevant requirements as well as the essential characteristics of a system. (Haberfellner, et al., 2012 p. 135f) Complexity is a key factor in the system's insecurity. This factor has an effect on possible unexpected consequences during development. From this, adjustments must be made to the system properties as well as the modification of the already existing requirements. (INCOSE, 2006 p. 2.1)
Product development is divided into several phases. Including planning, requirements assessment as well as implementation and testing. For the various structured phases, the procedures describe the processes and activities. For the department of software development, various approaches exist which make the complexity of the software development more manageable. As synonymous with the approach model, the conceptual process model is also used.
Approach models describe processes and activities for the phases of a development. The goal is structured phases, which make the complexity of the development manageable. (Grande, 2014 p. 111)
The goals for the deployment and use of business models are improved product quality, better communication between stakeholders and an improvement of the processes. (Grande, 2014 p. 111)
The core process of the system engineering plans and controls the various development processes. In The core process architecture definition, requirements are raised, the architecture of a solution is developed, and the assignment of requirements to elements of the solution is established. (Schäppi, et al., 2005)

## 3.1 Nomenclature and Structure of the SE-Process

The system development process of Azimi refers to two functions which are the basis for the successful development of a system. The first function refers to decision-making. This function is to be carried out on the basis of the most suitable information. The second function is system design. This again correlates with the decision-making during a development. The design or the quality depends on the information basis which is available for the decision. In order to achieve maximum performance, decisions must be made on the basis of the best information available. These decisions should form the base around specific questions. The questions are structured in five process steps. These Questions are listed below. (Azimi, et al., 2011 p. 10)

| | |
|---|---|
| **Conceptual design:** | Is the conceptual design idea feasible? Which technologies or combination of technologies should be used? Which technologies should be used for subsystems? What are the different possibilities for extended research? |
| **Preliminary design:** | Is the preliminary design feasible and effective? Which alternatives for the primary system architecture are optimum and appropriate? What are the resource allocations for different components, depending upon different function, prototype, and requirement? Has the preliminary design been validated? |
| **Full scale design:** | Is the full scale design feasible? What are the costs and benefits of manufacturing a product or product component against purchasing it? What is the desired functionality from the different available alternatives? |
| **Integration and qualification:** | Have the different components been satisfactorily integrated? Has the integration process been successful in terms of schedule, time and cost constraints, equipment, people, facility and resources? Which models can optimize the overall system design? What are the current and prospective issues? Which criteria have been used to measure performance? |
| **Product refinement:** | What is the timeframe for product improvement? Which technologies are required, or which technologies need advancement? What are the cost issues? |

**Table 1: Decision questions (Azimi, et al., 2011 p. 10)**

(INCOSE, 2004 p. 16) defines the System Engineering Process as a combination of technical management, acquisition and supply, system design, product realization and technical evaluation at each level of the system. The process approach is iteratively driven and managed from the top to the bottom. The purpose of the process is that series of process steps will lead to the preferred systems solution. To make this “problem solving approach” possible the process must include lifecycle considerations of development, deployment operations, maintenance and the system disposal.

**Processmodel:**

In practice, it is repeatedly shown that supposedly promising innovations fail nevertheless. The reason for this is often the lack of adjustment and the coordination of product development and market introduction processes. A lack of alignment along the development process, but also especially before the market launch, often leads to delays, unnecessary increased resource use and the dissatisfaction of the customers. The sales team is often surprised by a new product. (Schäppi, et al., 2005 p. 5f)

Today it is not enough to simply develop products. Parallel to product and service development, strategic and operative market decisions are to be taken along the market launch process. Already at the beginning of the innovation process, it is sensible to incorporate the marketlaunch and -processing into the consideration of innovations (Schuh, et al., 2011). The focus is, as already described, on the identification of market and marketing opportunities, analyzes of customers, customer groups and competitors as well as the design of concrete business models and implementation strategies. In the long-term forecast, assumptions or estimates regarding the product lifecycle can be taken and merged into a business plan. In very early stages, this allows the consideration of the marketing-relevant aspects and, if necessary, the initiation of important steps in the direction of market and organizational development. This ensures a smooth and timely marketlaunch. (Ehrlenspiel, 2006) All product-specific processes, such as services, sales, repair and disposal processes, etc., must be prepared or already implemented in an operational manner. Another important success factor is cooperation with innovative customers, so-called lead users. If customers or, for example, suppliers are involved in the

innovation process, the success depends heavily on communication between the marketing, sales, R&D and external partners divisions. (Schäppi, et al., 2005 p. 6f)
The actual product development and the development of a market introduction concept or a market introduction plan are therefore to be understood as parallel processes. The content and framework conditions for the launch and monitoring of the market have to be defined and documented in a market launch concept, starting with the information developed during the early phase (description of the idea, requirement specification document, business plan). The defined documents (in particular the requirement specification document) serve as an orientation for all involved. They are an important source of information not only for technical product development, but also for the parallel process of the marketlaunch. After a successful launch of a product or a service, a dynamic control of the innovation success should finally be ensured. (Kohnhauser, et al., 2013 p. 61)

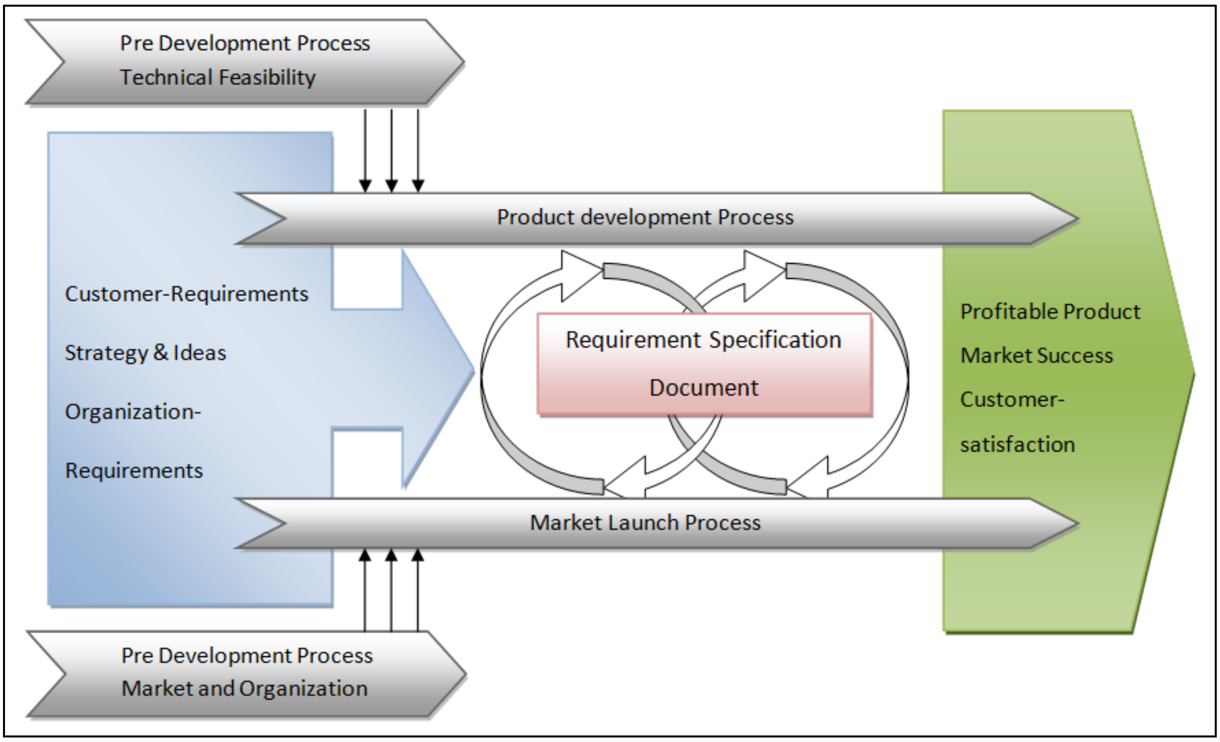

**Figure 3-1: Processmodel (Kohnhauser, et al., 2013 p. 61)**

The following process model shows a possibility to improve communication and coordination as well as to integrate the above mentioned approaches to the design of innovation and product development processes into a holistic process. In doing so, the actual development process, the parallel process of the launch of the mark, as well as the pre-development processes to safeguard the feasibility of market and technology is taken into account. The parallelization of project activities is clearly evident as the sequential and iterative approaches. (Kohnhauser, et al., 2013 p. 62)
Regardless of the actual project responsibility, the process model in Figure 3-1 will make clear that the adjustment and coordination of the departments and persons involved from the development to the marketlaunch is absolutely relevant for the success. It ensures the smooth execution and mutual understanding of the individual areas. After all, it is not a business area alone, which is decisive for customer satisfaction and market success. Through the early integration of all departments, practical solutions can be generated, which reduces the effort for expensive adjustments or improvements. At the same time, transparency, quality and safety can be ensured in the cooperation of various departments. (Kohnhauser, et al., 2013 p. 62)
Not only physical products have to be developed professionally, especially software development is becoming more and more important. Software development is characterized by increased communication and organization requirements. For this reason, several models have emerged into the software development process in recent years. In addition to the waterfall model, SCRUM, SPIRAL model, the V-model has also established itself as a more suitable tool. (Kohnhauser, et al., 2013 p. 62)

**Performance Criteria: Product Development Process**

- Clarity in the structure of the development process
- Definition of the essential sub processes and the necessary interfaces
- Clear responsibilities of the development team for overall and partial processes

**Product Engineering Process:**

Innovation and development processes are very difficult to standardize and, in most cases, a strict standardization even proves to be an obstacle to innovation. During development, iterations, overlapping of process steps and parallel sequences in the development process should be planned. Nevertheless, a new development process cannot and should not be defined before each development project. Much more is the assumption that development projects go through defined phases from idea to market launch. These phase-finding processes, with so-called milestones, determine whether the respective project is to be discontinued or, if necessary, which additional measures are important to reach the project goal. (Kohnhauser, et al., 2013 p. 81f)
In the literary, but also in the practice, there are different phase divisions. Here, a phase concept with the building blocks is presented below:

- Strategy- and Initialphase,
- Requirementphase,
- Conceptphase,
- Detailing and Testphase,
- As well as the Realizationphase and the
- Marketlaunch.

Depending on the nature of the development project, the individual phases can vary in content and scope. (Kohnhauser, et al., 2013 p. 81f)

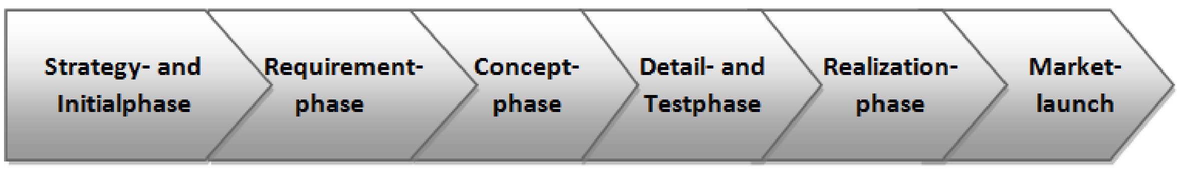


**Figure 3-2: Possible phases of a standardized Product Engineering Process: (Kohnhauser, et al., 2013 p. 81)**

The individual phases of the above-described process are briefly described below.

**Strategy- and Initialphase:**

As the strategic focus of this diploma thesis is not at the forefront, this part of the product development process is briefly considered. In the strategy and initial phase several activities run parallel. In addition to strategic planning, the product ideas are collected, concreted and finally selected. In addition, necessary preliminary investigations are started as well as the assurance of the feasibility of the planned developments. These include technical developments as well as market-related feasibility studies, the legal assessment of the patents situation and the economic evaluation of the product idea. Experiences from previous projects as well as from the development of technology flow into one another and, if necessary, the company's own pre-development projects have to be started. (Kohnhauser, et al., 2013 p. 82)

**Requirementphase:**

Often, at the outset of the product development, it is clear that there is no adequate clarity on how the new product or the new service should look, or the sales, the marketing and the development department know exactly what the result of the development should be. The practice shows that each department has its own concept, which is often very contrary. Thus necessary adaptations of the different ideas lead to corresponding additional costs and time delays. It is only when the requirements for a new product are clearly and unambiguously defined that this can ultimately become a successful innovation. In order to be able to define the requirements for a product or service, product-responsible persons must know the following key factors: (Kohnhauser, et al., 2013 p. 82)

- What the customers want
- Why the customers want (to determine what the customer is worth the product or the service)
- How customers make their decision
- According to which criteria the customers measure the fulfilment of their product requirements
- How well the competitor meets the requirement

The requirements must, on the other hand, be set high enough to achieve an advantage over competition. On the other hand, products must not be loaded with functions and features for which the customer is not willing to pay. Especially in the German-speaking world, the use of RSDs has been used to document customer requirements and product requirements. It is to be understood as a clear goal for the development team. In RSD all requirements for the project results are described from customer view. All relevant boundary conditions must also be considered. The RSD is based either on the knowledge of market research or on the demands of a specific customer. (Kohnhauser, et al., 2013 p. 82) Customer statements must often be transferred by the company into concrete customer requirements, formulated in the language of the company in order to make a concrete product reference possible. If the customer requirements are known, they should be weighed against each other. These weighted requirements then serve as a prerequisite for product development. (Schuh, et al., 2011 p. 184)

**Conceptphase:**

Jointly formulated specifications ensure that the new product meets customer expectations, that development can be completed within a set timeframe and that development and product costs remain within defined boundaries. While the requirement phase in the RSD defines what is to be developed, the focus in the conceptual phase is on the possible implementation concepts, that is, how. In the ideal case, at the end of the concept phase, various product concepts are available, which can be analyzed, assessed and assessed with regard to the costs, the market entry time and the risk of implementation. The documentation of these realization concepts, i.e. the problem solving and the target achievement, is carried out in a so-called FSD. In doing so, statements from the RSD on sales targets and planned sales prices in the FSD are supplemented by concrete target cost and economic calculations. Already in the concept phase, it should be ensured that the product concept is tailored to the manufacturing and distribution facilities and is technically described up to the level of the modules and the individual parts. (Kohnhauser, et al., 2013 p. 82f)

**Detail- & Testphase:**

Construction and design as well as extensive tests are the essential building blocks of the Detail- and Testphase. A review of the product and service concepts resulting from the phase of the concept development at and with customers is to be striven for. (Kohnhauser, et al., 2013 p. 83)

The concepts are checked for their attractiveness and acceptance at potential customers. This is to ensure that the objectives pursued with product development can also be achieved. Demand and buying probabilities can be measured, sales, turnover and market shares can be projected, as well as product name, design and packaging designs. In addition to numerous methods used in this development step, project management also has a special task since many parallel work steps and processes have to be coordinated. The steps of prototype design and prototyping ultimately lead to the first physical realization of a product. Here again, the involvement of the customers in the development process plays its own role. The prototypes can be verified using different concepts and methods (lead user method, open innovation, customer process monitoring, usability tests, etc.).

Concept and prototype tests also take place when a modification of an already existing product is planned. (Kohnhauser, et al., 2013 p. 83)

**Realizationphase:**
The phase of the realization is about the concrete implementation of the detailed and already tested product concept. The main focus of this phase is the planning and preparation of the production and / or performance of products and services. It should be noted that the prototypes and products mostly developed in the laboratory can differ significantly from serial production. The handling of these partly large differences is one of the greatest challenges in this phase of development. Measures to harmonize the new products with the production organization must be initiated. Important steps for careful production planning are:

- Production planning
- The quantity planning
- The scheduling
- The capacity planning
- Production control

Innovation is usually accompanied by the new design and / or adaptation of production. New processes and manufacturing disciplines are necessary to enable the production of new products. The timing of product and process innovations has to be considered and important decisions have to be taken regarding production capacity, production organization and design engineering solutions. After all, it is the aim of this phase to achieve the planned product activity as well as the target costs at the highest quality. Only by means of low-cost, flexible and quality-oriented production, the product properties can be ensured and the above-mentioned objectives can be achieved. (Kohnhauser, et al., 2013 p. 84)
Finally, the start of production includes the ramp-up of all supply and production processes. The results of the product and process development are examined in the context of a so-called zero series on their standard maturity. Children's diseases can thus be identified and eliminated. At the latest at the end of the production start, the employees also have to be trained for the new product. (Kohnhauser, et al., 2013 p. 84)

**Marketlaunch:**
The final phase of the product development process starts with the actual launch of the brand and the establishment of new products and services on the market. The R&D department must record customer feedback from market tests and, if necessary, make changes to the product. In addition to the activities of the R&D department, in order to be optimally prepared for the launch of the market as a whole, the focus in this phase is on communication to the outside. Creative and competent communication is required to convince customers of new and innovative products. In addition to communication policy, price and conditions policy, distribution policy and product policy must also be considered. The marketing mix is also expanded by personnel policy, process policy and equipment policy for services. (Kohnhauser, et al., 2013 p. 84)
However, the process is not completed with the launch of the market. Only by the consistent recording, processing and the renewed application of feedback from the market, customer satisfaction and finally the market success can be ensured. (Kohnhauser, et al., 2013 p. 84)

System engineering should deal with technology management in relation to the project objectives. The experience shows that good results could be achieved with the integrated product and process development. Technology management includes planning and reviewing the system development process. Planning should include the system engineering management plan (SEMP), which is used as a contract instrument. Ultimately, all activities are aimed at keeping the costs of development as well as the degree of risk as low as possible. (INCOSE, 2004 p. 31)

System design is an iterative process that involves the identification of customer requirements into a cost-effective solution, which means the balance between customer requirements and risk. (INCOSE, 2004 p. 32)
Complicated problems at the beginning of a system development are present when the solution approaches for the operating steps are still largely open, as new situations and perspectives develop for each solution step with increasing insight. According to (Rittel, 1991) problem processing can be characterized by the following special features: (Bruns, 1991 p. 5)

- Development-related problem formulation, only as a provisional result in the information exploitation process
- Coupling of formulating and solving processes
- Indeterminateness of the problem-processing levels due to the lack of allocation to a certain level
- Inscrutability of target- and actual state problems
- Uniqueness
- Evaluation difficulty
- Test difficulty
- Difficulty in assessing the adequacy of the approach
- High risk of development
- Lack of facts

**Tailoring the System Engineering Process:**
Every organization needs to design its own type of system engineering process and therefore its terminology, development and support approaches. This individualized process should be the backbone for the development of a system. (INCOSE, 2004 p. 55)
A successful system development process involves certain activities that can be used to plan and develop a specific product. This also includes a certain detail accuracy with regard to accompanying analyzes and iterations. According to INCOSE, the main focus is on the reduction of the development risk as well as on the economic cost-specific consideration of resources. It is important that all the required requirements are defined and verified during system development. All technical and economic risks have been identified and assessed, and these defined values have also been adhered to in the system development. (INCOSE, 2004 p. 55)
For the stakeholders of system engineering, the task is to record the technical complexity of the system and to define its assessment. Both development and management are involved in this process. When negotiating resources and time, the management has to make precautionary measures as well as to identify the development risk with the developers. This requires competence in the area of negotiation and communication. In doing so, compromises have to be found between tasks, risks and costs. According to INCOSE, many system developments begin with inadequate stakeholder willingness, often with the actual development risk as well as the costs wrongly estimated. From this, INCOSE has derived four important points which result from unrealistic expectations and inadequate readiness. (INCOSE, 2004 p. 55)

- Insufficient system engineering leads to a lack of defined requirements, interfaces and system components at the start of projects, which in turn leads to a delay in product specifications and inadequate design maturity.
- The non-recognition of risks in the area of system components or elements during the development and as well as untarnished planning and integration leads to design revisions
- The distribution of the resources is carried out in an unacceptable manner and does not match the needs in relation to the work tasks of the individual working groups. This results in a lack of resources during development.
- Serious technical problems that occur during system integration and the test phase, or from design to production, lead to cost-intensive revisions and time shifts.

**Mapping the System Engineering Process:**

INCOSE describes for the development of a system engineering process four different stages. These stages are shown in the figure. In this master thesis the third stage will be described in more detail. Nearly in all stages the topic of system engineering is part of those process activities, but the other stages are the subject of well-defined fields of study and beyond the scope of this thesis.
An overview about the range of systems engineering gives the table with its four phases. These four phases comprise the entire program life cycle from system analysis, requirements definition and conceptual design as well as manufacturing and development and last but not least the production and support level. This table is basically an example from the United States Department of Defense. This table shows twenty-two key program tasks which are shown from a system engineering viewpoint. These tasks comprise the typical steps during a program life cycle. Also companies direct their activities in a similar way, but with different definition terms. (INCOSE, 2004 p. 21)

### 3.1.1 Requirement Management

Complex systematic challenges require knowledge from a wide range of disciplines, which must be coordinated and made available during the design process, as well as the integration of a design life cycle of the requirements and their relationships. (Azimi, et al., 2011 p. 9)
In product, system and software development, the professional handling of requirements plays a decisive role for the success of the entire development and for the resulting product. (Grande, 2014 p. 1) Therefore the requirement management includes the entire process from the initial customer request or the order to the development of a solution, the operation and the subsequent further development (Stevens, et al., 1998) distinguish explicitly between a customer request process and a system requirement process. Similar aspects such as risk management or the degree of maturity improvement are considered as essential tasks of a successful management of requirements. For the Management of Requirements according to (INCOSE, 2004), it is crucial to deal with those requirements, within a project in an efficient manner. Within the next pages the topic of requirement management will be discussed and furthermore the different types of requirements as well as the assessment of those. As mentioned before in the System Engineering Process chapter the management of requirements is one of crucial issues for an efficient development of a product or a system.
In the development of complex systems, mistakes were identified in the course of the process of analyzing and identifying requirements, which in turn had a negative impact on the development of value chain as well as the increase in development costs. The efficiency in the system development depends very much on, when the requirements are met. If requirements are defined in the early stages of development, this reduces costs over the remaining development time. Therefore, a higher discipline and structure must be taken in the area of system development in order to achieve a maximum performance. On the basis of this fact, system engineering was defined as a system for the development of systems. In this approach, you will find all the important criteria that are relevant to the development of a system. (Azimi, et al., 2011 p. 9)

**Requirement Definition Process:**

A crucial issue is the handling of requirements within a project. Requirements are the basis for the development of a product, therefore a major objective is the identification of the right requirements and express the customer needs in a verifiable way. It is necessary that each requirement is established as soon as possible in the development process because every requirement carries costs. These costs increase the more the later requirement changes occur in the requirement definition process (Kohnhauser, et al., 2013). According to INCOSE, requirements are the foundation of every project. In addition to designing a product, validating and manufacturing, this also opens up the development itself. As every requirement affects the costs of development, it is essential to define a certain minimum of requirements at the beginning of a system development. The more requirements are defined at the early stage of the development the less is the impact of costs (INCOSE, 2004 p. 99). In addition to the complex process itself, which deals with performance analyzes, business studies, as well as constraint evaluation and cost analysis, the requirements manager also includes the effect of elements in the system itself (INCOSE, 2004 p. 99). For a more fundamental understanding, the terms requirement or requirement management are central. A requirement is first of all a special or technical performance characteristic that the application to be developed should have. Requirement is a condition or skill required by a person to solve a problem or to achieve a goal. Frequently, the term is extended to the development process and other framework conditions to be met. (Grande, 2014 p. 2)
(Rupp, 2001) defines the requirement in a more development specific manner:
“A requirement is a statement of a property to be fulfilled or a service to be rendered of a product, a process or the persons involved in the process”. (Rupp, 2001 p. 10)
A major role for the quality of the development of a system plays the determination of requirements within the requirement specification phase. The reason because requirement management is applied in the structure of product development process is, because the orientation on the customer demand builds the essential backbone for the further product development. Moreover the Requirement management is responsible for the prioritization and the structuring of the important requirements.

Another crucial issue of the requirement management is the reduction of complexity of the product development due to a higher of the level of transparency. The clearer the transparency of requirements at the beginning is the lower is the development risk and the complexity of the product development. Therefore is the Requirement management responsible for the reduction of complexity and the risk of a product development as well as the definition of the needed quality standard. (Kohnhauser, et al., 2013 p. 106) There are clear areas of responsibility for handling requirements from the point of view of the customer, the product and the project. Role conflicts are minimized by defined customer- contractor roles in the context of a contract-oriented approach. (Schienmann, 2004 p. 19)

Tightly defined task areas allow a concentration on the respective core competences (customer, product, and project). The responsible for customer requirements management does not have to provide product management, the product manager does not have to manage project requirements.

The sufficient stability and completeness of the requirements is examined and an early customer-based validation is achieved, for example by acceptance criteria. An agreement is reached between all involved persons concerned (so-called stakeholders) with regard to the requirements, even in the event of changes. An attempt is made to uncover deficits and defects of requirements at an early stage and to remedy them in a defined process. The application development can thus be carried out in a significantly more efficient and cost-effective manner. The development cycles can be accelerated as the identification of customer requirements and the derivation of product requirements are carried out continuously. This allows for slighter development processes, which are less risky. (Schienmann, 2004 p. 19)

**Consequences of inadequate requirements management:**

Inadequate or missing requirement management results in products that do not meet the requirements in part, inadequately, or at all. This leads to a result that the customer or the own company did not want to achieve. In the course of the process, misunderstandings are detected very late at the acceptance of the organization or by the customer. The consequences are then discontent, a poor quality in the development results as well as exceeded costs and increased development times. The impacts are inadequate RM are missing or incorrect requirements for the product. This leads to dissatisfaction in the organization and the customer. In addition, this leads to poorer product quality and increased time and costs. (Grande, 2014 p. 9)

The increase of complexity and the shorter product lifecycles as well as the rising pressure on innovation and competition is leading to strong reduction of the time to market. The time to market is a very important indicator for the capability of completion. Products and services are increasingly converging to provide a holistic range of services for the customers. For requirements management, however, this means increasing the complexity and the need to think and implement completely new concepts. Challenges arise, in particular, because customers and their needs and requirements are developing more and more rapidly. This increases innovation and competitive pressure and results in a sharp reduction in product life cycles. This increases innovation and competitive pressure and results in a sharp reduction in product life cycles. "Time to market" has become a, if not the most important, competitive factor of a new product. Consequently, decisions must be made not only correctly but also quickly and bindingly. The later and more often a change in requirements occur, the higher the necessary time and the associated costs will be. (Kohnhauser, et al., 2013 p. 106f)

A real improvement will only be achieved if the entire process of requirements management is optimized and anchored as a continuous, permanent process in an organization. (Schienmann, 2004 p. 24)

The essential task and goal of the requirements management is to specify the requirements of the system resulting from these tasks and to adapt them to changes in the application area. Only when the problem is known in the application area, a suitable solution can be developed in the application development. (Schienmann, 2004 p. 18)

**Main Activities of RM:**

The illustration shows the four main activities in the requirements management. The arrows show the standard flow from start to specification. The activities will be repeated several times in practice. The maintenance and administration of the requirements is then continually taking place in parallel to other main activities.

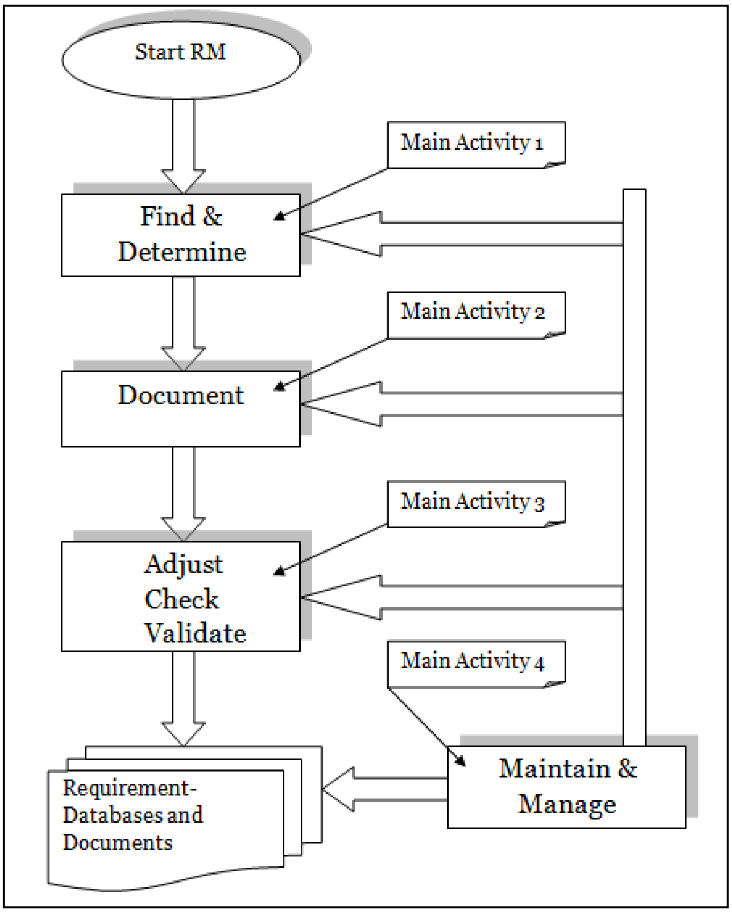


**Figure 3-3: Main Activities of RM (Grande, 2014, S.10)**

Any application development requires the identification and administration of requirements. The earlier it is possible to maintain the customer's requirements correctly, the more cost-effectively and faster a suitable solution can be developed. If the requirements management is comprehensively implemented, changes in the requirements can be recognized more quickly and integrated more effectively.

Why is requirement management so important? Research shows that more than half of all application development projects extend the duration of the project and about one third of all projects are terminated without results. The reason for this error is mainly due to a lack of requirements management. (Schienmann, 2004)

Requirement management is a successful help. Even very simple measures, such as an early prioritization of the requirements, can achieve good results. However, in order to achieve a fundamental improvement, it is not enough to introduce individual techniques, such as application cases for the specification of requirements or Quality Function Deployment (QFD) for product planning, and to establish individual organizational measures such as a change control board. Instead, a project- and phase-interrelated requirements management as a continuous process must be introduced from the customer to the customer in an organization and be anchored step by step.

The core idea of (Schienmann, 2004) is to develop the requirements management from three angles, customer, product and project, and thus to develop the process from the ascertainment of a requirement to the provision of a solution.

**Customer orientation**: Customers are asking for solutions to their problems. Their customer requirements do not have to refer to concrete products or projects.

**Product orientation:** Products with applications represent solutions to these problems and the resulting requirements of the customers. Product requirements are specified on the basis of customer requirements and implemented in projects.
**Project orientation**: In application development projects with a limited duration and a defined goal, products are realized and thus problem solutions are made available to the customer.
**Customer requirements** can initially be set or raised in a product-neutral manner. In order to avoid that requirements which are not directly attributable to a product or an application are not covered, they may not only be levied from sight-specific products. In the same way, continuous project-specific requirements management is required to ensure that requirements can be determined project-neutral.
The central process areas of the requirements management are derived from these three perspectives. (Schienmann, 2004 p. 16)
Distinction of Requirements:
A distinction is made between different requirements. According to (Schienmann, 2004 p. 50) requirements are divided in four types:

**Functional requirements** - what should the system do? Which data is to be processed, which services are provided and which processes are supported?
**Non-functional requirements -** in which quality should these services be provided? How can the application be fail-safe or performance based?
**Framework -** which restrictions should the solution suffice? Are there legal or organizational restrictions that need to be considered?
**Development and production requirements -** what requirement do development and production meet? Are there any special requirements for the maintenance of the product?

**Validation of Requirements:**

**Satisfaction Categories or the Kano-model:**
To correctly assess customer requirements is a basic need of the requirements model. The KANO model provides for a simplification by classifying it. This classification is carried out by means of a diagram in basic factors, performance factors and enthusiasm factors. (Schuh, et al., 2011 p. 183)
The requirements are made by the stakeholders to the product. The model of Dr. Noriaki Kano, who describes three types of product requirements: the basis factors, the performance factors and the enthusiasm factors, are how the stakeholders are satisfied with certain requirements. (Kano, et al., 2012 p. 177)
**The basic factors** are self-evident to the customer. These requirements do not really occur to the customer. Only when they are lacking does certain dissatisfaction arise.
**The performance factors** are the requirements the customer would like to have explicitly. If these requirements are not met, dissatisfaction develops, if the requirements are implemented the satisfaction increases.
**The enthusiasm factors** are the requirements that inspire their customers in particular. These are requirements which the customer did not want to have explicitly, but which raise the value and impression of the product at their customers accordingly. These factors could become a key feature which can bring the company a competitive advantage. (Grande, 2014, S.51)

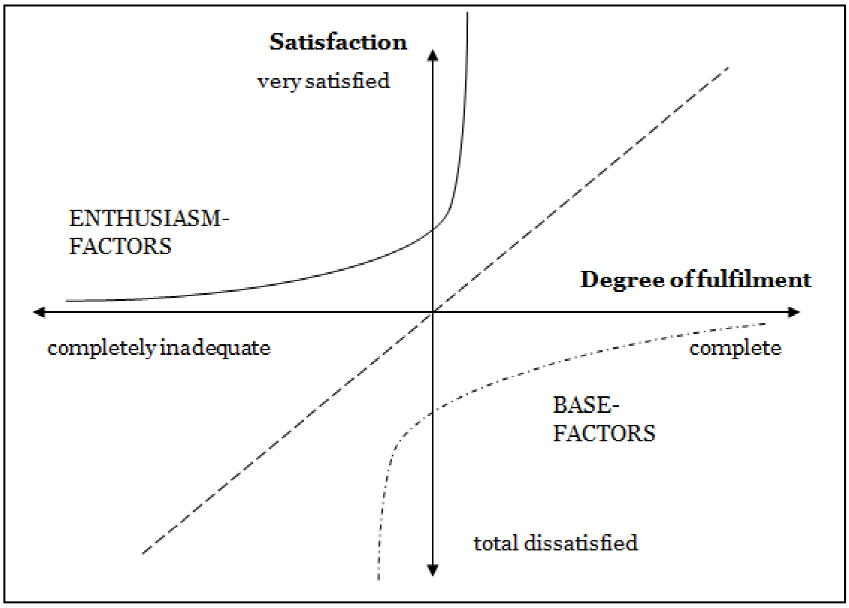


**Figure 3-4: KANO-Model (Grande, 2014 p. 52)**

**Structuring and Weighting of Requirements:**

If the customer needs are identified, they must be structured in the first step and displayed in the corresponding degree of detail. The needs such as increasing economic efficiency and productivity, high reliability, lowering the rate of complaints, reducing downtimes, increasing safety, or simplifying the use of the system are of just little use for the developers. The customer requirements should be detailed in such a way that measurement and target values can be defined. Thus the use of the product can be quantified later. This is necessary in order define the product requirements of the own product with the products of competition. (Kohnhauser, et al., 2013 p. 118)

| Customer Needs | Degree of Detail | Examples of measurement and target values |
|---|---|---|
| **High Reliability** | Increase in reproducibility | Number of reproducible results |
| | Increase in service life | Time (years, months, day) |
| | Increase in system availability | Increase in availability in percent |
| | More robust electronic structure | Increasing the duty cycle in percent |
| **Economic Efficiency / Productivity** | Lower energy consumption | In Wh |
| | Less wear and tear | Pieces per shift, day or kilometer kilometers traveled |
| | Low maintenance | Reduction of maintenance intervals by 50% |
| | Performance increase | Depending on the type of power (m / s, 70% effective operating time, etc.) |
| **Easy Handling** | Easy handling | Reduction of the operating steps (from 9 to 7) |
| | Reduced misuse | In percent |
| | Reduced programming time | Time (days, hours, minutes) |
| | Reduction of assembly and commissioning time | Time (days, hours, minutes) |

**Table 2: Structuring customer requirements (Kohnhauser, et al., 2013 p. 118)**

After the structuring and detailing of the requirements and requirements, the weighting of the customer requirement proves to be a further essential prerequisite for a customer-oriented development. In addition to the Kano model, simple evaluation methods, scoring models and value-in-use analysis have been shown as well-established methods for weighting requirements and product requirements. (Kohnhauser, et al., 2013 p. 118)

Another possibility to assess the degree of reliability was developed in the literature of (Bertsche, et al., 2009 p. 35). This evaluation approach is used for assessment, bases on the reliability of engineered systems, as well as the requirements structuring according to Kohnhauser. However, this method is based on the assessment of severity. Following the method is shown in table.

**Degree of Severity for the reliability determination of a system:**

For the Reliability of a system one very important aspect in addition to the quality of a product is the functionality. A functional defective product will affect the buying decision of the customer. In the last years the customer has to deal more and more with unreliable products. One of the reasons for this change is the increase of mechatronic products and variants on the market. Due to this development the engineers have to deal with a higher degree of complexity and functionalities which affects also the engineering efficiency of those systems and the development of new innovative technologies. Therefore a well-defined and reasoned Research and Development must be considered. The detailed engineering of a system in consideration of all important factors, data and the involvement of accurate methods is the key performance indicator for the solution of a problem. Failure in the development of a system could lead furthermore to reliability problems. A fact is that the incremental amount of mechatronic systems is the reason for unbalancing the development triangle of quality, costs and time. The costs will be reduced, the development time decreased and therefore the quality is getting progressively worse. An important possibility is the management of the reliability of a SE with the focus on the early development phases. (Bertsche, et al., 2009 p. 1ff)

Based on the reliability assessment of mechatronic systems, (Bertsche, et al., 2009 p. 35) designed an assessment of system requirements for severity. An approach is the utilization of the functional orientation of mechatronics. Especially in the early development phases, the approach is meaningful, since the determination of components is not possible. However, functions themselves can have a different value. A classification system can be used for this purpose. Table shows an example of the classification system applied in the automotive industry. The evaluation system differs in four degrees of severity.

| Degree of Severity | Description | Part | Example | Consequence for the customer |
| --- | --- | --- | --- | --- |
| **Critical(1)** | There is a direct risk of life and limb for users or other users with functional failure | Passive or active safety component | Defective steering or wheel suspension, tire damage, defective brake system. Defective at the airbag | Accident |
| **High(2)** | It has to be reckoned with a high damage to the vehicle, damage to the environment or infringement of a law | Risky component | Piston seizure, Damage to the catalytic converter | Immediate workshop visit |
| **Medium(3)** | The main function is not fulfilled | Standard component | Battery failure, tearing of the V-belt, loss of coolant | Remedy on site, Immediate workshop visit |
| **Low(4)** | Function loss in the comfort functions or a redundancy function | Standard component | interior lighting | Unplanned workshop visit |

**Table 3: Degree of severity for the determination of the reliability of a system (Bertsche, et al., 2009 p. 35)**

The reliability value which is described with the degree of severity 1 should be determined with the help of a safety standard. For other grades, there are several ways to determine the reliability target. On the one hand, the objectives can be met by market strategy requirements. On the other hand, it is also possible that similar already existing products are evaluated according to their reliability, and this value is adopted with a safety tolerance as a reliability target. (Bertsche, et al., 2009 p. 35) Another possible measure for the comparative analysis of the reliability of a system could be the benchmark method. This method is described in chapter 4.2.1.

**Quality characteristics:**

Quality requirements can be, according to ISO 9126, six quality features of software with the focus on product quality:

**Changeability**

How much effort is required to implement changes to the software? This concerns, among other things, the area modifiability and testability.

**Usability**

How well can a user handle the software? How quickly can he learn the handling? This concerns, among other things, the areas of understanding and operability.

**Efficiency**

How efficient, in terms of resources and performance, is the software? This includes time behavior (e.g. response times) and resource consumption

**Functionality**

Does the software fulfill the specific functions? This area concerns topics such as correctness and safety.

**Transferability**

What are the costs of transferring the software to a different environment? Terms are: adaptability and install ability.

**Reliability**
Does the software have a certain performance level? The key points are: fault tolerance and recoverability. (Grande, 2014 p. 38)
Non-functional requirements determine which quality characteristics the product should have and which boundary conditions are imposed on the product. (Grande, 2014 p. 39)

**Risk management:**
The implementation of requirements entails a wide range of risks. Typical risks in projects are, for example, frequent changes to requirements, too many requirements or a lack of user involvement, so it is not clear whether the right requirements have been identified. Through risk management, such risks are to be kept within acceptable limits or avoided altogether. The transfer of the risk to other parties involved (customer, subcontractor) is usually not possible. (Schienmann, 2004 p. 47)
Main tasks in risk management

- The identification of potential risks,
- The estimation of the probability of the occurrence of a damage case,
- The assessment of the serious and the consequences of a loss,
- The determination of measures to transfer or avert the risk

(Schienmann, 2004 p. 47)

**Quality of individual requirements:**
Individual requirements should have the following ideal properties.
**Correctness** - is the right requirement described?
**Completeness** - the requirement is completely specified?
**Uniqueness** - the requirement is precise?
**Consistency** - is the requirement non-contradictory?
**Retribution** - unity has been reached on the request?
**Prioritization** - How necessary, important, urgent and stable is the requirement?
**Verifiability** - is the requirement testable?
**Comprehensibility** - what is the context of the requirement?
**Intelligibility** - is the requirement understandable?
**Feasibility** - can the requirement be implemented?
Of course, the properties are not completely independent of each other. For example, the assessment of the correctness of a requirement requires its comprehensibility and non-contradiction. (Schienmann, 2004 p. 177)

### 3.1.2 Requirement Specification Phase:

The Requirement Specification Document (RSP) is the main result of the activities in the product RM. It specifies the product release which meets the determined customer requirements or product ideas. (Schienmann, 2004 p. 141)
The order documents summarize the requirements for a project. A deficient order is an ideal breeding ground for failing projects. To avoid this, an order should meet some quality criteria. Even if these criteria seem to be apparent, many negative examples show that their compliance is by no means self-evident. (Jakoby, 2015 p. 96)
Product managers are confronted with major challenges products and services are becoming increasingly integrated into a holistic range of services for the customer. For requirements management, however, this means increasing the complexity and the need to think and implement completely new concepts. Challenges arise, in particular, because customers and their needs and requirements evolve more and more quickly. (Kohnhauser, et al., 2013 p. 106)
Many clients formulate their requirements according to the principle of demanding the impossible to maintain the feasible. From the point of view of an effective and economic project implementation, such a principle is nonsensical and must be replaced by the quality feature of feasibility. An order should therefore only make realistic demands. Unrealistic receivables lead to increased expenses, greatly increased budgets and still remain unrealizable. There can also be problems with the combination of demands, each of which is realizable. Often, demands can contradict one another. This

is particularly the case when the formulation is extended over a longer period, or when the requirement specification is compiled by various parties. Therefore, the requirement specification document should always be viewed in its entirety and checked for non-conflict. (Jakoby, 2015 p. 97)
The desire for completeness often leads to very long lists of demands and the worry of simply forgetting nothing can lead to unnecessary demands. Therefore, attention should also be paid to the relevance of the requirements. Over and above the actual target requirements may contribute to a secure target, but they also increase costs. Every requirement costs money and any unnecessary requirement wastes money. (Jakoby, 2015 p. 97)
This increases innovation and competitive pressure and results in a sharp reduction in product life cycles. This also shortens the available product development time. Time to market has become a major competitive factor in a new product. Consequently, decisions must be made not only correctly but also quickly and bindingly. The later and more often a change take place, the higher the necessary time and the associated costs. (Kohnhauser, et al., 2013 p. 106f)

**Requirement Specification Document & Functional Specification Document:**
All requirements of the client must be recorded and documented before the project begins. An RSD is used for this. According to DIN 69905, it describes "the totality of the requirements for deliveries and services" from the point of view of the contracting authority. For the document that summarizes the requirements, other terms are in use such as e.g. Requirements specification or customer specification. In the following, the term Requirement Specification Document is used here. (Jakoby, 2015 p. 97ff)
Depending on the range of the project, RSDs can differ greatly in terms of scope, structure and content. For smaller projects, the requirements of the client can be kept on a few pages. Larger projects, on the other hand, may require RSDs with several hundred pages. For some jobs, even the creation of an RSD can be a separate project. (Jakoby, 2015 p. 98f)
The more precisely the requirements of the customer are fixed in the RSD, the more clear the verification at the project end. Even if this sounds trivial and has been known for a long time, many projects are still started without RSD or with incomplete RSD. Often, missing RSDs are justified by the fact that everything is clear. Too often, such assumptions have turned out to be illusions, so that they are not acceptable for the non-identification of an RSD. Engraving, but just as little sound is the fault, that at the beginning of the project much information is not yet known. If this is indeed the case, the information must first be procured, evaluated, and decisions made accordingly before the project is started. If this is not the case, massive deficiencies or even a failure of the project are threatening consequences. An RSD is therefore necessary for all projects, whether it is difficult or simply. (Jakoby, 2015 p. 98f)
The contractor’s response to the RSD is the Functional Specification Document. In this, he summarizes all deliveries to which he commits himself with the acceptance of the order. The FSD thus forms a kind of feedback from the Contractor to the Client, in which he describes how he intends to fulfill the contract. At the same time, the FSD forms the starting point for the customer to plan the product and the necessary work in the project. (Jakoby, 2015 p. 98f)
RSD and FSD form the basis for an agreement between a customer and a contractor. The RSD and the FSD have different tasks and are therefore also to be considered at least separately. Both can also be combined into one document. (Jakoby, 2015 p. 98f)

**Content and structure of RSD and FSD:**
An RSD is very much result-oriented, that means it focuses on the product as the desired result of a project. Depending on the application area, there are different requirements and different proposals for RSDs. In any case, the specification of the product functions forms the core of the requirements. It describes what the desired product must be capable of and what it should possibly be able to do. Very useful is also the demarcation that is the description of functions, which the product does not need. (Jakoby, 2015 p. 98f)
In the requirements specification all technical, economic and organizational requirements for the product that is being developed, will be presented. The requirement specification is basically a concept, which gives an overview of a project situation, if the project could be actually developed and

financed. Furthermore is the requirement specification at the same time a clear target setting for the project team. The creation of a requirement specification is a complex duty, because just a few detailed information about the being developed product are existing. In addition demands and requirements could change over the development time. (Kohnhauser, et al., 2013 p. 122)
In addition to the required functions, there is also a whole series of conditions that must be adhered to. A distinction can be made between product- and project-specific conditions. Product-specific requirements result, for example, from the operating conditions (temperature, feasibility, vibrations, standards and guidelines to be observed). Other product conditions are requirements for product costs and piece numbers. Project-specific boundary conditions are, for example, dates, requirements for the contractor (e.g. certification) and contractual conditions. (Jakoby, 2015 p. 98f)
The following structure does not necessarily represent a standardized structure for RSDs and FSDs, but rather lists possible components in an ordered form: (Jakoby, 2015 p. 98f)

- Introductory overview
- Output point, actual state
- Project purpose, target state
- Boundary conditions and target criteria
- Product specification
- The product environment
- Product interfaces
- Product function
- The basic conditions of production and product use
- Application scenarios and conditions of use
- Production conditions
- Norms, guidelines, regulations for the product and its use
- The basic conditions for the implementation of the project
- Requirements for the contractor (such as certification)
- Contractual terms (dates, warranty, reports, and documentation)
- Test, commissioning, acceptance, service
- Attachments: glossary, references

The entire process of project processing is a series of steps of increasing concretization and detailing. The problem analysis and the resulting RSD as well as the rough solution design, which leads to the FSD, are the first two such steps. The RSD describes the requirements for the project result, but leaves its realization details open. The FSD is more specific. Of the many possible solutions it describes one in concrete form. Often the FSD can therefore be regarded as an update of the RSD. (Jakoby, 2015 p. 100)

**The efforts-orders-dilemma:**
An offer and an FSD as a response to a project request must include not only technical statements, but also commercial statements, such as project costs and delivery time. The creation of an offer therefore already requires a task analysis, and at least coarse solution design, robust project planning and a solid project calculation. To create all this requires time and effort. However, in view of the risk of not receiving the order, the question arises as to how much effort is necessary and justified before the contract is issued. The problem is not so serious with company-internal project requests. Directs e.g. the management to the development department the request for the development of a new device, this of course has to make a statement about feasibility, costs and dates. The situation is not so critical, since there is usually no competitor for the order. The management decides whether or not to submit the project to the conditions offered and the promised result. With external project requests, however, there are usually several, sometimes even a whole series of competitors. (Jakoby, 2015 p. 101ff)
If only a small amount of the problem analysis, solution design, planning and calculation is involved prior to the assignment, uncertain statements about feasibility, deadlines and effort will be the result. In the offer, however, precise statements must be made. If the determination places at the lower

optimistic end of the range of estimates, the order probability is high, but the risk of valuation is the same. In short, in this case, you will be very likely to have a lot of probability. If, on the other hand, the upper, safe end of the estimated bandwidth is taken, the risk is low, but also the probability of the order. Here you will not earn money with great security. (Jakoby, 2015 p. 102)

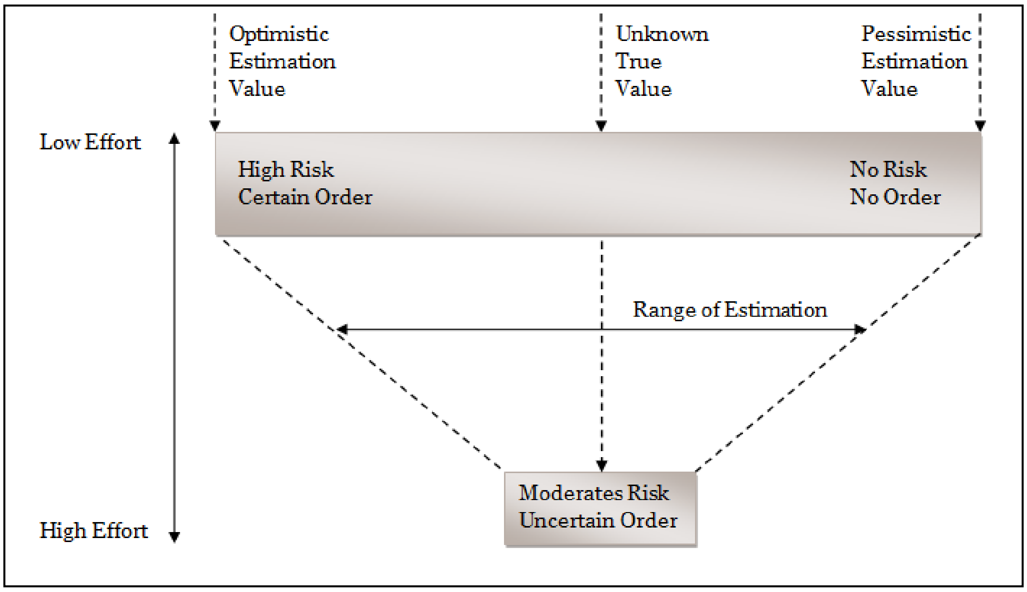


**Figure 3-5: The Effort-Order-Dilemma (Jakoby, 2015 p. 102)**

Uncertainties in terms of feasibility, deadlines and costs can be reduced by higher expenditure before order placement. But even then there is a problem. If other competitors do this too, they will come to similar results. The more competitors, the denser the offerings will be and the assignment depends on small differences, so it is more or less accidental. (Jakoby, 2015 p. 102)

**Possible Solution:**

For the described dilemma, there is no simple, flat-rate solution. The appropriate approach depends on various questions: Which own experiences with comparable projects are available? Which and how many competitors are there? How detailed is the customer's RSD? (Jakoby, 2015 p. 102ff)

The analysis of a requested task and the estimation of the required effort succeed the better and with less effort, the more experience with comparable projects. Therefore, it is important to systematically collect and evaluate the experiences gained during completed projects and also experience with queries that did not lead to the order. The insights gained thereby make it possible to quickly grasp the critical points of a task and, e.g. with the help of knowledge, to create rapid cost estimates. In addition, it is obvious to concentrate on those questions which are similar to those already carried out. (Jakoby, 2015 p. 103)

If the analysis of a task, the design of a possible solution and the associated calculation is complex, a smaller project can be connected to the actual project. It consists of an analysis of the most important requirements (pre-analysis) and a sketching of the solution design (preliminary design). On this basis, a calculation can then be carried out, from which the greatest uncertainties are eliminated. (Jakoby, 2015 p. 103)

If not only the cost budget and the timeframe are questioned, but the basic feasibility, the feasibility study can also precede the actual project. In DIN 69905 it is called a project study. This path makes sense especially for research and development projects with a high degree of innovativeness. (Jakoby, 2015 p. 103)

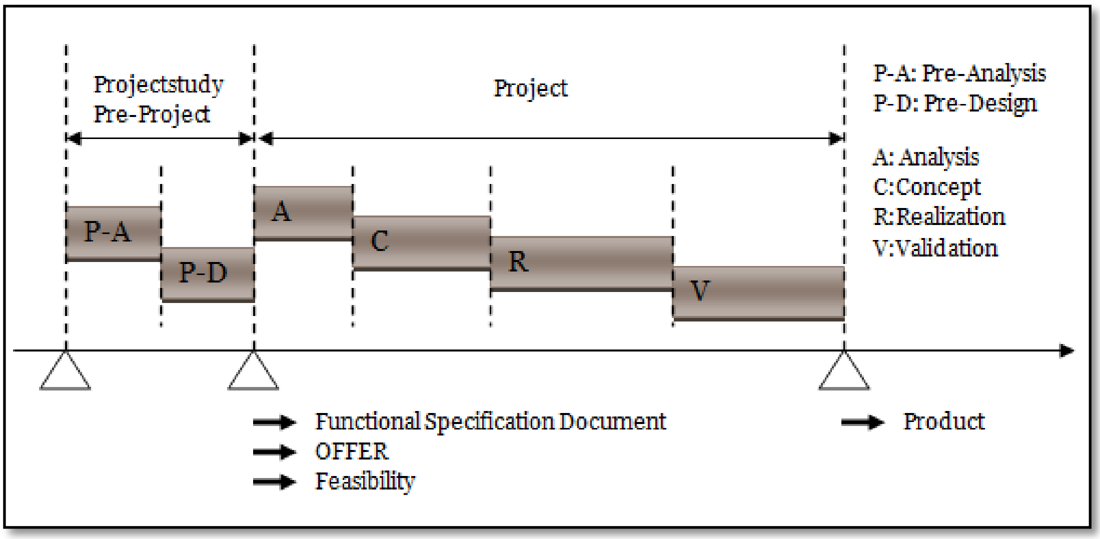


**Figure 3-6: Pre-Project and Projectstudy (Jakoby, 2015 p. 103)**

**Summary:**

The task, content and scope are the basis of the project foundation. In the RSD, the client describes his requirements for project implementation and project results. The contractor's response to this is the Functional Specification Document, explaining how these requirements are to be met. (Jakoby, 2015 p. 103)

Both documents are an integral part of the projectorder with which a contract is concluded between the customer and the contractor. This contract also contains statements on the costs, the services to be rendered and the financial contributions of the contractor. (Jakoby, 2015 p. 103)

Because of its uniqueness, each project contains many uncertainties. Reliable statements about the expected project costs are therefore difficult and complex. The effort before the project assignment is a major problem. Possible solutions are standardized tendering or project studies. (Jakoby, 2015 p. 104)

Not only objective criteria are important. The question must also be clarified whether the planned product or the future service corresponds to the customer's requirements profile. Defined quality and performance characteristics must therefore have a high priority for the customer in order to be able to generate a competitive advantage and to increase the feeling of quality. It is therefore necessary to determine, within the framework of the requirements management, the desired requirements with which values and which priorities. (Kohnhauser, et al., 2013 p. 108)

The first requirement for an order is to emphasize its intelligibility. Just because it is often a matter of professional tasks, a clear and simple language should be used. Clear and consistent requirements make the task clear. Misunderstandings and anger at the project conclusion is thereby avoided. Clients and contractors are often located in different specialist languages. Therefore, all important terms should be defined. The next step is to ensure that the catalogue is complete. Problems are usually not the core requirements of a project. These are under special consideration and are therefore seldom forgotten or presupposed by the client as self-evident. Both will lead to an annoyance in the course of a project or even only at the end of the project. A performance which has not been expressly requested cannot be complained afterwards. (Jakoby, 2015 p. 97)

Identifying customers and product requirements is one of the most important tasks within product development. For this, it is necessary to see the world with the eyes of the customers, in order to recognize the needs and wishes of the customers. If customer requirements are not taken into account or if important product requirements are forgotten and thus not realized, the result is usually a unsatisfied customer. It is immaterial whether the customer communicates his needs or not. In the end, it is the task of the manufacturing company to prepare structured and transparent requirements and thus to ensure that the needs are met as best as possible and the customer is delighted. (Kohnhauser, et al., 2013 p. 106f) For more complex products, the RSD can be relatively extensive. In order to facilitate the introduction of the RSDs to the problems of the RSD and to provide a quick overview, an introductory survey should form the beginning of the RSD. The survey should present a description of the current state of affairs in an easily comprehensible, not too detailed form, and list the important boundary conditions. (Jakoby, 2015 p. 98f)

As a result, the requirements management is highly responsible for defining the required quality, reducing the risk and the complexity of a product development. (Kohnhauser, et al., 2013 p. 106f)

The following diagram shows the schematic course of the influence, the definition and the development of the costs during the development. (Kohnhauser, et al., 2013 p. 107)

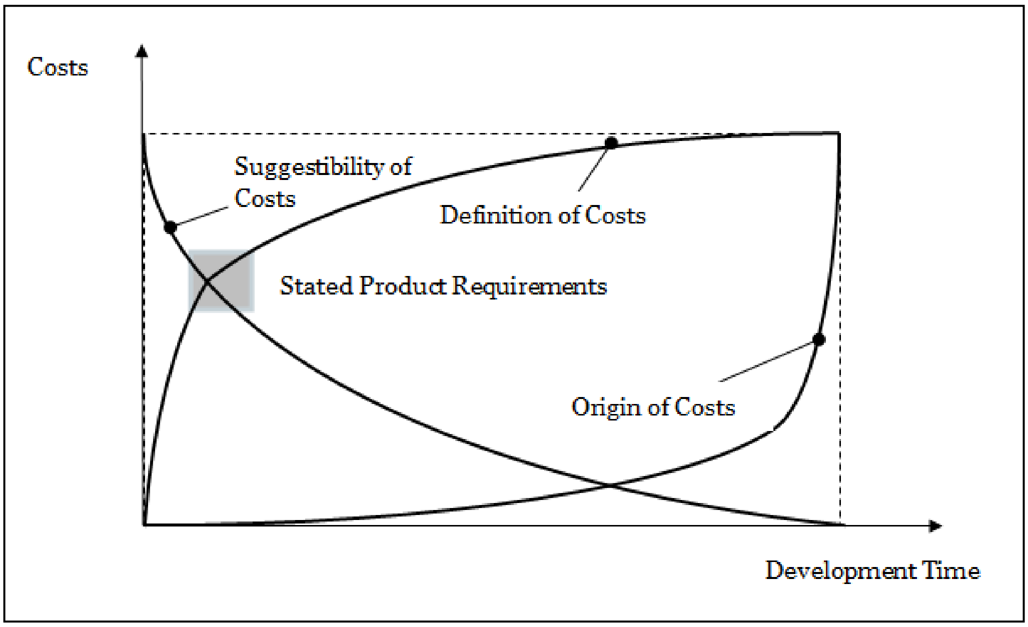


**Table 4: Suggestibility, Definition und Origin of Costs: (Kohnhauser, et al., 2013 p. 107)**

Much of the development and manufacturing costs of a product are fixed in the early development phases. Especially when specifying the requirements for the future product, the influence on the product and project costs is extremely high. The cost-effectiveness of the costs, on the other hand, decreases with every development step. In practice, it is always apparent that the cost of error prevention or fault elimination increases by around a factor of 10 in each phase. (Kohnhauser, et al., 2013 p. 107)

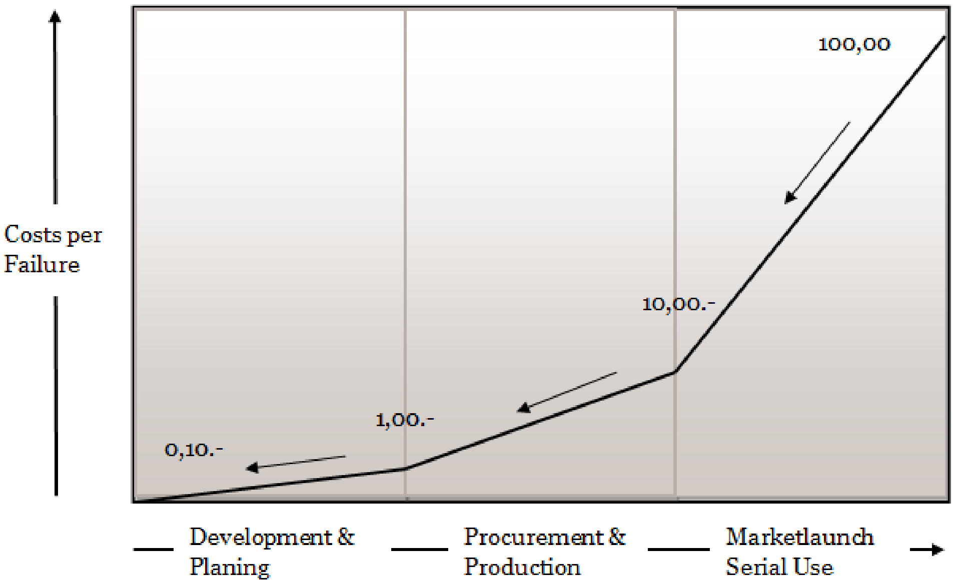


**Figure 3-7: Rule of Ten, Costs per Failure: (Kohnhauser, et al., 2013 p. 107)**

This means that mistakes made during planning and design, which are only discovered when the product is designed, in the course of production, during the final inspection or in the worst case only at the customer's own, are up to 1000 times higher than the cost of fault prevention during planning and design. In addition, this also means that the quality of the future product is already being influenced by the product requirements. (Kohnhauser, et al., 2013 p. 108)

In order to lead all parties involved in a project, in particular contractors and clients from different initial positions to a common legal basis, a general description of the object of the contract is necessary. This can be the description of the problem that causes the order. For product development the intended use is to be described. In addition, the initial state of the contract and the target state of the project should be documented. Useful is a glossary that defines the most important subject terms. (Jakoby, 2015 p. 99)

Therefore a constant monitoring, to guarantee the best customer orientation is necessary. In the specification requirement is listed what exactly should be developed. Demands and product requirements, the essential performance indicators, the target costs as well as the company internal and market relevant basic parameters. All those parameters must be defined in one coherent language, that every stakeholder understands exactly the same. The requirements must be clear, relevant and consistent as well as traceable. The key is to determine those parameters in the earliest possible stage of the product development and to scrutinize the necessity of them. Because every developed product has its unique specification requirement a standardization of the whole requirement specification is difficult. Anyway the development specific criteria should be defined to generate a basic structure of a guideline through the process. (Kohnhauser, et al., 2013 p. 122) An important tool for this measure is a criteria checklist:

| Content-related-Criterion fulfilled? | Yes / No |
|---|---|
| 1. Have the customer needs been adequately considered? | |
| 2. Are all functional requirements, procedures and relationships at the user level completely and unambiguously described? | |
| 3. Is the use of the system adequately represented? | |
| 4. Are the interfaces of the system sufficiently defined? | |
| 5. Have sufficient statements been made about non-functional requirements (Quality, ergonomics, system security, ...)? | |
| 6. Are the applications sufficiently described and defined? | |
| 7. Are the requirements decidable and verifiable? | |
| 8. Is the description of the business idea or the innovation complete and clear? | |
| 9. Does a complete system description exist? | |
| 10. Was a market segmentation carried out and is the target market sufficiently described? | |
| 11. Were regional requirements as well as specific customer requirements taken into account? | |
| 12. Were findings of a competitive analysis identified? | |
| 13. Are the essential performance data presented and described? | |
| 14. Were the individual product variants sufficiently defined? | |
| 15. Have relevant statements been made about the temporal goal (launch, product lifecycle, ...)? | |
| 16. Were applicable framework conditions observed? | |
| 17. Has a market valuation and sales volume estimate been carried out? | |
| 18. Has a expected pricing or an idea about price-willingness been fixed? | |
| 19. Have any guarantees or warranties been considered? | |

**Table 5: RSD product specific criterions (Kohnhauser, et al., 2013 p. 123)**

A good RSD must impress by clarity. It is not convinced by the wealth of information, but by the prioritization of the individual statements and the concentration on the essentials. The tone should be factual and also be comprehensible for technical amateurs on all important points. The RSD is based on the business plan or a visions document for a product. The business plan describes the economic environment, the targets and the resources to be devoted to a business idea. The RSD represents the corporate overall concept of a product for an investment decision. Furthermore, the RSD contains the contents of the business plan for the development of a product in a project. (Schienmann, 2004 p. 142)

**Content of the Requirement Specification Document:**

When preparing the RSD, particular attention should be paid to the precise formulation of the product environment and the necessary product properties in this environment. A detailed list of all requirements with variants and exceptions is out of place. This is the major objective of the Functional Specification Document (FSD).

The following points should be described in the RSD:

- ➢ The introduction gives an overview of the entire document. It serves as a summary for management and includes the following parts:
- ➢ The product overview closely reflects the current business plan of the product. The business idea, the target customer, the competitive advantage position and the necessary development steps are described.

- The problem description presents the current weak points of the actual state and shows how these should be remedied by product development.
- Subsequently, the objective pursued is sketched. This is done with regard to the planned product properties, which are to be modified, expanded or newly realized in the release.
- Finally, reference documents are mentioned which are relevant to the RSD (business plan, etc.)
- The next section characterizes the application area of the product. All factors are described which, as technical framework conditions, have an effect on the design of the product or must be taken into account in the product so that it can be successfully used. The two central elements for describing the application area are the business processes and the business objects.
- The business tasks and the resulting work organization including the involved roles in the application area are described with the business processes.
- The business objects specify the task carriers and control objects that are the central entities of the application area and their relationships among each other.
- The other professional frameworks cover all legal and cultural restrictions that must be taken into account in product development. (Schienmann, 2004 p. 143)
- Next, the technical environment of the application, including the system interfaces, is defined. The current technical environment can only be described as a framework condition if it is valid for the future product or if migration and conversion measures are an essential part of the product development.
- Firstly, the hardware and software configuration, on which the application system to be developed is based, is precisely analyzed and described.
- Subsequently, all interfaces that the system must operate in conjunction with other technical systems are identified and briefly presented.
- Finally technical or physical framework conditions are defined.
- Development and production frameworks are often defined in their own documents as organizational standards. In this case it is sufficient to refer to these documents in the RSD. Otherwise, the anticipated procedure, the results of this procedure and the tools used will be determined. However, development and design requirements should be limited in the RSD; they are described in more detail in the FSD together with the contractor.
- The following is a structured list of all essential product requirements
- All requirements are initially structured in group tables and grouped. The survey tables show at a glance priorities and underlying customer requirements. If available, should also be referred to existing applications. The structure is according to product-specific factors, for example the orientation on already identified building blocks or market products.
- Following the tabular overview, the individual requirements are described at this point. If an application case model exists, it is sufficient to refer to this.
- The application model provides an overview of all primary applications with the corresponding communication relationships with the model actors of the system.
- As a framework for development, the RSD should, of course, also contain information on the time and cost framework.
- The readability of the RSD and the search for content is increased by final directories (literature, index, and glossary). (Schienmann, 2004 p. 144)

In contrast to the RSD, the focus in the FSD is no longer on the environment, the customer requirements and the framework conditions, but on the precise representation of the system properties that must be implemented in the project. The product requirements of the RSD are re-examined in the FSD under the aspect of detailing implementation. The requirements described in the RSD are specified in a referenced and detailed manner. This is done both in a natural language form and through the refined modeling of applications and information objects. (Schienmann, 2004 p. 145)

# 4 Technology management

Technology management is a part of the corporate management's content. The technology portfolio includes planning activities for the long-term securing and strengthening of the market position of a company. The focus is on the targeted change of a technology, a product or the production technology used. The task of technology management is to provide the technologies required for current and future services at the right time and at reasonable costs. A separation of technology management from neighboring disciplines is not always possible. Technology and innovation management overlap and complement each other. Differences, however, exist in the respective objects considered. While technology management focuses on technologies in the sense of being able to do so, the concrete product is at the forefront of innovation management. Research and development management represents a cutting edge between technology and innovation management. (Schuh, et al., 2011 p. 5)

Technology includes knowledge and skills for solving technical problems as well as procedures and systems for the practical implementation of scientific knowledge. Technique is regarded as a sub-system of technology and is embedded in the traditional concept of understanding, which defines technology as the materialization of technique. (Bullinger, 1994 p. 34)

Functional technology management must also have a lifecycle of a technology in view with its spread. In the past, various models have been established which, in the light of various criteria, provide an understanding of fundamental aging phenomena of technology. The knowledge of these models is of great importance in the development of technological strategies. (Schuh, et al., 2011 p. 33)

With regard to technology, it is clear that there is a considerable potential for increasing competitiveness in technical progress. This is reflected in new products, better quality and increased efficiency of the products and also leads to considerable changes in almost all areas of life. Furthermore, due to technical progress, the development of ever shorter product life cycles has been achieved. (Bullinger, 1994 p. 5)

This development has led to profound changes in entrepreneurial activity in many areas of scientific research. In the past, technical knowledge and its consequences only gradually became apparent due to sparse flow of information and little accumulation of knowledge. Today, they are the immediate cause for permanent adaptation problems. In view of the international competition situation, technology-oriented companies are thus compelled to incorporate relevant technological developments through directional decisions within the framework of company management. (Schuh, et al., 2011 p. 6)

Therefore, technologies have a major influence on the competitiveness of companies. On the one hand, new technologies present strategic business opportunities with considerable chances for development. On the other hand, new technologies threaten those companies that base their success on obsolete technologies. Companies are therefore forced to develop, deploy and promptly replace technologies in a fast and customer-oriented manner. To achieve this, a company's management competence must be complemented by technological competences. This challenge is to be implemented by technology management. (Bullinger, 1994 p. 3ff)

In order to obtain a clear understanding of the scope, the contents and tasks of the technology management, a transparent and comprehensible structuring of the subject area is necessary. This structuring is seen primarily as internal factors such as research and development, production and management, as well as in the environmental spheres as external influencing factors such as competitors, suppliers. The internal aspects are divided into company processes, company development and corporate structure. Business processes for technology management include technology early detection, technology engineering, technology development, technology utilization, technology protection and technology assessment. The technology development as well as the evaluation is illuminated in more detail in these chapters due to the relevance in the practical part. (Schuh, et al., 2011 p. 11)

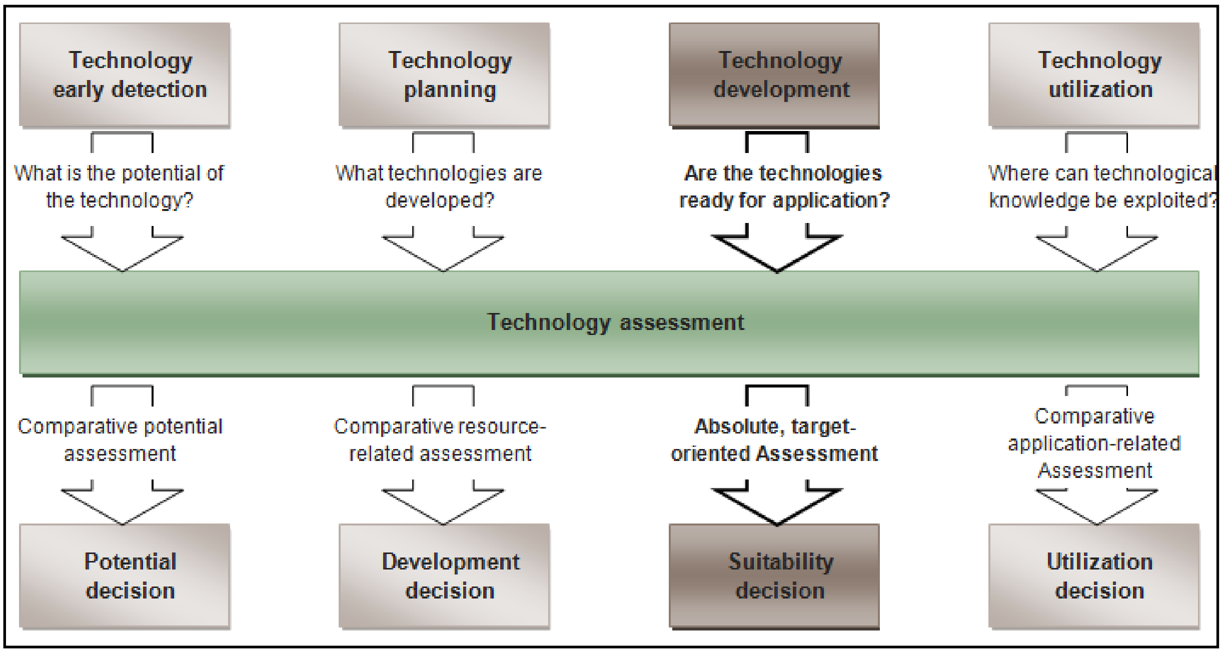


**Figure 4-1 : Situation of decisions within the Technology management (Rummel, 2014)**

Technology is defined as a factual approach that results from combined techniques. In the technical interpretation, in production technology the laws of procedures for the production, transformation and processing of material, in work organization the structures of technical, economic and organizational components, in economics the technical knowledge in the whole of technical knowledge, skills and possibilities and in science theory from derived system of rules for practical action in any human action areas. (Bruns, 1991 p. 62)

The target of this chapter is to gather a generic overview of technology validation systems as well as how these technological concepts could be measured and managed. “Technology Management could be defined as the planning, organization, realization as well as the knowledge about technologies, which already exists for the company and could be used for the creation of new products”. The basic idea is to generate a structured approach of the development steps of a product technology and to identify the major important criteria for each step and the validation with degree of maturity systems to evaluate the suitability for a finished technology. (Rummel, 2014 p. 23) Technology Management could be therefore another important column for the increase of transparency of a system engineering process.

## 4.1 Basic Concept

The triggers for technology development could come from different direction. For these Master-theses the terms “Market-Pull” and “Technology Push” will be explained within more detail. Market-Pull means that the demand for innovation or a new technology is coming from outside the company. The requirements are generated from the customers need or the market. So the basic impulse is coming from the market and the company should be able to solve the customer problem with innovative, efficient manner. (Vahs, et al., 2005 p. 80) For most cases the Market Pull approach is leading to product- and improvement innovations (Strebel, 2007 p. 41).

The opposite is the Technology-Push which is oriented from the inside of the company. This approach is used mostly for technologies with a higher degree of innovation. (Schmeisser, et al., 2010 p. 30) This is the autonomous approach basically for the development of new technologies or different combinations of existing technologies for innovative products (Specht, 1999 p. 32). Due to development of technology push products, the Risk of failure is greatly higher than Market Pull technologies. (Strebel, 2007 p. 41)

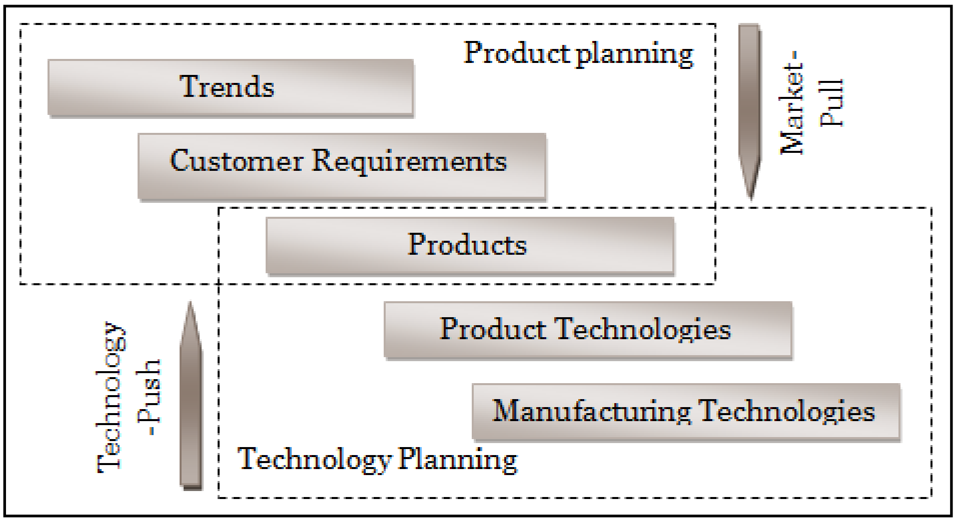


**Figure 4-2: Areas of influence of product and technology planning on planning levels (Schuh, et al., 2011 p. 189)**

The product program can be planned as a Market-Pull approach on the basis of the identified customer requirements by defining product-relevant trends to meet customer requirements. On the other hand, new product ideas in the Technology-Push can also result from the technological skills of a company. (Vahs, et al., 2005 p. 80)

One goal of technology planning is, in particular, the fulfillment of the requirements defined by the product program and / or by technological projects. It is thus decided to use the technology to implement the product program. Trends with direct technological relevance as well as specifications from the technology strategy are also taken into account. Thus the product program of a company forms the interface between product and technology planning. Synchronization of the planning levels takes place in different ways in the case of short- or long-term planning horizons. (Schuh, et al., 2011 p. 189)

The product program has already been defined for a short-term planning horizon. The products are described by means of characteristics, often already finished. Within the framework of technology planning, the necessary information on the realization of the product characteristics and the production of the components and the overall product are listed. In addition, it is conceivable that short-term technological alternatives which have so far been discarded make possible product features or production variants possible. In this case, in the sense of an iterative process, modifications of both product and technology planning are carried out in order to maximize the utilization and to identify technologically and economically feasible solution variants. Coordination between both planning processes is absolutely necessary here. This tuning can be supported via the so-called Technology-Road mapping. This method compares and combines the product and manufacturing technologies involved in planning. (Schuh, et al., 2011 p. 189)

However, no product program has yet been defined for a long-term planning horizon, so that this cannot be used as a starting point for the synchronization of product and technology planning. Synchronization of the planning levels is carried out in this case with the aid of the technological-strategic requirements. These requirements describe, for example, technological competences and technology fields that are to be built over the long term. Such a long-term approach is indispensable as the life cycle of technologies typically exceeds those of products by a large number (Schuh, et al., 2006). Synchronization of product and technology planning takes place with long-term time horizons therefore by careful definition of long-term technological competences and by their consideration in technology planning. (Schuh, et al., 2011 p. 190)

| Description features | Technologie Push | Market Pull |
| --- | --- | --- |
| Technical feasibility | high | low |
| R&D expenses | High | low |
| R&D time | Long | short |
| Related uncertainty | high | low |
| Marketing start time | Unsafe / unknown | Safe / known |
| Customer integration in R & D | difficult | simple |
| Type of market research | Qualitative-discovering | Qualitative-testing |
| Customer behavior / competence change | To a considerable extent required | Hardly required |
| Type of Innovation Process | "Trial and learning process" | "Structured milestone process" |

**Table 6: Idealistic characteristic of innovations with very high and very low degree of innovation (Ziegler, 2006 S. 96ff)**

## 4.2 Technology Management Process

Targeted technology planning enables companies to adapt effectively and continuously to a highly complex environment both on the market side and in the technology. The central element of technology planning lies in the creation of transparency, which is generated by the communicative exchange of the various business areas (e.g. research, development, production, sales, product management, marketing) in the preparation and discussion of the technology plan. This result in more effective and efficient technology planning that reduces the number of misfits and shortens the response time for unexpected market or technology-related changes. In the case of unforeseen situations, this transparency makes it possible to recognize and elaborate possible action alternatives more quickly. The process of technology planning must ensure the following aspects in order to enable effective and efficient technology planning: (Schuh, et al., 2011 p. 190)

***Targeted discussion*** makes it possible to present a technology plan, e.g. as a road map, is intended to increase the understanding of the connections between individual planning levels. This enables the discussion of a company's overall technology plan without losing itself in detail discussions.

***Synchronize the planning levels*** Technological planning must allow the adjustment of different levels of the technological plan, in particular for market, product and technology. Significant is the visualization of the interrelationships between the individual levels so that the effects of changes in a level on the other levels can be quickly recognized. Any existing gap in the planning can be identified more quickly. Instead of optimizing optimal but isolated plans for every planning level, technology planning is optimized throughout the company by a holistic approach.

***Stakeholder commitment*** Technology planning is a holistic approach that should involve all actors relevant to the technology (development, production, marketing, etc.). This creates a high degree of binding as all stakeholders are involved in the development of the technology plan and agree to it. The technology plan thus becomes the basis for strategic and operational technology planning. The technology plan must therefore be used as a key element in decision-relevant boards with regard to technology-oriented topics.

***Anchoring of alternative thinking*** A technology plan should consider alternative future developments and derive alternative technology paths. Technology-related plans are therefore possible. This results in the ability to react quickly to changes and to better position them in a dynamic and complex environment.

***Ensuring planning efficiency*** Targeted technology planning requires a concentration on essential aspects. Contrary expectations are revealed and contrary planning can be more easily identified.

Without an interdisciplinary and cross-functional planning, many disagreements would remain hidden until a later, more unfavorable time.

***Integrating Early Detection*** It is important to predict and evaluate the future technological developments in a field of action by means of a systematic collection and bundling of expert knowledge as well as the coordination of divergent opinions and expectations. Based on the technical planning guidelines, search fields can be derived for a goal-oriented early detection. (Schuh, et al., 2011 p. 191)

The structure of the technology management process is oriented primarily from a strategically oriented view to technology management, primarily in a business process for the strategic design of technology management along the lifecycle of technologies. The business process is understood to be the core market activities of the company (Perillieux, 2011). All the selected approaches have in common the fact that the use of technology requires an early discussion with boundary conditions. This includes the complex consideration of the technical, economic, ecological and social aspects of technology. As already mentioned, the process of technology management is divided into six interlinked aspects. (Schuh, et al., 2011 p. 15)

- Technology early detection: The early recognition of technology represents an element of strategic entrepreneurial recognition. The purpose of this early warning is to provide timely relevant information about changes throughout the company's environment in order to identify potential opportunities and risks at an early stage. The creation of a strategic information base supports strategic decision-making processes within the company and represents a link between strategy formulation and technology planning. The objective is to identify developments in relevant technology fields as the basis for technology decisions within the company.

- Technology planning: Planning involves the determination and systematization of all activities, processes, costs, resources and schedules, and represents the intellectual anticipation of future action (Strebel, 2007). Within technology planning, this means making the right decisions with regard to the future technological orientation of the company and thinking ahead of its implementation. It is therefore necessary to answer the questions of the technologies and ways in which the turnover and the market shares of a company are improved, customer requirements are better met, company potentials are strengthened and competitive advantages are achieved (Specht, 1999). While the technology strategy describes the objectives, technology is used to design the way of achieving the goals. The results of the technology planning are the technology plan, which describes which technology is to be used at which time and for what purpose. In addition, resources are defined with regard to resource planning. As a result of the technology planning process, concrete, implementable requirements for the development and use of technologies are emerging (Klappert, 2006).

- Technology development: Technological development has the goal of efficiently implementing the requirements of technology planning. This means that the requirements for the development of new or improved technologies have to be defined already in the enterprise of existing technologies in the given time and with the existent resources. For this, a stringent technology development process is required that already uses a technology at the idea stage. Technology development projects can be processed by means of internal resources (Ehrlenspiel, et al., 2007). The development process thus applies to internal developed technologies as well as projects with external development partnerships. The formalism of the process is indispensable for the generation of transparency and for the preparation of a decision-making process for technology planning. However, the process should not behold the engineers from being creative and further the process should give also a certain amount of flexibility to the employees to react on changes in the development more smoothly and rapidly.

- Technology utilization: The strategic framework for action, which opens up to the question of technology utilization, first comes into the two neutral dimensions of internal technology utilization and external technology utilization (Birkenmeier, 2003). Internal technology utilization focuses on the use of unique technological skills in the company's products. The goal is to provide the company with a sustainable competitive advantage through the use of technological capabilities in products as well as to enable a broad use of technologies (Brodbeck, 1999). In external technology utilization, technology is transferred to third parties, which has a positive effect on the profitability of technology investment.

- Technology protection: Technology protection aims to use its own innovation power to protect its own technological developments before know-how transfer to competitors in which protective mechanisms are developed. These should prevent the imitation potential of a technology.

- Technology assessment: Decisions that require a technology assessment occur in all phases of technology management. High performance in the technology assessment is an important, cross-phase requirement for the more efficient and effective design of technology management. The technology assessment defines the determination and assessment of the degree of fulfillment of given objectives.

(Schuh, et al., 2011 p. 15ff)

### 4.2.1 Validation of technologies

Technology assessment means the validation of a technology against the background of different criteria in different decision-making situations; different methods of the technology assessment have to be used. The methods can be distinguished into quantitative and qualitative methods. While in the early stage of technology, the focus should be on qualitative assessment methods, the quantitative processes are at the forefront in the later phases of the technology manning sector. Therefore, an appropriate valuation method must be selected for the respective decision-making situation. The exact knowledge and the relationship of the underlying assessment logic are important for the application of the method. Only then is the result of the evaluation comprehensible and debatable. (Specht, 1999 p. 337)

The technology assessment plays the role of a cross-section function within the technology management process. It serves to provide the necessary information basis in various decision-making situations. Decisions that require a technology assessment occur in all phases of technology management. A high efficiency in the technology assessment or the ability to select, apply and control the respective decision-making process is therefore an important, phase-wise requirement for the efficient and effective design of the technology. (Schuh, et al., 2011 p. 309)

Technology assessment is used to prepare different decision-making processes. Examples of this are yes / no decisions concerning the fulfilment of target criteria, selection decisions for the formation of rank and sequence, or the selection of favorable alternatives or decisions to change influencing factors on the value of technologies. Technology assessment can therefore mean determining the advantages and disadvantages of different alternatives from different perspectives, but also measuring or estimating parameters of the assessment object. The evaluation, or rather the comparison between the determined the target state with the actual state of a valuation object, is carried out on the basis of valuation measures and with the help of appropriate assessment methods. Within the framework of technology management, a large number of different approaches and procedures are available. (Specht, 1999 p. 337)

The use of assessment methods is intended to increase the quality of the decisions and thus the probability of success. In a first step, the various grades according to Schuh can be divided into the following classifications:

- Classificatory assessment of technology or rather the formation of technologists
- Comparative assessment of technologies (technologies are put in relation to one another)
- Metricated valuation of technologies (classification of numerical values)

A key feature of technology-related assessment and decision-making processes is the processing of information, which often has a high degree of uncertainty, as well as the generation of forward-looking statements. The number, type, complexity and dynamics of technology development give the technology planning of companies a changing framework that makes the assessment considerably more difficult. In addition, technology decisions are increasingly influenced by a series of characteristic developments linked to the changing contexts of technical innovation: (Pfeiffer, et al., 1995)

- Increasing knowledge deficiencies and problems in the prognosis of technical developments and needs
- Increasing cross-linking and multi-step progress of technical innovations that lead to ever-increasing prognosis problems
- Increasing dynamics and complexity in the reciprocal feedback processes during the emergence of new technologies

Due to the incomplete and uncertain information base, on which technology assessments often have to take place, the qualitative approach in the expert circle must be given precedence over quantitative reductionist values. (Schuh, et al., 2011 p. 311)
The tasks of the technology management as mentioned before could be divided in four areas:

- Technology early detection
- Technology planning
- Technology development
- Technology utilization

These four management areas also represent the phases that technologies are going through sequentially in a company over the course of their stay. The decision-makers within each of these four phases must ensure that only such technologies are permanently built up in the company, which increase economic value. Likewise, obsolete technologies must be replaced timely. (Schuh, et al., 2011 p. 312)
Evaluation of early-stage technologies means the assessment of incomplete information. In order to supplement missing information, empirical analyzes or expert assessments must therefore be used to a great extent. Due to the early development stage of the technologies considered, future performance features can only be prognosticated and there is no concrete information on the application of the technologies considered within the products or production processes. (Schuh, et al., 2011 p. 313)
The selection or application of valuation methods is significantly influenced by the uncertainty prevailing in this early technological stage. Their common feature is a very weak or low level of information, which can be interpreted in a clear manner. But the very early detection of weak signals is essential in order to secure a sufficient reaction time and to increase the scope for action against the competitors. Therefore, these decisions must be made with high uncertainty. (Rummel, 2014 p. 63)
An important point in technology early detection is the assessment and procurement of the available information. This requires enormous experience and technological expertise. Information can be obtained by scanning the technological environment up to the appropriate monitoring up to the order-related information procurement (scouting). The purpose of the information assessment is to create a sound information base for the technology orders to be developed, and to assess the performance parameters as well as the definite company-specific key factors. The assessment is based on the context, that is to say, according to the criteria and requirements defined by the stakeholders, and to be further adapted in the next phases. The following criteria can be used to evaluate a multidimensional analysis. (Schuh, et al., 2011 p. 314f)

- Possible (technical) performance parameters of the new technology
- Forecast of the expected costs and the use of the technology option
- Detailed assessment of opportunities (e.g. market / synergy / competition potential) and risks (e.g. implementation / acceptance risks)
- Determination of the (strategic) relevance of the technology options for the company

- Estimation of the necessary implementation costs (including financial expenses for R&D projects, need for help technologies, etc.)

The evaluation of these criteria is based primarily on the assumptions of the technology forecast and serves as a prognosis for the development. These analyzes are intended to ensure that only the technology options with the greatest chances for the technology selection are transferred into the technology planning. The objective of the information evaluation is to obtain a comprehensive assessment of the respective technology to be evaluated. (Schuh, et al., 2011 p. 315)

The decision which technologies should be adopted as technology alternatives in the planning phase cannot be based on a complete, quantitative statement on the monetary value contribution of the technology but must be made on the basis of a predominantly qualitative assessment. Because no direct investment decisions or research and development budgets follow the decisions taken in early detection, more complex, quantitative assessments are already unjustified at this time. (Rummel, 2014 p. 41)

In order to increase the reliability of these projections, both quantitative and qualitative methods are used. **Quantitative** approaches are mainly based on models of technology evolution such as, for example, Lifecycle-related and demand-driven models. In the following, the following approaches can be mentioned: cost-benefit analysis, value-utilization analysis, as well as regression analysis and model simulation. (Schuh, et al., 2011 p. 316)

Qualitative procedures, on the other hand, integrate quantitative information, but are based to a great extent on expert surveys or assessments. These include the scenario technology as well as the Delphi method as specific methods of technology early detection. Finally, it is indispensable to use a series of basic methods for evaluation in early technology detection. The advantage of those methods is the high level of flexibility which allows an adaptation of company-specific boundary conditions. (Schuh, et al., 2011 p. 316)

The major objective of all those assessment methods is basically the approach of reducing the uncertainty in the development within the technology lifecycle. (Schuh, et al., 2011 p. 316)

The pre-development projects initiated in technology planning must be subject to regular controlling. This is due to the logic of the stage gate approach, which is intended to specify the structure of technology development projects. Here, the development process is divided into phases and gates. An illustrative analogy is the product development process. This is subdivided into different work steps that are carried out sequentially or in parallel. There are quality control points between the individual workstations, where certain work results must be available or quality criteria must be met (Cooper, 1990 p. 44ff). In principle, it can be said that the expenditure per development phase increases as the project duration progresses. At the same time, however, the information basis of the valuation is improved according to each gate. Therefore, the criteria for the respective project phase must be carefully considered and tailored to the respective project phase. (Schuh, et al., 2011 p. 320)

Technology development projects are inherently risky because, as a rule, at the beginning of the project, there is no concrete application in the form of products or processes for which the new technology is to be applied. The commercial use is thus not yet clearly recognizable. There is also great uncertainty about the technical feasibility. Because of these many unknowns, there is little point in evaluating technologies in the early stages of their development with monetary indicators. As regards the valuation of projects with a low risk of development in relation to the probability of success, the experience shows that quantitative methods are better suited to these projects than qualitative ones, as these projects usually have a low degree of novelty and are therefore more easily valued on a monetary basis. Unlike innovative projects with a high degree of novelty, a quantitative assessment often would distort the results. (Schuh, et al., 2011 p. 321)

Decisions that require a technology assessment occur in all phases of technology management. High performance in the technology assessment is an important, interdisciplinary prerequisite for the efficient and effective design of technology management. The ability to select, apply and control the valuation approaches adapted to the respective decision-making situation is of great importance. In the sense of a general conceptual definition, technology assessment means the determination and assessment of the degree of fulfilment of predetermined objectives or states for a particular

technology-related assessment object in order to make decisions in the development, introduction and use of technologies. (Schuh, et al., 2011 p. 17)
Benchmarking requires application-specific assessment methods. Therefore, it is necessary first to consider the objectives and the content of the evaluation. Assessment in the most general sense is the validation of the degree of goal fulfilment for a particular valuation object. It is necessary to make the best decisions for the company's activities. The focus is always on the best possible fulfilment of corporate, technical, ecological and social goals. From this it can already be seen that it is generally a multidimensional problem. Assessment therefore requires an exact determination of the actual situation for the object in question, the definition of challenging and realistic goals which are to be achieved within the company, which are derived from the strategic orientations as well as from external requirements and standards as well as the comparison of the target and the actual state on the basis of a clear assessment scale and with the help of appropriate assessment methods. (Birkhofer, et al., 1997 p. 26)

**Benchmarking:**
Benchmarking involves the comparison of the product, process or other evaluation object with suitable, comparable reference objects from the sector or beyond the sector, the determination of the respective best solutions and the estimation of the achieved development level. A variety of methods are available for the evaluation. Their general classification shows Figure 4-3: Assessment methods . In the benchmarking process, one-dimensional as well as multi-dimensional and qualitative procedures are used for the complexity of the evaluation objects.

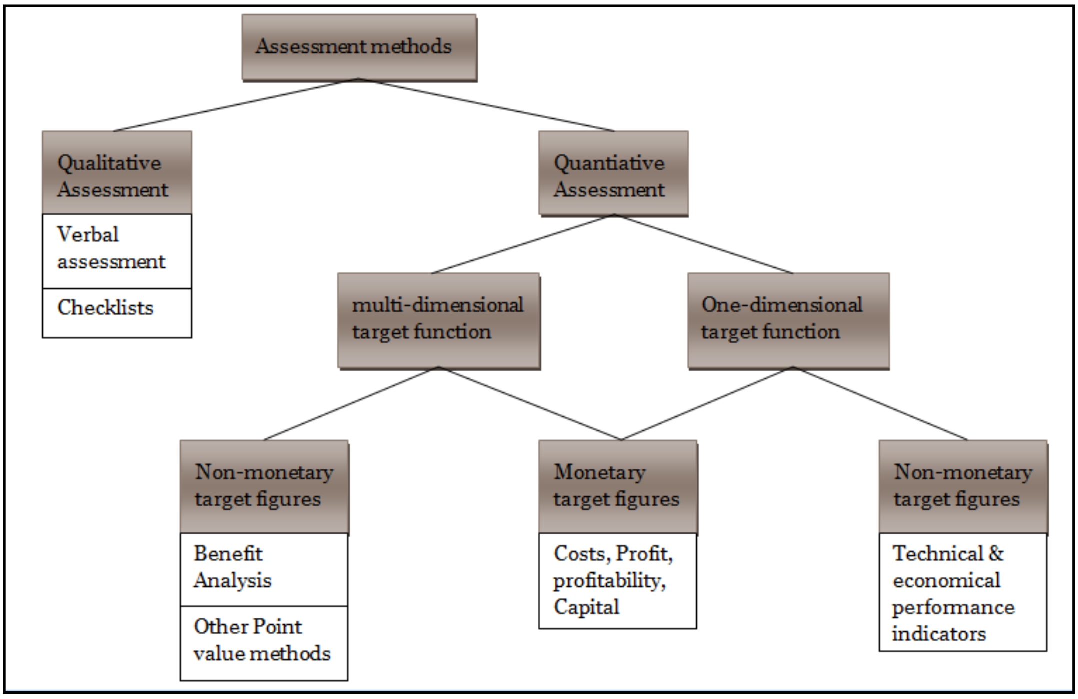


**Figure 4-3: Assessment methods (Birkhofer, et al., 1997 p. 27)**

The application of benchmarking is not a one-time task, but it permeates the entire innovation process from the idea finding to the market introduction. This requires:
A constant update and clarification of the benchmarks determined for the development of the FSD in accordance with the constantly changing market and technology situation.
The adaptation of the methodological instrument to the progress of the innovation process
The integration of benchmarking and development
Benchmarking is therefore to be designed as a process-integrated and dynamic management tool. Another crucial aspect is that it is not considered as a method for the simple copying of already existing solutions, but also supports and inspires the creativity of the researchers and developers.
(Birkhofer, et al., 1997 p. 47)

The typical benchmarking values for innovations are both quantitative (key figures) and qualitative (verbal expressions and values). The determination, analysis and evaluation provide crucial starting points for the improvement of the results and the process sequence of innovations and are one of the tasks of research and development controlling. The possibility to apply in benchmarking in research and development is decisively determined by the structure ability of the problems to be solved and the R&D processes applied for this purpose. The more easily structured the individual processes, the easier is the measuring, comparing and evaluating, the higher the implementation opportunities for benchmarking. (Birkhofer, et al., 1997 p. 47)
Benchmarking is a useful tool in determining the performance of a system and if it meets the right requirements. (Azimi, et al., 2011 p. 16)
Benchmarking requires both quantitative and qualitative assessment criteria. While quantitative variables can be clearly measured and expressed in figures, qualitative variables are not objectively measurable. The assessment of qualitative criteria can be carried out in two ways: on the one hand, the measurement of auxiliary variables. This would be, for example, the complexity of a product due to the number of parts or functions. On the other hand, the assessment can also be carried out through the subjective assessment of developers or engineers, such as person surveys or customer surveys. (Birkhofer, et al., 1997 p. 27)
Benchmarking as an instrument for the consistent orientation of a company to the relevant best solutions is not limited to the improvement of existing products, processes and organizational structures, but also serves to create new problem solutions. By selecting the existing or expected best performances as the benchmark in the idea finding, designing and planning of innovations, the greatest possible potential for improvement can be developed. Benchmarking therefore has particular significance for innovation management. Innovation is the enforcement of new technical, economic, organizational or social solutions to problems within the company. It is designed to meet corporate objectives in a new way in order to be able to cope with the intensifying global competition. Innovations arise through complex processes, ranging from the generation of ideas to research and development, to the production and launch of the market. They include the successful practical application of new problem solutions and must be measured at the degree of novelty. In this respect, as innovation capability requires the detailed knowledge of the performance level of the company and of the most important competitors. The better this condition is fulfilled, the more effective the former can be in new territory.
Innovation does not come by itself, but requires professional innovation management. Innovative management includes complex strategic, tactical and operational tasks for the planning, organization and control of innovation processes, as well as to create the necessary internal conditions as well as to make use of the existing external framework conditions. Its specific is that the processes to be designed are not routine tasks, but are new activities with uncertainties and risks. This requires the use of new, powerful instruments. One of these is benchmarking, which implies improvements and delivers key points. (Birkhofer, et al., 1997 p. 45)

**Technology Readiness Levels:**
Another important approach for the assessment of technologies is the definition of the Technology Readiness Levels after (NASA, 2007). The concept was first used in the 1980s for the measurement of the maturity of different technologies. The validation system was invented by the former advanced concepts director, John Mankins who defines TRLs as "systematic metric or measurement system that supports assessment of the maturity of particular technology and the consistent comparison of maturity between different types of technology". (Azimi, et al., 2011 p. 116)

| Technology Readiness Level | Description |
|---|---|
| 1. Basic principles observed and reported | Lowest Level of technology maturation. At this level, scientific research begins to be translated into applied research and development |
| 2. Technology concept and/ or application formulated | Once basic physical principles are observed, then at the next level of maturation, practical applications of those characteristics can be invented or identified. At this level, the application is still speculative: there is no experimental proof or detailed analysis to support the conjecture |
| 3. Analytical and experimental critical function and/or characteristics proof of concept | Active research and development is initiated. This must include both analytical studies to set the technology into an appropriate context and laboratory-based studies to physically validate that the analytical predictions re correct. These studies and experiments should constitute "proof-of-concept" |
| 4. Component and/or breadboard validation in laboratory environment | Basic technological elements must be integrated to establish that the "pieces" will work together to achieve concept-enabling levels of performance for a component and/or breadboard. This validation must be consistent with the requirements of potential system applications. <the validation is relatively "low-fidelity" compared to the eventual system |
| 5. Component and/or breadboard validation in relevant environment | The fidelity of the component and/or breadboard being tested has to increase significantly. Basic technological elements so that the total applications can be tested in a simulated or somewhat realistic environment |
| 6. System/subsystem model or prototype demonstration in a relevant environment(ground or space) | A representative model or prototype system would be tested in a relevant environment. At this level, if the only relevant environment is space, then the model/prototype must be demonstrated in space |
| 7. System prototype demonstration in a space environment | Actual system prototype demonstration in a space environment. The prototype should be near or at the scale of the planned operational system and the demonstration must take place in space |
| 8. Actual system completed and "flight qualified" through test and demonstration(ground or space) | The end of true system development for most technology elements. This might include integration of new technology into an existing system. |
| 9. Actual system "flight proven" through successful mission operations | The end of last "bug fixing" aspects |

**Table 7: Technology Readiness Levels (TRLs) (NASA, 2007)**

The valuation based on the TRL is a risk-based assessment method which according to AZIMI determines the risk for integrated technologies. This assessment is also available for the integration of technologies and their development maturity. (Azimi, et al., 2011 p. 124f)
The Technology-Roadmap is used to structure and present the technologies to be developed and to determine the maturity of a technology. (Azimi, et al., 2011 p. 121f)
According to (NASA, 2007 S. 295), the technical assessment of a system development at an earliest possible time is decisive. The idea of the technical assessment process is the division of the problem into systems and subsystems as well as components which can be verified with a higher accuracy. It is a process based on two aspects. The first aspect deals with the technological development level on the basis of the TRLs. The second aspect is linked to the first aspect, with the determination of technology from one TRL to the next on the basis of the Advanced Degree of Difficulty Assessment AD. The AD includes the provisional development costs as well as the provisional risk assessment. The scope of the assessment process is an iterative approach which in the early development phase starts the preliminary costs, schedule and the risk reduction plan. (NASA, 2007 S. 296)

### 4.2.2 Methods of Technology Validation

Technological assessment methods are used in every phase of technology management. They make it possible to prepare a decision based on a complex information basis. Against this background, many evaluation methods have been developed in the past, which help the decision-maker in different situations to draw the essential insights from an initially opaque information situation. An important aspect here is the structuring of the information basis in the context of a concrete decision. The methods can be distinguished between qualitative and quantitative methods. While in the early stage of technology, the focus should be on qualitative assessment methods, the later phases of technology management tend to focus on quantitative methods. The appropriate assessment method must therefore be selected for the respective decision situation. (Schuh, et al., 2011 p. 363) Within the next few pages the method of Technology-Roadmapping will be described in detail.

**The procedural Method of Technology-Roadmapping:**

Technology-Roadmapping has become established as a standard in industrial practice for the implementation of technology planning. The methodology of Technology-Roadmapping provides an approach to support the process of technology planning and, in particular, the coordination of the planning levels considered in technology planning. Roadmaps provide information on current and planned projects, previous decisions, dependencies and causalities. As the name suggests, the roadmap helps the tax-hiring manager to control his entrepreneurial drive through the unknown terrain (Möhrle, et al., 2008 p. 1ff). It is not only possible to determine the current position, but also to clearly plan and display the route to the destination along with its intermediate and alternative routes.

The two main components of Roadmapping are the road map and the roadmap process. Roadmaps are available in many versions. Roadmaps can thus be used to plan products, capacities, strategies, as well as for long-term planning and integration planning, whereby different forms of representation can be used. A generic presentation exists from the European Industrial Research Management Association (EIRMA), which is shown in Figure 4-4. (Schuh, et al., 2011 p. 207)

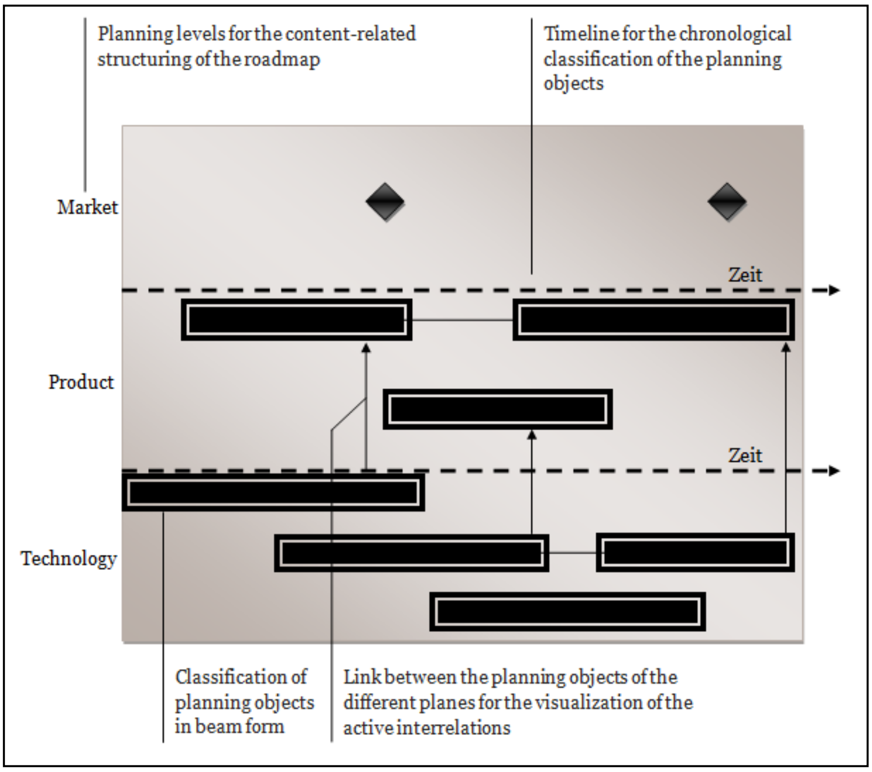


**Figure 4-4: Constituted elements of the technology roadmap (Schuh, et al., 2011 p. 207)**

In order to support technology planning through technology-Roadmapping, a clear target definition is the basis for the successful initiation of the Roadmapping process. Another important aspect of technology Roadmapping is the creation of binding. All those involved in the process commit themselves to the decided planning. (Schuh, et al., 2011 p. 212)

The participants of the Roadmapping process are responsible for contributing all relevant information, open communication and finding a common path in the Roadmapping process. There is, so to speak, an obligation to vote for a common one. (Schuh, et al., 2011 p. 216)

Within technology planning, this means making the right decisions with regard to the future technological orientation of the company and foreseeing its implementation. It is therefore necessary to answer the questions of the technologies and the ways in which the turnover and the market shares of a company are increased, which better meets customer requirements, strengthens company potentials, strengthens competitiveness advantages and accelerates time, and remove weaknesses (Pleschak, et al., 2002 p. 337f). Product engineering in a wider sense focuses on all activities for realizing a specific product. This also includes process development for the realization of the production technologies required for the production of the products. Furthermore, external development work must be taken into account by suppliers. (Schuh, et al., 2011 p. 225)

With high technical uncertainty, a decoupling of the technology development from the actual product development process is useful (Brodbeck, 1999). The separation of technology and product development is, on the one hand, also required to pursue risky, more radical and potentially more promising technology and innovation (Möhrle, et al., 2008 p. 1ff). On the other hand, it is necessary to increase efficiency throughout the entire development. The success rate for product developments should be 90%. The content risk is to be intercepted within the technology development projects. The organizational separation between technology and product development is a key issue here. This separation forms an interface that must be carefully designed to ensure a successful transfer of the technologies developing into mature products into product development. The two development processes must therefore be linked by a technology transfer. (Brodbeck, 1999)

Technology developments can be guided by future market requirements or customer requirements (market pull). The development is not yet aimed at a specific product, but rather on the fulfillment of the identified customer requirements in one or more product segments. Technology development is thus determined on the one hand by the product market strategy (Möhrle, et al., 2008 p. 1ff). The potential of a technology development can be measured against the market potential when meeting the anticipated customer requirements. In addition, technological developments can result in market demand (technology push). On the other hand, current technological developments influence the technology strategy and also influence the product and market strategy. (Schuh, et al., 2011 p. 227)

The technology development process has the task to efficiently implement the planning requirements. This means that the requirements for the development, new or an improvement already exist in the existing technologies, with the existent resources (Beckermann, et al., 2008 p. 513ff).

The formalism of this process is indispensable for the generation of transparency and for the preparation of a decision preparation for technology planning. (Schuh, et al., 2011 p. 228)

The task of technology development is to develop the technologies to a degree of maturity in which basic feasibility is demonstrated and a product development process can be initiated (Burgstahler, 1997).

The technology development process must ensure the most efficient processing of the technology development projects possible. In addition to efficiency, the efficiency in technology development is a major challenge (EIRMA, 1997).

It is therefore a central challenge of technology management to prioritize the right ideas and technologies and to stop technology developments with a low potential at an early stage. To ensure this, a structured process requires continuous monitoring of the progress of the technology development projects as well as their evaluation. On the other hand, the formalism of the process must not be overwhelming in order not to limit the creativity and freedom of new developments. (Schuh, et al., 2011 p. 228)

Because of the risks inherent in technology development, there is no guarantee that a development process will ever lead to a successful product development. Therefore, a technology development process, in contrast to the product development process, must not be judged as to whether it leads to many product developments, but must be assessed according to how efficiently it analyzes and evaluates the suitability of a technology for the exploitation in products. A poor technology

development program is not focused and moves on erroneous paths, which makes it inefficient and the company leads to false conclusions about its potential (Eldred, et al., 1997 p. 41ff).
Against the background of the tasks and objectives outlined, the following requirements after (Lichtenthaler, 2008 p. 59ff) can be derived from the development of technology in general and the technology development process in particular:

- Structured process with defined milestones and project controlling
- Complete transparency on all ongoing technology projects and aggregations of information as a decision-making tool in the milestones
- Clear responsibilities
- Sufficient flexibility to react quickly to changing environmental conditions
- Early integration of product development to prepare the transfer of technology development projects into the product development process
- Assessment of the potential benefit of planned and current development projects, thereby providing a more comprehensive information basis and risk minimization
- Integration of partners, suppliers ...etc.
- Best possible support for employees in their activities through methods and tools
- Minimum administrative burden, no hindrance to the day-to-day business
- Defined connecting points for the transfer of knowledge

A multiphase technology development process, which is characterized by various milestones, is suitable for fulfilling the requirements described above. The principle, conceptual and application suitability have to be proven as milestones. (Schuh, et al., 2011 p. 229ff)

**Transfer to product development:**
Product development is, on the one hand, the recipient of fully developed technologies, which are then processed into concrete products. It is integrated into the process at an early stage as it has to set central requirements for the technology to be developed. On the other hand, product development is the recipient of prototypically developed process technologies, which they use to manufacture products. (Taguchi, 1993)
The transfer of technological knowledge should be perceived as an independent process. In order to increase the binding nature, a defined plan for integration in product development should be defined, taking into account tasks, resources, and milestones. (Burgelman, et al., 2008)
The effective use of the recent described validations and criteria could only be used sufficiently with the right Technology Management. The management is a key position for the successful development of technologies and includes furthermore the areas of the product development as well as the capability of competitiveness. The basic idea is that through the management of technologies in the company innovations will be generated just as a better market positions and a realization of profit, finally an increase of competitiveness is the result. (Quian, 2002 p. 39)

# 5 Case Study Palfinger

In the Case Study of the Master thesis the major process specific criteria of the system engineering process were defined. These criteria were collected from all departments and later in workshops discussed, to gather an overall approach, how the optimized system engineering process should look like. Also the discussion of literature in the field of process development and system assessment is necessary, to gather new approaches for the development within the SysEP. Furthermore the measurability of the SE as well as the stage of maturation must be figured out and implemented in the optimized SE approach. Therefore the organization and the involved departments will give an internal look into the procedure of process development. The reached target should be a SysEP which could be implemented to fulfill the determined criteria.

## 5.1 Introduction of the Company

Founded in 1932 by Richard Palfinger as a locksmith and repair shop, the organization developed into a global company over the years. In particular, the year 1964 marked the company's decision to specialize in hydraulic lifting solutions for trucks. This was the beginning of the age of cranes, which was an era of expansion and internationalization. (Palfinger, 2017)

Today, the company Palfinger AG, headquartered in Salzburg, is one of the technology and innovation leaders in 34 production and assembly plants in western and Eastern Europe, North and South America and Asia (state 2015). It has been possible to establish itself as a world market leader in the fields of loading cranes, forestry and recycling cranes, marine cranes, wind cranes and hooklifts. Furthermore, Palfinger is the leader in the area of board walls and railway systems. The company's aspiration to itself is also decisive for its success. The sales and service network comprises 200 independent general importers and approximately 5000 bases in 130 countries. (Palfinger, 2015)

## 5.2 Field of Research

For Palfinger the drive for excellence is both rooted in the way innovations get efficient developed and also implemented properly. Based on the project “Marktreifer Kran” the consideration about how complaints could be lowered significantly to reduce later cost and time intensive compensation of the occurred failures. Therefore the project “Marktreifer Kran”, which means that the finished product/ crane must be developed and engineered in a manner that the complaints will be reduced significantly by a higher maturation of the finished product. (Haberl, 2016) This project was invented by Walter Haberl after complaints of finished products, which already had been launched. The field of research comprises in particular two phases, the first phase was the implementation and the development of the “Marktreifer Kran” project and the second phase is the development and optimization of the System engineering process. (Wieder, 2016) These two phases comprise the complete range of determination to guarantee that the complaints will be as low as possible. After the “Marktreifer Kran” project was determined, one of the important outputs was the optimization of the existing system engineering approach. Thus the executive management decided to investigate the SysEP of the mechatronic department within more detail and determine the success criteria as well as the measurability regarding to the maturation of a system and its integration into the product. In the practical part of this master thesis the second phase will be discussed with more detail. For a better understanding what in Palfinger “terms” a system and a product development exactly comprises, will be introduced within the next few subchapters.

### 5.2.1 Marktreifer Kran

The “Marktreifer Kran” or the „Null-Fehler Kran“ which the project was defined in 2015 from Mr. Haberl, who was at that time the Head of Construction in Köstendorf. The main focus was the reduction of guarantee costs through the occurrence of complaints after the serial introduction of the finished product into the market launch phase. The basic idea was described within an effort/time diagram. The main consideration here was according to Mr. Haberl, if the value chains were involved earlier in the development process of the development teams of the R&D, the flatter will be the errorline after the serial production Contradictory to complaints. In other words, focus is placed on the increased R&D

effort over the development period of a product and value-added chains in order to keep complaint rates as low as possible after serial introduction. (Schinwald, 2016)

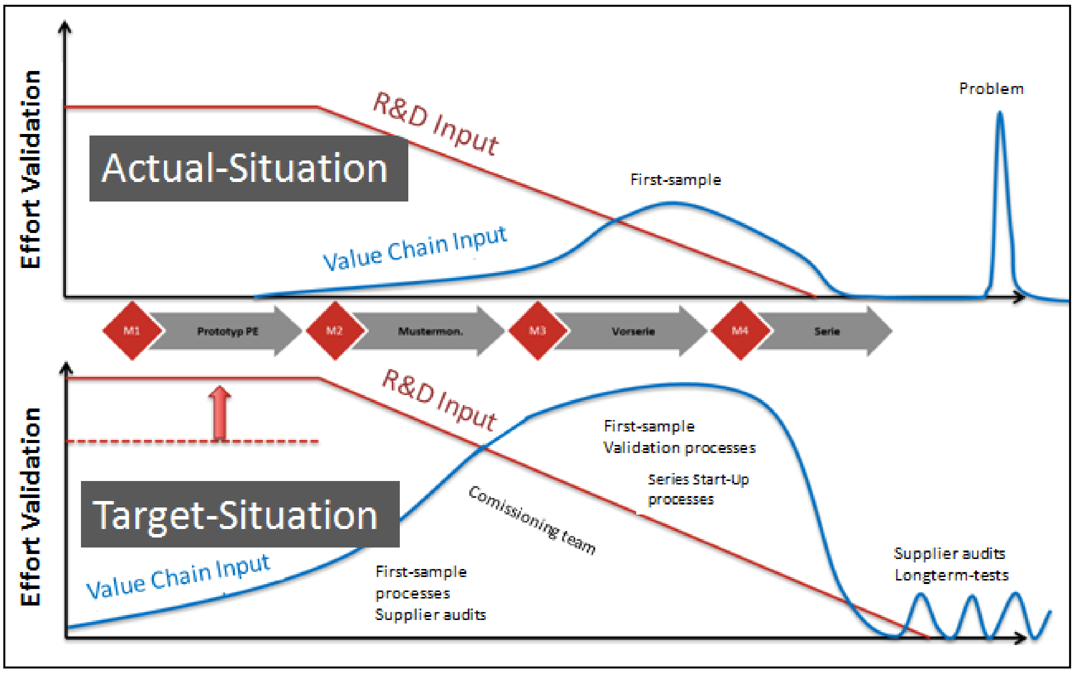


**Figure 5-1: Effort through the Development time of the product engineering process: (Schinwald, 2016)**

Another important aspect of the project was to develop a uniform, cross-process understanding. In doing so, the company should work on product development in terms of binding and developmental quality in order to further increase its development efficiency. This reflected the binding nature of the fixing of clearly defined milestones and the definition of stakeholder-specific work packages (Kohnhauser, 2015 p. 4). Furthermore, it was necessary to develop the system developments with sufficient maturity so that they could be seamlessly integrated into the product development process. For this reason, it was also determined that there must be a project manager who monitors the development of a product and coordinates it as well as responsibility for the seamless connection of the development-engineering interface processes. The transparency as well as a uniform development-technological understanding of the stakeholders participating in the process as well as its development processes, should become a further basic prerequisite for future product developments (Kohnhauser, 2015).

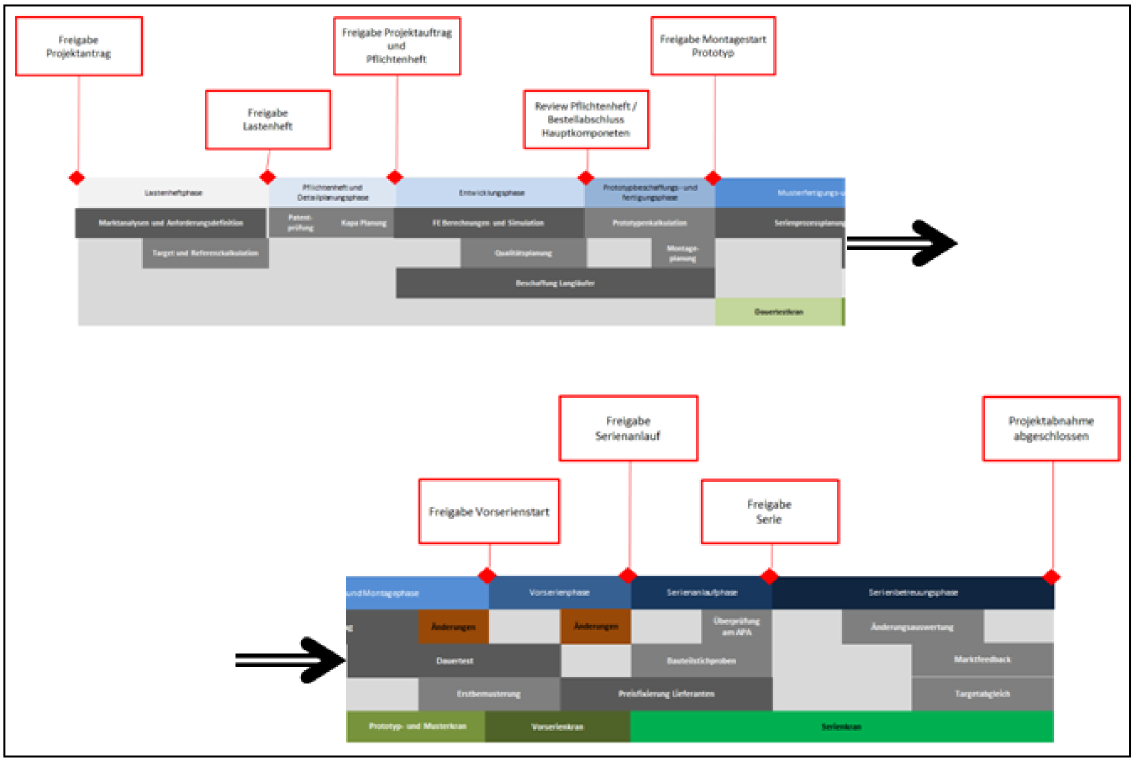


**Figure 5-2: Product Engineering Process with Stakeholder Synchronization of the “Marktreifer Kran” Project: (Schinwald, 2016)**

The targets resulting from the stakeholder surveys were not only to reduce the development period to twelve months, but also to reduce warranty costs to below 1% of sales, but further to achieve a comprehensive understanding of the process in order to ensure the company's competitiveness and success. (Schinwald, 2016) Another important output of those surveys was the closer determination of the development efficiency and quality of the system engineering process as well as the seamlessly transfer into the product engineering process. This was considered as Phase 2 of the project initiation, the “Marktreifer Kran”. For a clearer picture of how the system engineering process is correlated with the product engineering process and how the generic process map of Palfinger is built, Figure 5-3 provides a clear picture.

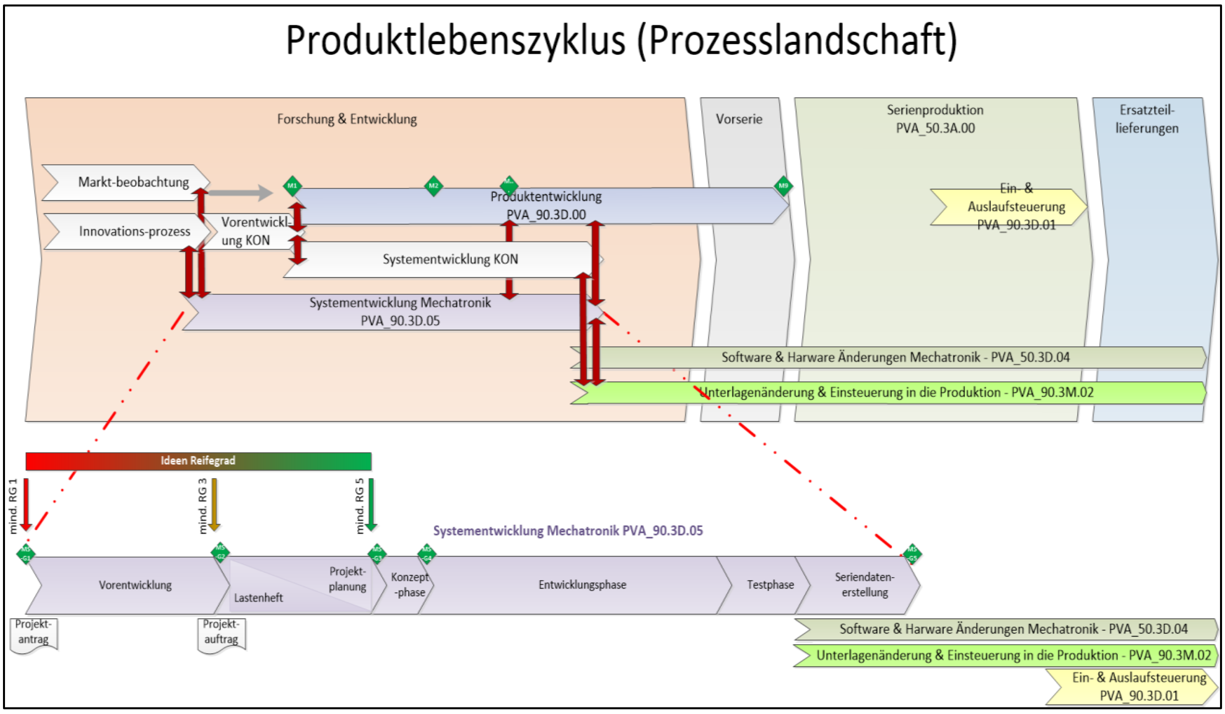


**Figure 5-3: Product Lifecycle of System Engineering and Product Engineering Processes**

In the practice part of the master thesis, the system development process mechatronics is discussed in detail and project premises are determined by workshops and stakeholder surveys. First of all, a clear initial situation had to be defined. This took place after various brainstorming sessions with Mr. Wieder and Mr. Schinwald, who had the leading roles in the evaluation of the SysEP. For a better understanding, which persons were involved in the whole evaluation process, the Stakeholders and their particular project premises will be discussed within more detail.

### 5.2.2 Mechatronic Systems Engineering at Palfinger

For Palfinger, the introduction of innovations or changes to existing systems can be carried out in two ways. On the one hand, systems are engineered by the R&D CON and on the other hand, the system engineering by the mechatronic department, the systems are developed both software and hardware-based and via product development. A typical mechatronic system, for example, is a crane control system. This is roughly defined by hardware and software systematic. Furthermore, it is not only necessary to develop innovations, but also to make any changes that are difficult to implement technically or on the market side. These have to be brought successfully to market launch via the product crane.

**Actual System Engineering Approach**

The actual SysEP was defined by Palfinger specific documentations which determined the different process steps and milestones which are important to fix certain process tasks of the development teams. The SysEP is similar to the structure of the product development process from chapter Figure 3-2.


**Figure 5-4: System Engineering Process of the Mechatronic Department**

The system development process mechatronics is starting with a **Pre-Development Phase (PDP)** in this Pre-Development; the actual expectation of the system is examined more closely and tries to concretize a rough idea further. The pre-development was started with a project application which basically adheres to the framework conditions. It is also possible to carry out a coarse test setup and to check the system's feasibility (referring to chapter 5.4). In the pre-development must be fought often with conditions of a nebulous state. This affects the development efficiency. If, at the outset of a system development, an unclear, nebulous state prevails, as can be the case with innovative projects, as discussed in chapter 3.1 of the Fuzzy Front End, the concretization in the Requirement Specification Document (RSD) is difficult. Therefore, a system prior to moving from the concept to the development phase must have a clear state of systemic expectation.

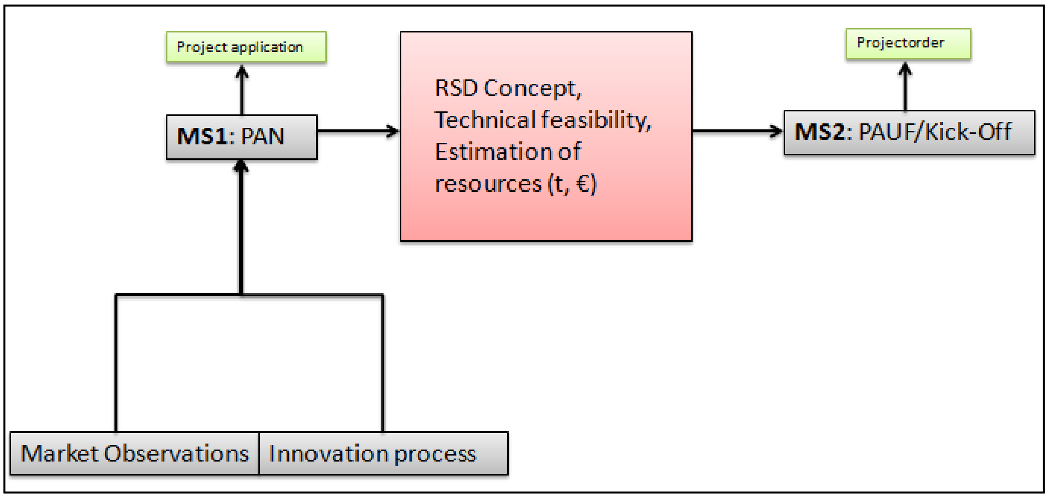


**Figure 5-5: Blackbox visualization of the Pre-Development Phase**

After the concretization or idea-finding of the system requirements, the idea is further dealt with in the Requirement Specification Document (RSD). According to Mr. Wieder, the **Requirement Specification Phase (RSP)** serves to further concretize and specify requirements and system functionalities. The purpose of the RSP was described in detail in chapter 3.1.2. The RSP represents the planning phase in system development. In order to be able to carry out the system planning, the initial document must be as concrete as possible. Due to the past problems with inadequate concretized RSDs at the beginning of the RSP, a degree of maturity system was introduced by Mr. Wieder to promote discipline in the idea concretization. This maturity model is explained in more detail within this chapter.

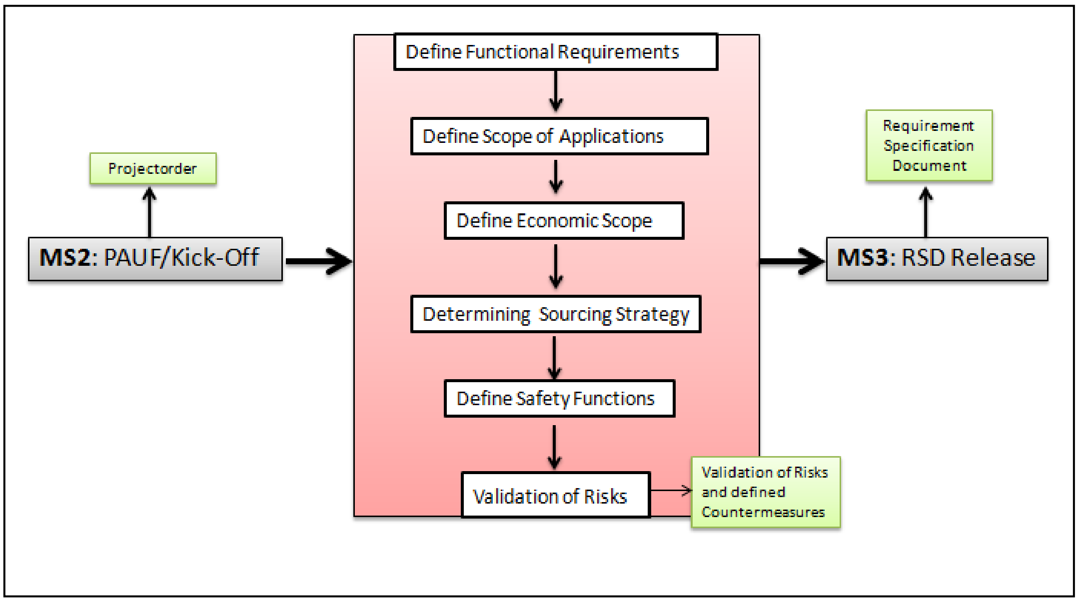


**Figure 5-6: Blackbox visualization of the Requirement Specification Phase**

The **Functional Specification Phase (FSP)** serves as a conceptual phase and fixes the functions and requirements to be implemented. This is the starting point for the later prototypes and initial samples. In the FSP, the requirements and functions from the RSD are prepared for the development. This phase ends with the fixation of the FSD and with its release. While the RSD can be designated as the requirement determination phase, the FSP serves to specify which requirements are to be implemented and which requirements are not.

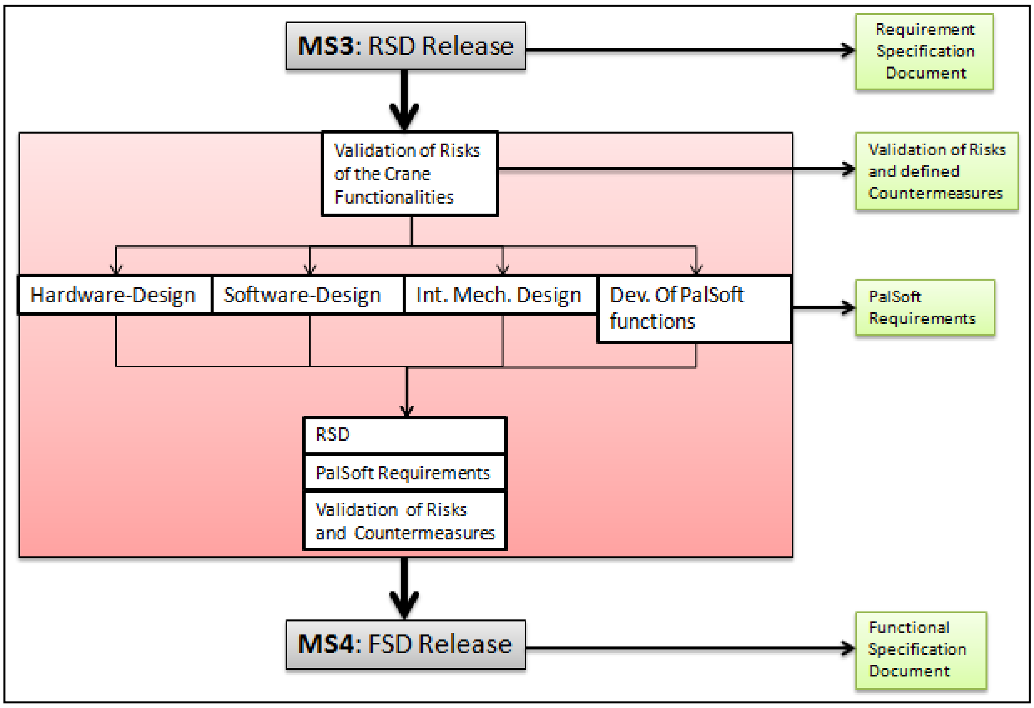


**Figure 5-7: Blackbox visualization of the Functional Specification Phase**

When a concept of the system has already been designed and proofed that it is feasible. The next step is the development of first samples followed by prototypes. This phase is called the **Development Phase (DP)**.

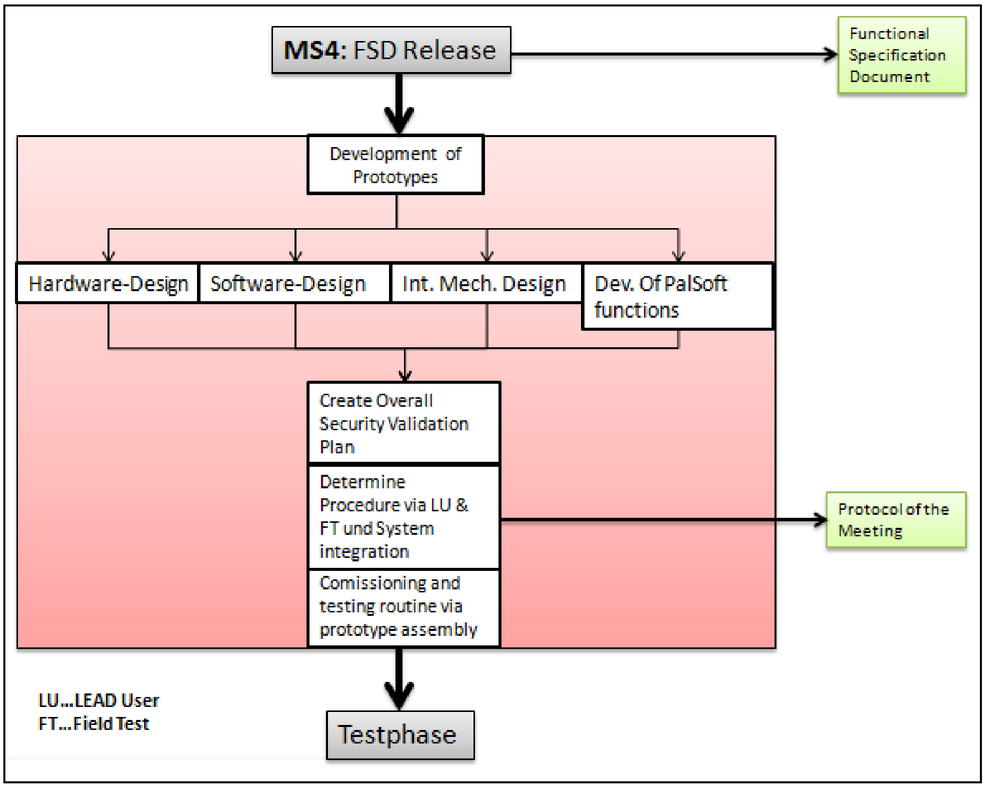


**Figure 5-8: Blackbox visualization of the Development Phase**

In the development phase the prototypes should be generated and further developed till the **Testphase (TP)** could start with the implementation of the system on the Crane Prototypes to test it.

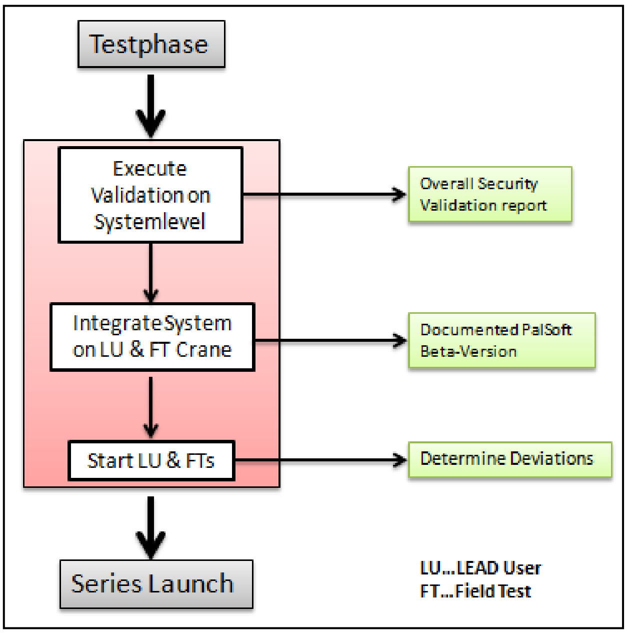


**Figure 5-9: Blackbox visualization of the Testphase**

Further within the Testphase the assessment of the system will be executed as well as the integration on Lead-User or Field-test Cranes. The terms Lead-User and Field-test have Palfinger specific meanings which will be defined within the next pages with more detail.
According to Mr. Haberl a crucial issue in the Testphase of a system would be the determination of which other systems are going to be mounted on the crane prototype and therefore an Overall System Test should be taken into consideration. After the successful testing of a system the start into the **Series Launch Phase (SLP)** begins. In this phase the system is judged if it is ready for the

synchronization on the engineered product and if it is ready for assembly. The whole SysEP is fixed by four different Milestones. Each Milestone stands for the fulfilment of the specific working tasks.

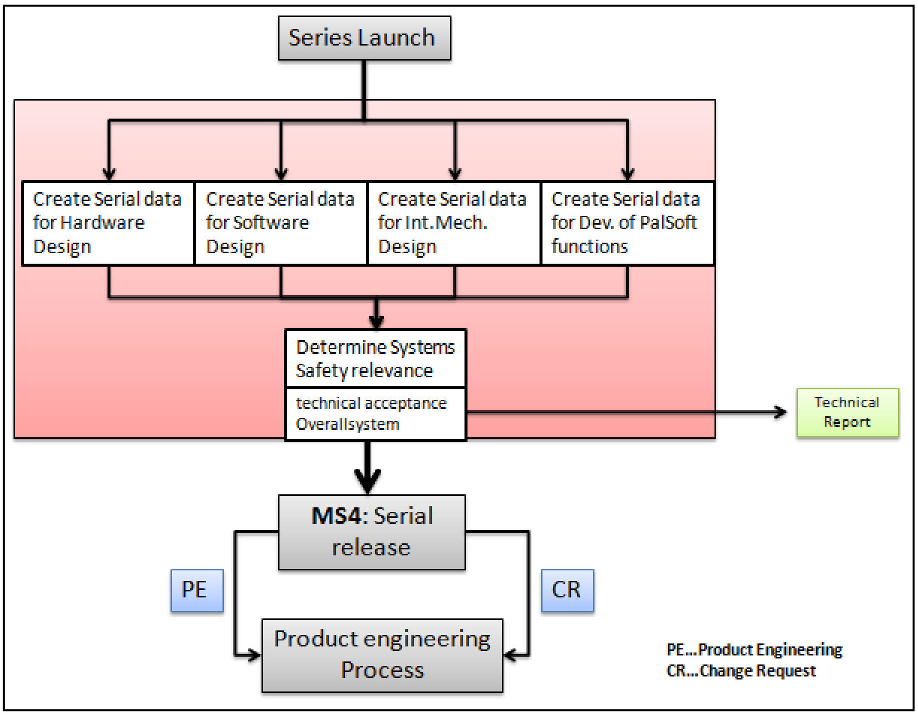


**Figure 5-10: Blackbox visualization of the Series Launch Phase**

In the Series Launch Phase the Serial Data for the different design is created and determined by the systems safety relevance. The last step of the Series Launch is the technical acceptance test of the overall system.

**Palfinger specific Understandings:**

Since Palfinger, under certain connotations, has different or partial definitions, compared to the literature discussed in the theory section, the following are now explained and discussed in detail for the basic understanding.

**Lastenheft (Requirement Specification Document):**

The Requirement Specification Document or Lastenheft is a detailed documentation about the system functions requirements as well as the definition of needed resources and the systems architecture. The need of the RSD is to determine the whole components, subsystems and elements of a system (referring to 2.1.1) and their relations, to guarantee a coherent well-defined initial state for the further development within the Functional Specification Phase. This Phase is a key performance indicator for a SysEP.

**Lead User:**

Palfinger defines Lead-User as a Customer which is not just giving an input for the development of a system, the LU also provides a Crane for the integration of a new developed system for the testing within the Testphase of the SysEP. Thus the LU more involved in the Testphase and through the provided product the LU is able to give an immediate feedback for the Engineering team.

**Synchronization of the System Engineering into the Product Engineering:**

The synchronization is the last complex process step of interlocking the system with the product. After the system engineering the finished and tested system should be at a certain level (cf. 4.2.1). This is a crucial issue for the successful launch of a system, which will be mentioned and discussed later in chapter 5.3.2.

**Reifegradmodell (Degree of maturity model, DOMM):**

The degree of maturity model developed by Mr. Wieder is a method for the assessment of the maturity of a system through the RSD. The main focus was to determine how far a RSD is developed and defined for the next process steps and if it is ready for further development. The DOMM is divided within five maturity levels. These Levels are defined as follows: (Wieder, 2015)

**DOMM 1/ RG 1**

- Transfer of the valuation from CIT including short comments
- More detailed (ideas) scope description

**DOMM 2/ RG 2** Stakeholders involved (PM, MEC, KON,…)

- Detailed Description MV, SV, ROI, TU
- Short competitor analysis
- Assessment of technical feasibility
- Evaluation of the evaluation matrix

**DOMM 3/ RG 3** (Concept development)

- Underlying crane series strategy / crane models etc.
- Assignment in function matrix
- Approx. Number of pieces (niche application or over entire crane series)
- Approx. Target costs (partial / total system costs)
- Stakeholders for implementation (KON, MEC, CS, MCC, PM, ...)
- **Data basis for effort estimation System development  Project prioritization**

**DOMM 4/ RG 4**

- Project application
- Additions / evaluations of specialist departments

**DOMM 5/ RG 5**

- Project assignment
- Transfer of ideas to a total booklet

Another important issue of this model is to determine the state of a RSD were the cost, time and resource factors are predictable and therefore possible to define for the development of the system bindingly. Thus the involved stakeholders have to commit themselves with more discipline because the initial situation is clear defined. Because in the past of the system development a major problem was the right commitment at the right time of the stakeholders, first to defines the RSD properly and second to increase the level of discipline within the development and the RSD inflation. This was the main driver for inventing this validation system by Mr. Wieder.

**Security Lifecycle:**

The Security Lifecycle is the parallel process of defining safety requirements based on the Technischer Überwachungs-Verein (TÜV) norms. These norms are standardized safety requirements which must be realized for a functional safety system. This comprises beside the planning and development of these safety standards also the documentation of those. The documentation as well as the change of those specific requirements leads to massive effort in development time and resources.

**Stakeholder synchronization:**

This means in particular the link between the working packages or stakeholder working process. The purpose of the synchronization likewise in the “Marktreifer Kran” Project was the determination of the process interfaces of each stakeholder working package. These working packages were defined through the “Marktreifer Kran” Project with the complete determination of the Product Engineering Process landscape through the involved departments, as shown in Figure 2-1.

**Crane Innovation Team (CIT):**

The CIT is a Palfinger interdisciplinary team of development managers who deal with innovations and their evaluation as well as their implementation and the further development.

**PalSoft:**

PalSoft is the documentation and service center at Palfinger and is dealing with the required documentation for the developed system as well as other customer related services. It is the development team of the corporate service department lead by Mr. Gwechenberger.

**PalDiag:**

Is the diagnose system of software related system functionalities. After the software functionality of a system is programmed and finished the testing and validations get started through the PalDiag team. This is the last assessment before the system is getting implemented into the product.

## 5.3 Procedural Method

The Procedural Method of the practical part is structured in two phases the first phase describes the determination of the actual state of the System Engineering Process and its structure as well as the evaluation of the whole process, the second part is dealing with the creation of new process approaches based on the generated process specific criteria of the Stakeholder meetings and workshops. The chapter 5.3.1 is starting with the initial situation based on the evaluated SysEP of chapter 5.2.2. This was basically the state on which the stakeholder surveys were based. After the descriptions of the initial state the Stakeholders as well as the Stakeholder based Project potentials and process specific criteria will be determined. Based on the output of the workshops the adapted and redefined approaches will be discussed.

### 5.3.1 Initial System Engineering Process

In this chapter the initial basis for the meetings and workshops with the stakeholder will be explained with more detail. The initial SysEP was based on the process instruction of the mechatronic department. The structure of the process is similar to the mentioned product development process in chapter 3.1. The basic phases were already mentioned in the chapter 5.2.2. After a few brainstorming sessions and discussions with Mr. Wieder and Mr. Schinwald the Initial SysEP as shown in Figure 5-11 was created.

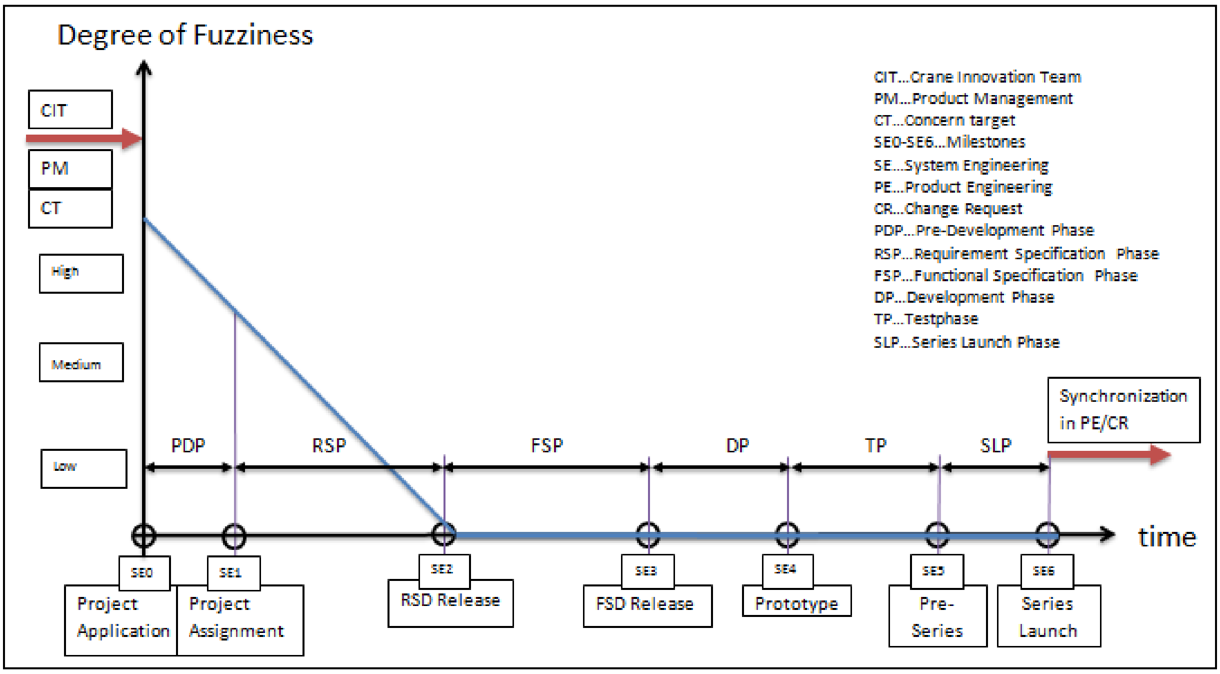


**Figure 5-11: Initial State of the System Engineering Process**

This figure represents the first version of the initial state and shows the Degree of Fuzziness over the development time. The term Fuzziness is linked to the definition which was discussed in chapter **Fehler! Verweisquelle konnte nicht gefunden werden.** the **Fehler! Verweisquelle konnte nicht gefunden werden.**. The term "Fuzziness" was firstly defined as a nebulous state at the beginning of the SysEP high and over the development time, when more and more information about the system and the target is collected, decreasing. The idea of the decreasing fuzziness is directly linked to a stronger commitment of the stakeholders which should result in a more efficient inflation of the RSD. The Fuzziness should therefore decrease to a point of constriction were the fuzziness is at lowest possible level. After discussing the point of constriction Mr. Wieder came to the conclusion that the creativity and innovative thinking within a SysEP must be enhanced. Referring to the discussion of flexibility within a SysEP Mr. Wieder mentioned that it is necessary to open the FSP for creativity. According to Mr. Wieder the point of constriction was removed from the RSD Release to the FSD Release. The reason was because the creative input must be still possible within the FSP. Therefore the SysEP was adapted in the FSP. The opening of the FSP for creative input is shown in Figure 5-12.

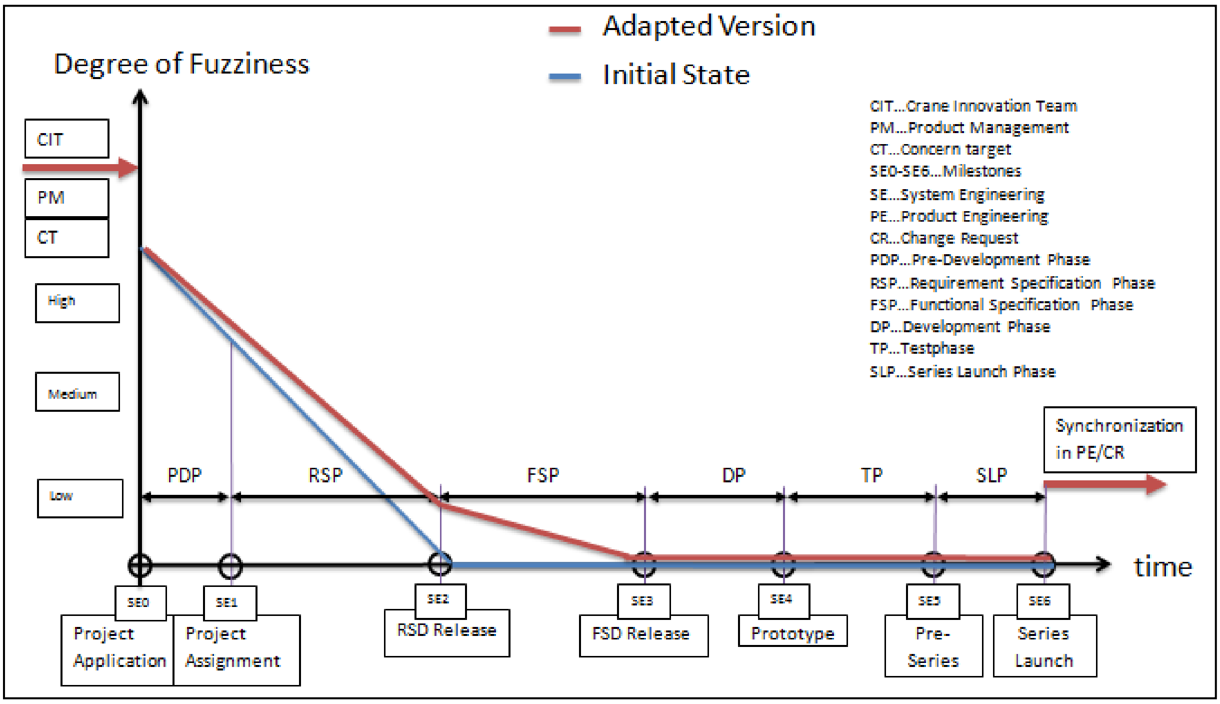

**Figure 5-12: Initial State & Adapted State**

According to Mr. Wieder in the past within previous development of systems the problem was that the Fuzziness was not decreasing over the development time it was even increasing in some stages of the SysEP. The problem according to Mr. Wieder was the lack of commitment from the involved Stakeholders at the beginning of the PDP and RSP and the lack of discipline for the RSD inflation. The effect of the implementation of requirements or functionalities after the FSD Release was sometimes very critical. The reason was that those “late integrated Requirements” were creating a high amount of Fuzziness within the development, because of increase of time and resources which were needed to integrate these requirements. This postponed the completion of the system even further and ended in huge schedule difficulties. Another critical fact was through the postponement of the system development time, the following product has also been affected by it. Therefore the main research questions could be defined:

- **How can the development efficiency regarding to the time to market be ensured?**
- **How could the topic of agility be implemented in the SysEP?**
- **What affects the successful integration of the engineered system into the Product Engineering?**

Through the discussion with Mr. Wieder and Mr. Schinwald the Adapted State was divided in three process types. This process types represent the different system development possibilities within a SysEP. This was leading to the most resent version of the initial SysEP (Figure 5-13).

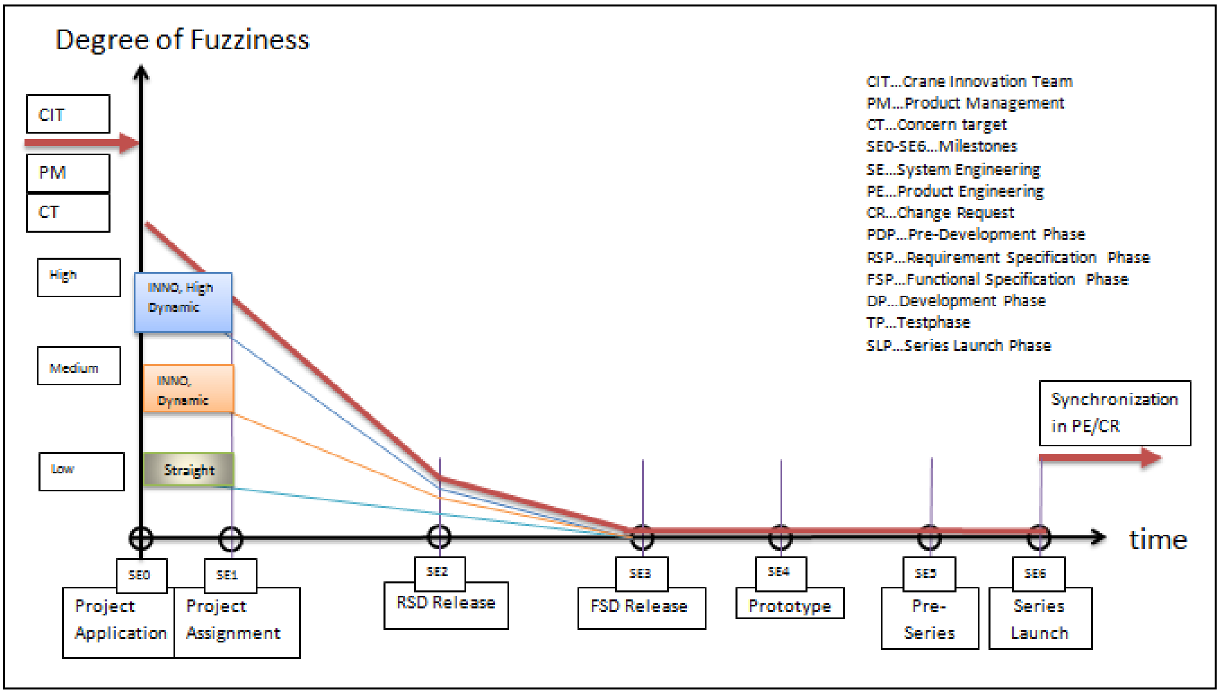


**Figure 5-13: Actual State of the SysEP for the Stakeholder surveys**

This process types are divided after their degree of fuzziness. Because there are existing specific types of systems which are already very clear from the state of information or the state of functionalities. The development task and the target are available with certain clarity. This means that the straight approach with a low degree of blurring is essentially clear with regard to the development framework and only has to be maintained for the resource release in order to be able to develop through an important key performance indicator with regard to time to market development efficiency. Furthermore, due to the logic of the Fuzzy Front End thematic the more the effort is introduced in the first development phases, the lesser difficulties arise in the subsequent development phases. This correlates with the logic of the increased involvement of stakeholders in the early development phases in order to achieve a maximum output in the RSD filling and thus to be able to develop more efficiently in the later development phases. The other approaches based on a higher degree of fuzziness which represents the higher innovative types of systems which need a certain time of pre-development to decrease the fuzziness to a level of a robust system development situation which means that a needed minimum of requirements and functionalities could be identified and this information is lowering the degree of fuzziness to a certain degree at which an effective development is possible. Those to dynamic approaches also depend closely on the approach of the Fuzzy Front End or the pre-development of systems by (INCOSE, 2004) in chapter 0. As mentioned in the chapter 3.1.1, the management of requirements is a crucial issue for development efficiency of products or systems. The discussion of how to deal with those requirements and how to determine the importance of each requirement for the system was a major discussion point within the stakeholder surveys.

### 5.3.2 Stakeholders

In this chapter the stakeholder surveys are discussed and revealed by the process specific criteria. This is the result out of numerous discussion and workshops with the major Stakeholders involved in the development of a system. This chapter will give a first orientation about the Palfinger specific Stakeholder situation within the company and their working environment. Following the extraction of those surveys is going to be discussed with more detail and the Project Potentials based on the SysEP initial approach shown in Figure 5-13 will be analyzed more specifically. Referring to the first Stakeholder surveys the process specific criteria were extracted and build the basis for the workshops.

**Stakeholder based Project Potentials:**

The Project Potentials summarize the defined possibilities within the SysEP by each Stakeholder. These possibilities were the output of the first Stakeholder surveys; based on those surveys the process specific criteria were determined. Following the Stakeholders of the System Engineering Process are named and described as well as their understanding of measures for increasing efficiency of the current SysEP. The surveys and workshops were discussed with Stakeholders of the middle management.

**Managing Director (MD) represented by Mr. Pschernig and Mr. Rumpl**
The main drive for the optimization regarding the existing SysEP was introduced at first sight from the top of the Company. The initial impulse for the Phase 2 after the “Marktreifer Kran” Project was the optimization regarding the development efficiency and transparency of system development. Therefore the MDs were up to bring the development of systems a new level. According to the increase of efficiency within the development of systems and their transfer into the product development the need for the contribution of all involved Stakeholder was a basic requirement. The importance of this evaluation was introduced from the top to the bottom.

**Project Lean Office (PLO) represented by Mr. Schinwald, Head of PLO, Mr. Katsch**
The project lean office, led by Mr. Schinwald, is entrusted with the task of carrying out the evaluation of the SysEP, with the cooperation of the MEC department under the direction of Mr. Wieder. The PLO also deals with the implementation of the "Marktreifer Kran" Project on the determination of the product engineering process (PEP). During the "Marktreifer Kran" project, it has become clear that a given milestone plan is essential for consistent implementation. Therefore, a system integration check was introduced for a defined milestone (Katsch, 2016). According to Mr. Katsch, this milestone is set according to the RSP within the PEP. The development environment for systems and their degree of maturity is already queried beforehand and estimated whether it is possible to complete it with the given milestone. A crucial issue for the successful implementation of the systems into the defined products is according to Mr. Schinwald the increase of transparency when it comes to the synchronization within the Stakeholder processes in the SysEP as well as the measurability of the system maturity with a coherent assessment model. The target for Palfinger should be an overarching process thinking of all involved Stakeholders and a further development of discipline for a higher consequence within the development of a system. (Schinwald, 2016)

**R&D Mechatronic and Patent Management (MEC) represented by Mr. Wieder, Head of MEC and Mr. Vierlinger**
Within the MEC department of Mr. Wieder the SysEP of mechatronic systems was closer discussed and based on the mechatronic SysEP evaluated. According to Mr. Wieder the Potential of the SysEP is closely linked to the defined term of fuzziness. The fuzziness is not just increasing because the system is highly innovative or through complicated ideas, the fuzziness could also increase through subsequent requirement changes (Wieder, 2016). Those requirement changes lead to huge increases of fuzziness and also to the postponement of the transfer from the system into the product. The focus within the development of a system must lie in the discipline of Stakeholder contribution. Furthermore is with the development of innovative systems the problem that the initial state of the development is nebulous and therefore difficult to grasp. The result is a higher level of frowziness in the overpass of the system into the next development stages of the SysEP. According to Mr. Wieder the restriction of requirements after completion of the RSD would be effective. This also poses the question whether further requirements are to be set up after the point of constriction, or whether it should be developed in order not to extend the development time and -quality. A further question is where is the point of constriction and how can this point be fixed, how does this point change with internal or external change of requirements when a competitor is the first on the market.
“The awareness about the requirements of the documentation effort is not available with regard to changes in requirements, for example: when changing a mechatronic system, the effort of the documentation is enormous in the case of a modification. Or. The expenditure of a lacing due to modifications arises due to the revision of the documentation. The problem is, if after the fixation of the

task book something has to be changed the effects are devastating. If, by comparison, requirements are changed in the "fuzzy" (agile) range, the effects are sustainable”. (Wieder, 2016)
The innovative character is at the beginning higher, the RSD funnel is split, whereby innovation can still be introduced at the end of the RSP, or at the beginning of a FSD, any innovative inputs are also possible. At the end of the RSP, innovative approaches can also be introduced. Before the point of constriction is reached, and if an essential feature arises spontaneously. This is even possible at the beginning of an FSD if it is a good contribution (Wieder, 2016). There must be an awareness of what it means to make retrospective changes and how are the effects in terms of cost and completion (time and money). This mainly includes the effort required by the necessary documentation, due to changes. Often, on the part of the stakeholders, the RSD is maintained until the RSD is fixed and then the requirements are introduced. In the RSP, funnel thematic appears very well. A substantial part of the input comes from ideas, but less the innovative contributions. “The RSD is not filled with 100% innovative ideas but with hard facts (costs, construction volume, dimensions, environmental conditions, etc.). Depending on the SysEP, the ratio in the funnel is balanced between hard facts and innovative ideas, or it is subject to innovation or hard facts (innovation plays a subordinate role)”. (Wieder, 2016) Mr. Wieder sees the major potential within the first three phases (PD, RSP, and FSP). Because if in this phases the effort and contribution of the Stakeholder would be maximized the output with the following development phase would be a more efficient with a higher development quality. Another crucial issue for the evaluation of the SysEP is according to Mr. Wieder and Mr. Vierlinger is the seamless implementation into the product engineering process. Mr. Schinwald mentioned that the critical success factors of the SysEP are closely linked to the degree of maturity of a system. For the integration of a system into the product development the system must be characterized by the level of maturity. Therefore it is possible to distinguish if a system is ready for the integration or not.

**Process Specific Criteria:**

- Discipline within the RSD inflation
- Definition of Requirements through a stronger Commitment of the involved Stakeholders
- Define a clear target/ Product strategy
- More engagement in the early phases
- Earlier Stakeholder Commitment within the First three development phases (PD, RSP, FSP)
- Integration of the SysEP into the PEP
- Assessment of the SysEP by the degree of fuzziness
- Distinguishing between different SysEP types

**Product Management (PM) represented by Mr. Reischauer, Head of PM**

The Product management, led by Mr. Reischauer, considers the potential of system development to be more agile. According to Mr. Reischauer, in order to remain competitive today, there must be a certain degree of flexibility in a SysEP. Mr. Reischauer’s opinion is more oriented to market requirements, which should be the focus of customer satisfaction, and if, for example, a market-based requirement is transferred into the system development, there must be certain agility available to milestone SE5. The general question is whether this type of system development process is not outdated, and agile development methods are constantly being discussed. “What is the optimal development process for the needs of the Company? All other well-known companies loose themselves from such a model. This model is actually no longer contemporary”. (Reischauer, 2016) Agility should be a key element in system development. Maturity management is a good approach since the assessment of the maturity of a SysEP is essential. The classic model with RSP and FSP is not enough. The goal would be to develop the system as quickly as possible during the development phase. Therefore the SE process in the front phases (PD, RSP and FSP) has to be changed in order to ensure a smooth development. Thus there lies great potential within the first three phases. Mr. Reischauer thinks that the separation between two process configurations of a Straight process which has a clear starting position. Within a Straight process the agility can be dispensed and the conventional approach with RSP and FSP and the constriction point are carried out. The second process configuration could be the dynamic approach in which agile process methodology is a possible tool to use. The term of fuzziness should be defined within more detail and in a Palfinger specific way. The more effort that is putted in the Pre-Development the lower the degree of fuzziness should be. Therefore the fuzziness will be flatter after the PD. “Why are there changes in the process? We try when a project in the house is started to make the FSD perfect. This results in a time to market margin. The more accurate the development of the system get the longer the development will take”. (Reischauer, 2016) Within In a project period of several years, a change in requirements may occur, this is a fact that cannot be prevented, since the RSD can still be fixed so firmly. The question is how much perfectionism tolerates a development of a system. It would be interesting how agile methods at Palfinger could be applied. It is about cyclical composition and to check whether one is still on the right way with right assessment methods and to determine if the needed requirements are feasible. A possibility for a smoother development could also be the merging of the RSP and the FSP. For the assessment of the SysEP a more frequent determination by Target Costing could be an effective measure.

**Project Specific Criteria:**

- Increased contribution of Agility within the SysEP (Agility as a Key element)
- Distinction in Straight / Agile Project
- Evaluation model for the process maturity of a system
- Reconsideration about the RSP and FSP model
- Measures after the integration of the SysEP into the PEP
- More frequent Target Costing
- Change of the SysEP within the Front phases (PD, RSP. FSP)

**R&D Construction (CON) represented by Mr. Haberl, Head of CON**

Mr. Haberl, the Head of Construction, was one of the initiators of the Phase 1 project “Marktreifer Kran”. This project led to the Phase 2 the optimization of the SysEP. Due to the fact that Mr. Haberls department is also involved in the development of systems his knowledge is a crucial foundation for the evaluation task of this project. According to Mr. Haberl within the evaluation of the SysEP the potential impacts for the overall development quality of the whole process lifecycle (Figure 5-3) are immense. A crucial issue for the successful development of a system is managed it with the right assessment. Mr. Haberl prefers the validation by development risk which is mentioned within chapter 3.1.2. According to Mr. Haberl the important questions are, how long is it useful to be flexible and when is it counterproductive? Mr. Haberl would distinguish between the valuations in risk low SE and costs stable, disciplined and in risk high SE with volatile cost curve. That means categorizing the SysEP by the development risk. Further a clear separation between innovation and system engineering must be considered. Mr. Haberls mentioned that the amount of innovative product is significantly low the lion’s share of the SysEP are process which are considered as adaption or upgrades of already existing system architectures which are from the functional point of view similar and therefore not new and innovative.

What also should be taken into consideration are the management and the classification of requirements, because not every requirement is that useful for the customer and every additional requirement or function which is implemented into the system is a critical success factor. Therefore an assessment of requirements and a classification could be an additional tool for the successful development.

A critical point is that Target costing takes place too less. The problem with system developments is that often only individual elements are captured cost-technically but none of them captures the entire system cost-technically. This problem is maybe rooted in the case of a not existing overall project leader who is able to identify problems above the subsystem level and sets the right countermeasures. This overall project leader should also be able to interlock the stakeholders working tasks to fulfill the requirements. At the end of the SE process, the transfer phase is important. What is the end result? Therefore an assessment method in the case of the degree of maturity system could be a solution. Important is the measurability of the system development, how far should a system be developed for the integration into the PEP. Another important measure could be the overall system integration testing. The reliability of the systems and the interfaces between the product and the systems to be implemented must be taken into account.

**Process Specific Criteria:**

- Clear separation between innovative and usual SysEP
- One overall project leader
- Relevance of Agility is high (when counterproductive)
- After the FSD Release a certain amount of flexibility is crucial
- Change Requests must be validated
- Degree of maturity model for the determination of System integration readiness
- Distinguish between High risk and Low risk systems
- Requirement management and classification
- More Target Costing

**Montage (M) represented by Mr. Pichorner, Head of M**

The Montage is essentially the receiver of the systems when it comes to the integration of those into the product. According to Mr. Pichorner there are huge possibilities within the optimization of the SysEP regarding the transparency and measurability of systems within the development stages. “It is important to look for "left and right" from the FSP of a SE process, that is, where do I want to go? When and where is the system transferred into the PE? For reasons of expenditure, etc., functions / requirements are often excluded, and these excluded functions / requirements will come to bear later in the introduction of the system into the product”. (Pichorner, 2016) It should be considered already in the FSP what interfaces / requirements have to be covered in order to ensure as smooth as possible integration. The introduction of the RSP into the creative part is perceived as positive. According to Mr. Pichorner it should be considered between the milestones SE2 and SE5 about the integration of which system in which product is possible and what is left and right affected by the system. This leads again to the question, could a validation with an overall system integration test be effective for the interlock of the system with the product? There should be one overarching competence that is responsible for all components of a system (HW+SW) which have to work before they are activated. The overall project manager responsible for the overall systems and their integration and seamless development is still a grey area. It is necessary to define somebody who is definitely responsible for the overall project. This refers also to the definition of interfaces which currently not considered. The reason is because every development team does first look after the fulfilment of their own task. The overarched process thinking is not existent. Mr. Pichorner mentioned that a huge potential lies in the definition of a transparent situation within the maturity of a system. The measurability of the system maturity based on montage specific factors would bring more clearness into the often fuzzy state of the system maturity. This could be a critical success factor for the successful implementation of the system into the product. Mr. Pichorner also thinks for the system transparency on a better information exchange of all stakeholders would be useful and an earlier contribution within the RSP and FSP. These raises further the question, when does it make sense to integrate the montage in the SysEP? And when does it make sense to consider about the integration issue? Within the departments exists a project control circuit. This circuit could be enlarged and therefore the montage is able to bring in earlier contributions. In the first few discussion rounds, when the system is not defined in a clear or robust state, it is difficult for the montage to contribute ideas when the system is still in a higher level of fuzziness. The time of involvement will be for every system development differently. A committee should decide about project status, resources ...etc. and that committee should clarify this particular status represents and then binds the staff into the system engineering. “In the projects where the Montage has been integrated up to now, the control has functioned acceptable”. (Pichorner, 2016) An important point is also the question how the integration of requirements is implemented after the FSP. A further essential point is the definition of the expectation on the systems requirements and for the implementation of the system into the PEP, that this has to be clarified especially at the beginning of a system development. This means in particular that a product strategy one of the key performance indicators for the SysEP.

It is to clarify whether a system is half way finished and a running crane and the PEP is determined at a defined time. Due to this time specification, not all requirements in the SysEP can be integrated. Very often the system is technically completed, but the documentation or administrative, quality, inspection plans suppliers, etc. is missing to a certain extent. This could be one of those reasons that

the system is only about 80% completed. Therefore it is of crucial importance to specify the framework conditions of the system and the PEP in which the system transferred. (Pichorner, 2016)
It is important to note that if a system with a strict timeline is to be introduced into a PE, it is also important to be aware that the system could probably only be managed with a degree of maturity of 80%. This means, however, that this degree of maturity of the system must also be clearly defined and communicated, so that the PE/ Montage can react to it! That means, however, if the system is only 80% completed, the strategically fixed time must be covered! It is important to explain which topics are still to be elaborated and / or dealt with, and these should be communicated openly so that everyone involved is aware of what needs to be done (Pichorner, 2016).

**Process Specific Criteria:**

- Expectations to the system
- Definition of the system maturity/ Measurability of the SysEP
- Integration of the SysEP into the PEP
- Check the environment of the system
- Factors for assessing the mounting capability of a system
- Reflection/ Lessons Learned
- One overarching project manager who has the responsibility
- Creation of an overall process thinking within the different development teams
- Product Strategy
- Increase the transparency through better information exchanges (Project Control Circuit)
- Integration of the Montage in an earlier development state
- Requirement management
- Creative part within the FSP is positively

**Corporate Service (CS) represented by Mr. Gwechenberger, Head of CS**
Mr. Gwechenberger the Head of CS is one of the Stakeholders who insist on more responsibility for the requirements which the market or the customer is wanting from the system. In the past system development the CS was mostly introduced too lately into the requirement determination process of the system development. According to Mr. Gwechenberger the development team defines the system from the technical side and sticks more to the technical requirements. The CS does instead of the development team look more on the customer benefit of the system. Therefore the System defined by the development team as straight can nevertheless lead to a huge increase of the fuzziness level, in the case of later application of service requirements. Because those service specific requirements are crucial for the customer satisfaction or for the market benefit but those requirement aren't according to the development team necessary to fulfill the functional or technical framework of the system. Therefore according to Mr. Gwechenberger it is necessary to incorporate the stakeholders who implemented their requirements already within later development stages of the SysEP into the early development phases. This would also be useful for the determination of the right market strategy, because the service and also other stakeholders like sales, customer service…etc. could provide a different more customer oriented point of view to the development of the system. Right now the strategy which system will be synchronized in which product does not work properly. One of the main reasons is that there exists no validation method for the determination of the systems maturity. Mr. Gwechenberger mentioned that a validation model for the determination of the system maturity for the integration into the PEP would be critical, but a maturity system like the DOMM from the MEC department just determines the development level or the technical/ functional point of view regarding the system development. Therefore information driven model could be more properly for the determination of an overall assessment method. Because there exits according to Mr. Gwechenberger two approaches the first approach is the validation of the technical/ functional development maturity the second is the information content regarding the product strategy fulfillment and the service, sales or customer requirements. "The requirements must also be integrated earlier on the CS side" (Gwechenberger, 2016). Further a determination of how requirements which will be integrated into the SysEP have to be related to the effect on the degree of fuzziness. Because requirements later integrated into the SysEP will rise the degree of fuzziness way more than in the earlier development

phases. Make or by decisions should be taken not only on the basis of technical development plans, but also in terms of service-specific requirements. (Gwechenberger, 2016)
This does for the corporate service not inevitably mean, that a straight system which is quite clear in the technical implementation, but on the service side the introduction over several markets can be highly fuzzy. This is a factor in the development of a system which must be taken into account. In addition to the technical feasibility, there must be a consideration about which system will be synchronized in which product and at which market. Because for the CS it is a substantial difference if a product and its system will be introduced within one major market or more than one markets. (Gwechenberger, 2016)
A goal must be to anchor the cross-departmental thinking for the system development. In addition to being responsible for the project, the involved stakeholders must also be brought to a common overlapping process understanding. (Schinwald, 2016) "It must be clarified how and to what extent development-related decisions affect other stakeholder processes". (Gwechenberger, 2016)
Another important point to which Mr. Gwechenberger refers relates to the communication between the stakeholders. By means of cyclical adjustments, the information dissemination would be improved. This means that when it comes to making concrete decisions that apply equally to all stakeholders.
At the beginning of a system development it has to be clarified what the accompanying projects are and how these correlate with one another. An important aspect would be the implementation of a system-overall integration test. A technology portfolio has to be defined with which system in which product is controlled.

**Process Specific Criteria:**

- Previously inserting the CS into the SysEP/ more market oriented point of view
- Product strategy and technology portfolio which system in which Product
- More commitment in the early stages
- Requirement evaluation / time delay
- Maturity model (development side and market side)
- Better information exchange through cyclic adjustment
- System overall integration test
- Overarching process understanding/ Stakeholder synchronization

**Quality Assurance (QA) represented by Mr. Wolfinger, Head of QA**
Mr. Wolfinger the Head of QA is one of the Stakeholders who should be involved at the complete SysEP. For Mr. Wolfinger it is crucial that the QA must be introduced more to the development of the system because one of the major problems is the definition and determination of interfaces between system components. If three or more separate teams are involved within the system development every development team sticks to their specific working tasks and does not considered the impact within those system component interfaces. For Mr. Wolfinger the solution would be, beside one overall project leader, the clear open discussion of those interfaces and the determination of how these interfaces are related to each other by the Stakeholders and the overall project leader. According to Mr. Wolfinger this could be the solution for solving also the synchronization problem within the integration of several systems into the PEP. Mr. Wolfinger sees also the potential for the QA department to get involved within the earlier stages of the SysEP to determine as early as possible the systems elements and the needed interfaces. Also the assessment with process FMEA or system FMEA could be done by the QA. According to Mr. Wolfinger a coherent overarching process understanding of all involved stakeholders and a process overarching commitment is crucial for the successful development of a system.
"The Assessment of system or process specific failures leads also to the question how to deal with failures" (Wolfinger, 2017). It is also important that a finished system is assessed after its integration and a lesson learned could be achieved and documented. This could be a huge potential for the development of future systems.

A further potential lays for according to Mr. Wolfinger within the possibility of creativity though flexibility within the SysEP. A certain degree of agility is necessary in order to leave a certain developmental flexibility open. One example would be the possibility of agility open until the testphase; otherwise the possibility to iterate and to improve the system is deprived. (Wolfinger, 2017)
Another important point is the synchronization of the product and the system. It is important to clarify when and in which product the system is ultimately transferred.

**Process Specific Criteria:**

- Previously inserting the QA into the SysEP
- Overarching process understanding/ Stakeholder synchronization
- Assessment through quality related tools
- One overarching project manager who has the responsibility
- Reflection/ Lessons Learned
- Flexibility within the SysEP is necessary till the Testphase
- Synchronization of SysEP into the PEP

**Strategic Purchasing (SP) represented by Mr. Bodenhofer, Head of SP**
According to Mr. Bodenhofer, it is of utmost importance to consider the degree of maturity a system needs to be incorporated into the PEP. Or to what degree of maturity a system must be developed to be considered as finished. This also requires that every stakeholder involved, has the same system-process maturity based understanding. A SysEP can be developed and controlled efficiently with sufficient transparency and open communication. (Bodenhofer, 2016) The question is what happens with systems that cannot be transferred to the PE in time. The technology is either essential for the customer / market to be either integrated into the PE or will be implemented later with a change request. An important issue is that in the past the delay of the system development has in consequence of the product development also lead to a time lag.
Mr. Bodenhofer sees beside the importance of the synchronization topic also huge potential within the RSP. Regarding to Mr. Bodenhofer target costing is a must when it comes to the prediction if a system fulfills the strategic and operative goals within the development.
A further possibility for the synchronization of the SysEP into the PEP could be the definition of a concrete mandatory time schedule for which every stakeholder is responsible for making their required contribution at the required time. (Bodenhofer, 2016)
Mr. Bodenhofer also insists that the issue of agility is essential to a considerable extent. Because it can always happen that a feature or functionality is overlooked therefore it is necessary to iterate back and implement the requirement.

**Process Specific Criteria:**

- Agility is necessary for creativity and later changes
- Mandatory schedule for higher Stakeholder responsibility
- More Target Costing
- Synchronization of SysEP into the PEP (System measurability)
- One overarching process understanding
- Development of a Degree of Maturity system

**External Consultant (EC) represented by Mr. Prof. Kohnhauser**
Prof. Kohnhauser who was already involved as an EC in the first Phase of the “Marktreifer Kran” project mentioned that the first question which has to be answered is what means the development of a system within Palfinger? What effects does a system have on the market when it is not yet finished? According to Prof. Kohnhauser the major possibility lays in the transformation of the systems into the products. First of all a clear understanding of how Palfinger is integrating the systems into the PEP must be defined and structured which could be managed with a Technology-Roadmap. Palfinger has to make clear what does happen to systems which are not ready for the implementation? Is the PEP

still waiting for the systems or will the product be launched without it. This comprises also the determination of a product strategy and the assessment of the costumer related benefit for the integrated systems. The assessment of requirements according to chapter 3.1.1 could also be a reasonable system.
For the synchronization of the SysEP into the PEP it must be clear what the added-value for the customer is, because if a system is a component on a crane which a customer is not able to see or identify the system is according to KANO not that critical for the strategic market advantage. But if a system on the other hand is in the customer's eyes very important, if it is a so-called "Market or Demand-driven" technology than synchronization schedule is more critical. In other words, the system must be characterized if it is necessary to gather customer benefits or prestige for the image of the company instead of an upgrade which the customer is not able to appreciate. (Referring to Chapter 3.1.1).
For Prof. Kohnhauser the consideration of two SysEP approaches is reasonable because if a straight project is getting developed than the effort should be the development of the project within the time to market which is promised to the customer. The dynamic approach could be separated in a basic approach with RSP and FSP but with a higher effort in the PD of the system. The obligation within the SysEP could be guaranteed through a mandatory time schedule which will be determined after the pre-development of the system.

**Product Specific Criteria:**

- Two approaches reasonable (Straight/ Dynamic)
- Mandatory schedules for a higher obligation of Stakeholders
- Synchronization of the SysEP into the PEP
- Separation between of systems based on KANO-model
- Assessment of requirements
- Product Strategy
- Define the overarching process landscape (Technology Roadmap)

## 5.4 Optimization Output

On the basis of the stakeholder surveys, the process-specific criteria were collected in the first step. In the following chapter the output of the workshops will be discussed in detail. The basis for those workshops was formed beside the Stakeholder surveys by the definition of the term fuzziness. The Fuzziness which will be explained within the next page will make clear how Palfinger could formulate this term specifically for the system development. The chapter will be started by the before mentioned process specific criteria structured within a validation matrix over the SysEP milestones to visualize were the highest response of criteria was and in addition to the criteria categorization the most important criteria were discussed within more detail later in the workshops. According to the output of the workshops the new system development approaches as well as a generic Technology-Roadmap for the implementation of those two approaches was carried out and will be discussed within the last point of this chapter.

**Stakeholder Process Specific Criteria (Validation Matrix):**

For a clearer presentation of the process-specific criteria, an evaluation matrix was prepared in which the criteria are first summarized in overlaps and then listed in detail with the individual stakeholders. The evaluation matrix is intended to show which criteria of the priority of the individual stakeholders are regarded as very important or essential for the optimization of the SysEP. Four main criteria crystallized out. The evaluation matrix shows that with regard to the criteria listing and prioritization of the criteria, almost all criteria for the further optimization of the SysEP should be used. A clear product strategy as well as the synchronization of the individual stakeholder processes, which in turn leads to a uniform overlapping process understanding and finally the separation in two approaches the Straight SysEP for clearly defined development projects with low degree of fuzziness and The Dynamic SysEP for more complex developments with high degree of fuzziness. Of course, the implementation of all process-specific criteria is a must for the optimization of the system development process. A consistent opinion of the stakeholders also existed in the opinion of an overarching project manager who accompanies the system from the beginning of the development to the end and carries out the synchronization of the various stakeholder work packages and eliminates any difficulties with respect to the development discipline and consequences as well as interfaces. These should also be taken into account in the development.

| Process Specific Criteria/Stakeholder | MEC | PM | CON | QA | SP | M | CS | MD | EC |
|---|---|---|---|---|---|---|---|---|---|
| Discipline(Decisions, Target Definition) | x | | x | | | x | x | x | |
| Obligation(objective, requirements, fixed development time) | x | | x | | x | | | x | x |
| Agility | | x | x | x | x | | x | x | x |
| Requirement Management | | | x | | | | x | | x |
| Product Strategy/ Synchronization of the processes | x | | | x | x | x | x | x | x |
| Target Costing | x | x | x | | x | | | x | |
| Previous involvement of stakeholders / commitment | x | | | x | x | x | x | | |
| Overarching process understanding | x | | | x | x | x | x | x | x |
| Assessment of the System Maturity Level | x | x | x | | x | x | | | |
| Reflection/ "Lesson-Learned" | | | | x | | x | | | |
| One overall Project Leader | x | | | x | | x | x | x | |
| Process Separation ( Straight, Dynamic) | x | x | x | x | | | x | | x |

**Table 8: Validation Matrix of the Process Specific Criteria**

In addition to the interface functionalities and developmental disciplines, the earlier involvement of stakeholders in the areas of the RSP and FSP has also been mentioned as a result of which a more effective RSD filling and a quicker concretization of the requirements and functionalities of the system and its architecture are to be created. Since, according to the fuzzy front-end approach, a higher level of preparedness of the stakeholders involved and the introduction of more effort in the early development phases is also crucial for the reduction of the level of fuzziness, these criteria are also necessary for the achievement of the development quality.

Agility was considered to be one of the main factors for the successful development of a system. The question arose how for is agility within the SysEP reasonable? During the workshops, it was agreed that a certain degree of fuzziness and flexibility should also be possible in the test phase, since the feedback and the iteration are essential during the test phase. However, the aforementioned developmental discipline and consistency must be increased in the early development phases in order to be able to readjust and to avoid changes later on. Because according to Mr. Wieder: "agility should not be a carte blanche to sloppiness".

Another issue was the question of increased transparency during the system development. This repeatedly led to the question of an assessment system which should be used to determine system maturity. The maturity model of Mr. Wieder could be used as a basis for this. The uniform understanding of stakeholder interdependence is important for a rating system. The generation of an overlapping process understanding with the synchronization was already the basis of the predecessor project of the "Marktreifer Kran". The question is how can such a comprehensive understanding be achieved among the stakeholders involved? In the discussions with Mr. Schinwald, the synchronization of the stakeholders and their work packages as well as the representation of the stakeholders in a process landscape was already used in the implementation of the "Marktreifer Kran".

In addition to the generation of a process-oriented approach, the definitive product strategy was also demanded as a further priority. The product strategy is the strategic decision-making base for the future development as well as the integration of the finished system into the product.
It is important to pursue a clear strategic goal. This applies both to the synchronization of the SysEP to the PEP and to the introduction of requirements. In this case, a key point should be introduced when a SysEP requirement is required and when the integration of a requirement impacts on the development efficiency as well as the development quality.
A further essential output based on the workshops was essentially the difference between the two system types or system development approaches. At the beginning of the stakeholder surveys, the terms "straight" and "dynamic" were used as a basis for the definition of the system development projects. Straight system projects are therefore technically and functionally clear in the feasibility and which are based on a low degree of fuzziness. In contrast, the dynamic systems, which are still very unclear in the beginning of the system development and the pre-development phase and have a high degree of fuzziness. This naturally leads to the question of how the term fuzziness is defined at Palfinger. This is explained with more detail below.

**Degree of Fuzziness:**
The basic term for the degree of fuzziness were defined in chapter 3.1. After detailed definition with Mr. Wieder the Fuzziness was defined as shown in Figure 5-14. The fuzziness must be distinguished into two main aspects, the technical, functional part of the fuzziness and the market-side, strategic proportion of the fuzziness. Fuzziness defines the technical/ functional clarity of a system development as well as its market and strategic expectation. Fuzziness is a state of ambiguity at the beginning of a project; this state can be influenced by several aspects. Fuzziness defines the developmental clarity of a system as well as the goal from a market strategic perspective. Fuzziness is equated with the uncertainty, indeterminacy or inaccuracy at the beginning of a system development.

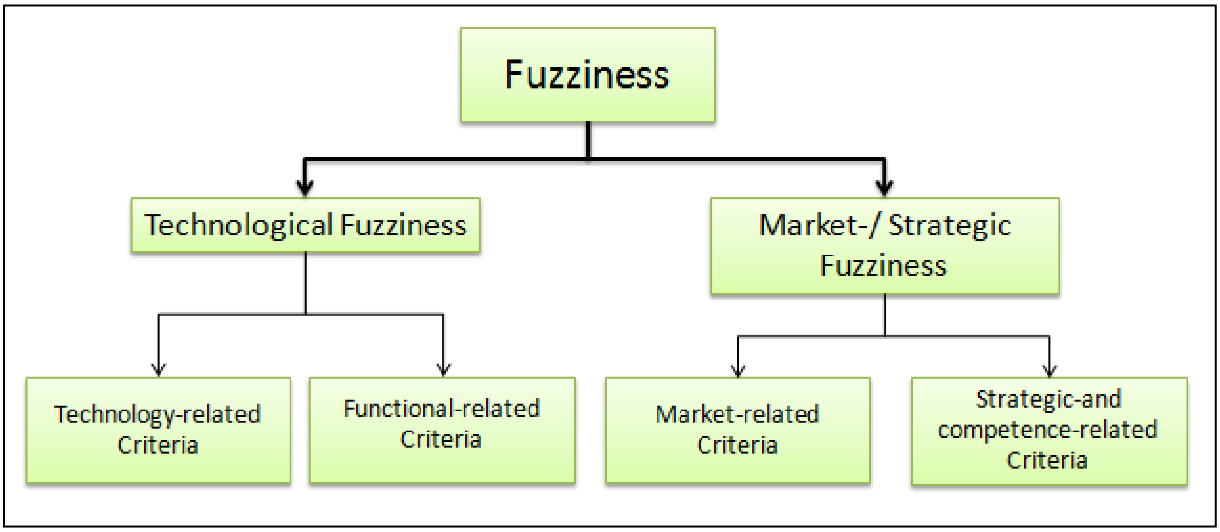

**Figure 5-14: Determination of Fuzziness for Palfinger**

From a technological and functional point of view the fuzziness can be further subdivided into several criteria. These criteria were extracted from the literature and presented in a valuation matrix. In technical fuzziness, the degree of fuzziness can be high due to lack of know-how or lack of specification of technical requirements and functionalities. Given the lack of market-side uncertainties or a lack of knowledge, fuzziness can increase in the case of the factual or strategic fuzziness. The case with probably the highest degree of fuzziness emerges when the technical/ functional fuzziness with the market side/ strategic fuzziness superimposes. This would mean a maximum of fuzziness. For a better understand of the term fuzziness in Table 9 is a validation matrix determined. But this validation matrix gives just a generic point of view over the fuzzy theme. This is not a Palfinger specific approach.

| Technology-related Criteria | Fuzziness 1-5 | Market-related Criteria | Fuzziness 1-5 | Funktional-related Criteria | Fuzziness 1-5 | Strategic & Competence-related Criteria | Fuzziness 1-5 | Degree of Fuzziness (in %) |
|---|---|---|---|---|---|---|---|---|
| Produced product and customer benefits | 2 | Time to Market | 1 | Performance data | 1 | Value through the use of technology | 1 | |
| Feasibility of technical solutions | 5 | Amortization period | 1 | Temperature | 1 | Customer service | 1 | |
| Technology fields and development scenarios | 1 | Market volume | 5 | Mechanical shock | 3 | Sectoral trait | 1 | |
| Development period | 1 | Expected market growth | 4 | Vibration | 3 | market attractiveness | 1 | |
| Functional safety | 3 | Break-Even | 1 | Moisture | 2 | Know-how | 5 | |
| modular construction | 5 | | | | | Planned introduction | 5 | |
| Degree of integration | 2 | | | | | Development costs | 5 | |
| | | | | | | Investment costs | 5 | |
| | | | | | | materials | 5 | |
| | 19 | + | 12 | + | 10 | + | 29 | =70 |
| | | | | | | | Summe | =53,8% |

**Table 9: Generic Assessment of the Degree of Fuzziness**

The term fuzziness is considered for Palfinger more as a guideline when it comes to the decisions making at the beginning of a project. Because of the enormous expertise and experience of the interviewed stakeholder the decision making through the knowledge of experts is the best way to determine whether it is a Straight or a Dynamic project. This leads to the definition of the two identified process approaches.

**Straight/ MEC Basic System Engineering Approach:**

The background of the straight approach is presented below. The straight approach was chosen as a basic process for the development of systems. The background was that not every system is high in the development complexity and technically hard feasible. According to Mr. Wieder and Mr. Vierlinger, a large proportion of the mechatronic system development processes are so-called "just do it" processes, which can be rapidly developed after the resource release and have a low development risk and a low degree of fuzziness.

The basic idea behind the straight approach is that a lead process from milestone SE1 to SE6 should be available which remains the same from developmental process structure, but by the combination with different pre-development phases either for long-term projects with high level of fuzziness or for short-term projects with a low level of fuzziness and can be applied in a standardized manner. Based on Table 6 to distinguish between a technology push approach and a demand pull could be taken also as a guideline for the evaluated SysEP approaches. Based on the demand pull approach, the Straight SysEP can be developed relatively quickly and a system or innovation required by the customer or the market can be brought to market more quickly and efficiently. This is, of course, based on the process-specific criterion of the product strategy, a key competitive advantage to know whether the project can be on the market in a certain mandatory development schedule before the competitor does so.

The strategic consideration is the direct and efficient development and smooth synchronization in the PEP. On the basis of target costing and the validation of the system maturity level, the ongoing progress is checked. The system shown in Figure 5-15 is based on the model of Figure 5-13, which means that the basic structure of the process phases and the milestones is the same. The differences exist essentially in the different pre-development phases and in the definition of the one point of robustness which defines a substantial point of concretization. At this point, the systems must have a condition on minimum requirements and a degree of fuzziness in order to be able to develop further.

The point of robustness acts as a barrier and allows the release of further system development only in certain circumstances. This means that the system defines the minimum requirements as well as binding resources and timetables. This should increase the willingness and the commitment of the stakeholders who are involved in the early stages and their discipline.

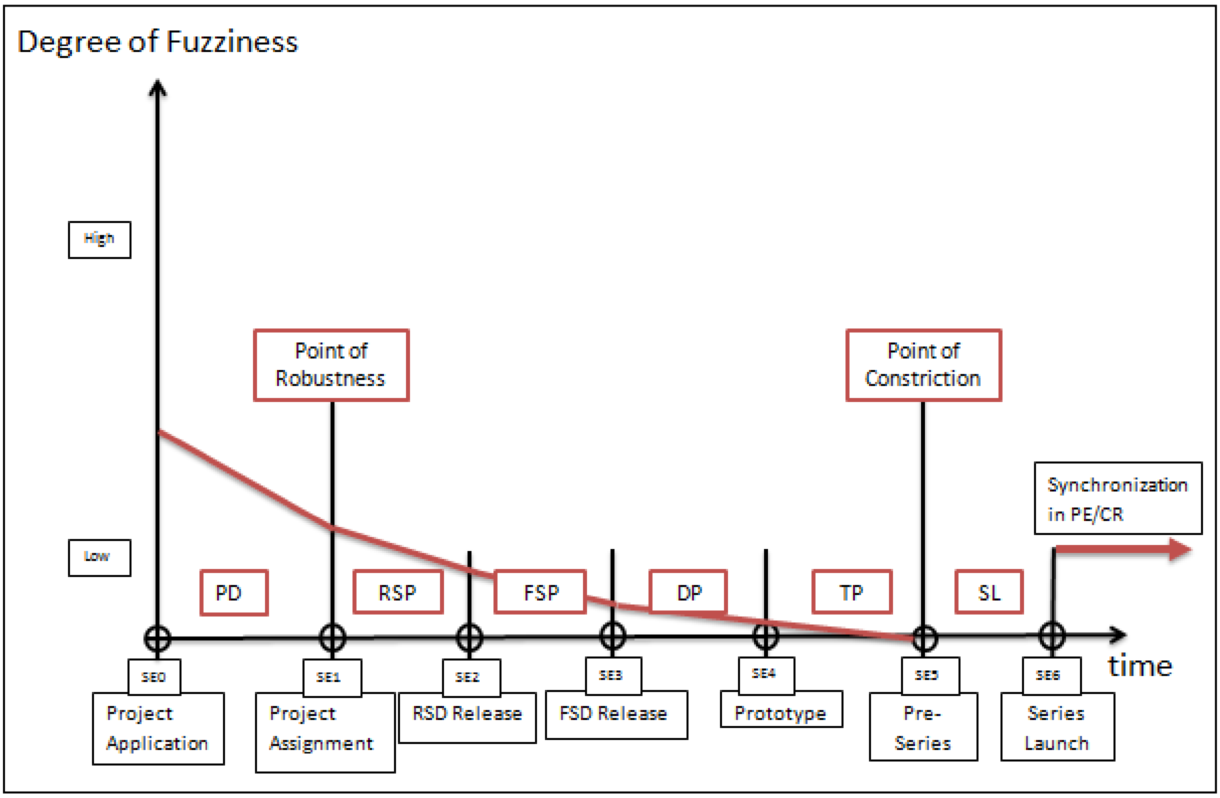


**Figure 5-15: Straight SysEP/ MEC Basic System Engineering Process**

The goal is to gradually reduce the degree of fuzziness during the development and bring to the level of fuzziness till the milestone SE5 to a minimum. During the development of a system, it would be useful to commission an overarching project manager who also deals with the optimal synchronization of the stakeholders involved. The Straight approach is therefore used for projects characterized with:

- Low development risk
- Mandatory schedule
- Consistent development
- Short development period
- Demand Pull

**Dynamic System Engineering Approach/ More extensive and Agile PD+MEC Basic SysEP:**
The dynamic approach serves the development of long-term projects which are unclear in the realization and have a high degree of fuzziness. These are complex projects that are highly rated by the development risk. The basic idea of this approach is to implement the ideas and the technical and market-side feasibility in a more elaborate pre-development phase or pre-study. In this more comprehensive pre-development phase, agile process methods should also be used, according to the stakeholders. In this area, stakeholders see the greatest potential for flexibility in system development. However, a suitable initial state must be present in the form of the appropriate system development in order to be able to concretely embed that system with agile methods. In this more comprehensive pre-development phase, the aim is to consolidate the system development or the idea so as to achieve a state of the minimum requirements or functionalities. This state was defined as the point of robustness. The point of robustness describes the condition of a system in which the degree of fuzziness could be reduced to a certain level in order to be able to implement the appropriate output

base for the development of a system with regard to the accuracy of information and technical and market feasibility. At this point, a certain stock of information must already be available and an idea must have been concretized so that the system can be optimally developed.

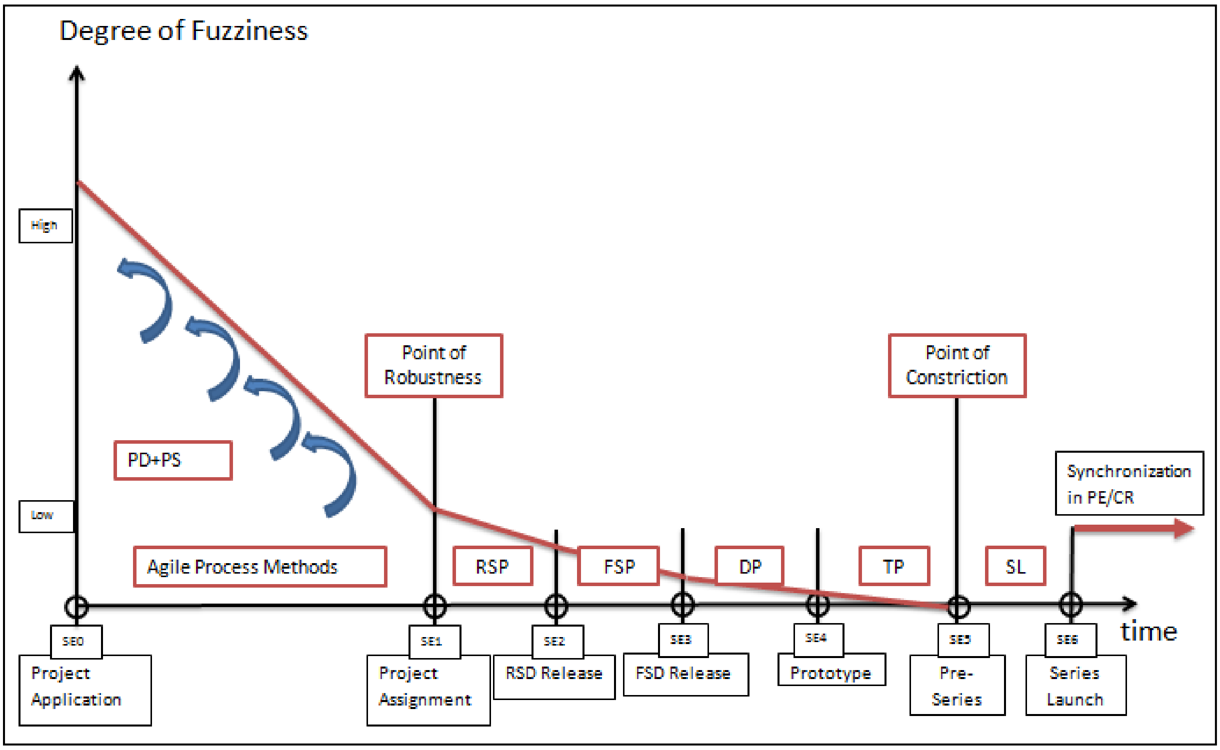


**Figure 5-16: Dynamic SysEP / Agile Pre-Development Phase + MEC Basic SysEP**

The characteristic of this approach is essentially the composition of two approaches. This means the extended pre-development phase, as discussed above, which can be carried out using agile methods, such as SCRUM, in order to be able to reduce the fuzziness through frequent meetings, to the point of robustness. The second approach is the previously described straight or MEC Basic SysEP, which is composed of the traditional RSP and FSP model and serves to further reduce the already low level of fuzziness of the system and to be able to successfully develop it.
The basic principle of this approach was the combination of a defined standardized basic process with the ability to generate more creativity for innovative projects through flexibility in the pre-development phase. The reason for the integration of the agility was to raise the efficiency within the area of idea concretization for reduction of the degree of fuzziness. Thus the dynamic approach for developing a system could be defined for the following project types:

- More complex developments
- Long-term developments with flexible approaches
- Comprehensive PS and PD with DMUs and frontloading, market-side analysis, technical feasibility
- High degree of fuzziness
- Technology Push projects

Figure 5-17 shows the two process types. Starting with the upstream agile process, this is then coupled with the Straight or MEC Basic SysEP. These approaches are also a key step towards more transparency in system development. Due to the introduced milestones and the conditions which are bound to the point of constriction and to the point of robustness, the binding and the discipline will lay the foundation for a more efficient development. Also the standardization of a basic system engineering approach will lead to a better measurability within the different development stages and further the system could be successfully synchronized into the product. Because as mentioned from Mr. Pichorner, the transparency of the systems which should be transferred into the PEP, must be clear for every Stakeholder how far a system must be developed to guarantee a successful implementation.

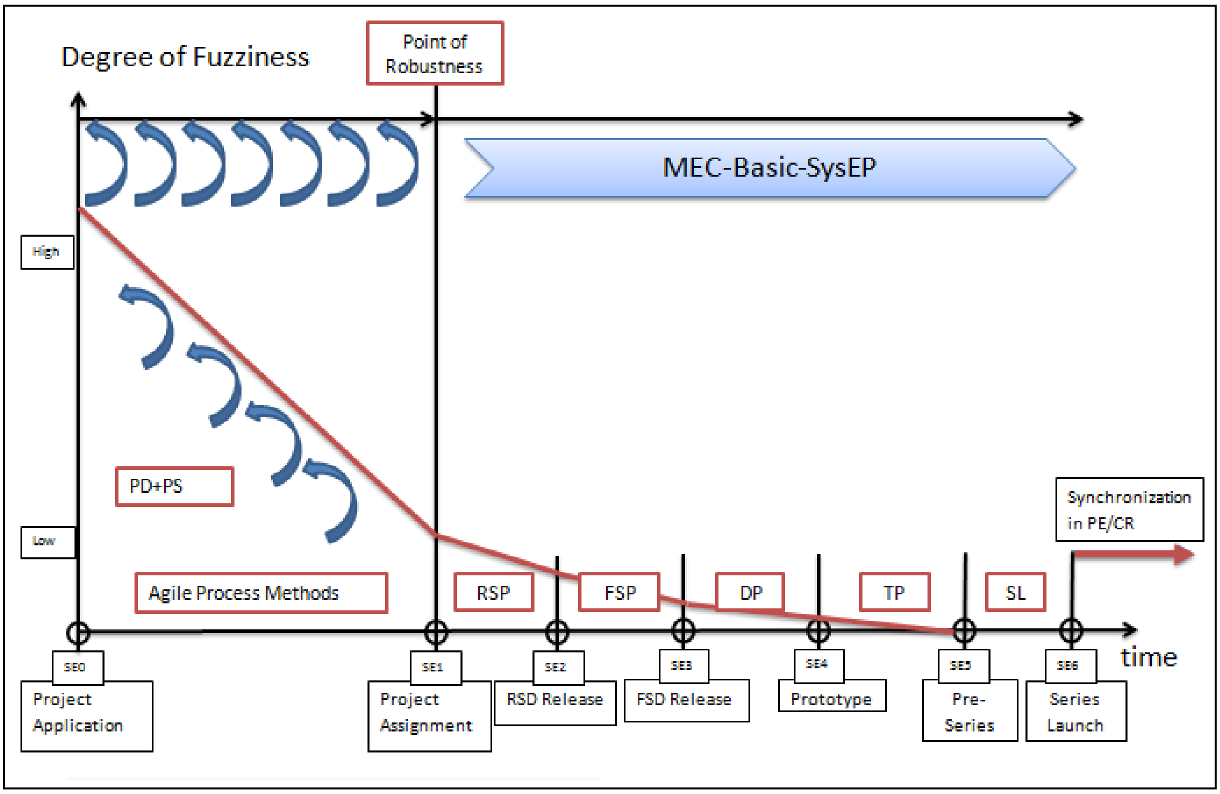


**Figure 5-17: Structure of the two System Engineering Approaches**

Based on the high potential of the synchronization topic another important output was the determination of a Technology Roadmap with regard to the previously defined system approaches and their relation to the synchronization into the PEP. This topic was last but not least considered as another crucial issue for the successful integration of a system into the product. This will be discussed within the last point the Technology Roadmap.

**Technology Roadmap:**

After the workshop evaluation, the need for a structured presentation of the synchronization scenario was determined. By the advice of Mr. Schinwald and Prof. Kohnhauser and in consultation with Mr. Wieder, a generic presentation of a technology roadmap was decidedly defined. In this technology roadmap the two determined Straight and Dynamic approaches should be presented and compared with the PEP or the crane series. Figure 5-18 shows the synchronization topics as well as their possible control options.

In the case of the integration into the PEP, this is queried at a specific fixed milestone, according to Mr. Katsch, the "Marktreifer Kran" project the MS4 milestone is defined for the integration check of the surrounded systems. The question is which systems are in circulation and whether these systems can be developed by a certain point in time. Naturally, as already discussed, this presupposes a certain degree of transparency and measurability with regard to system development and its degree of maturity. If those systems are not finished till the milestone MS6 the systems will not be integrated to guarantee a seamless synchronization and to provide from later changes which will cost a high amount of effort in time and resources.

In principle, the implementation of a system development can take place in two ways. The first possibility is for a new development of a system into the PEP. The second possibility is the integration of an existing system via a Change Request into the crane series. Or will the specific crane series be taken in some years from the market, than it is of course also not useful to implement the system into a product which is not available anymore in some years. In essence, it is a strategic question, which

system should be synchronized in which PEP. Since, for example, in the case of integration, software functionality has shown that the software diagnose must first check the software systems between the completion of the software from the development team and the implementation into the PE. This led to a considerable amount of development and costs and has not yet been taken into account. Therefore a very important question is to distinguish when the system must be synchronized into the product and when is it useful, because of market based as well as time- and technical reasons, to postpone the implementation later with a change request into the crane series.
To remember what the premises of the Phase 1 project the "Marktreifer Kran" was to increase the development quality and to reduce the complaints. Therefore it is necessary to have a high standard of development quality from the beginning of the system to the end of the market launch of a developed product. Thus the standardization of the synchronization topic as well as the development of the system itself should be one of the future targets.

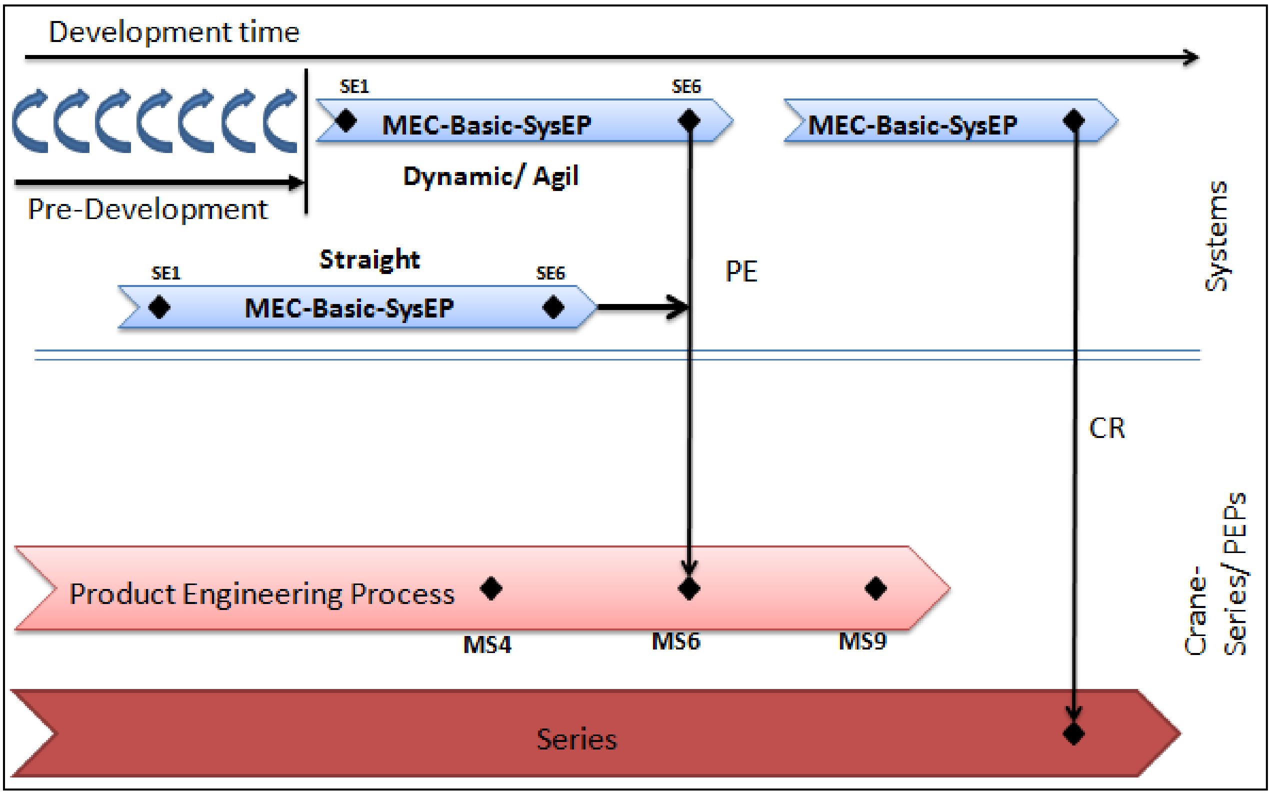


**Figure 5-18: Technology Roadmap of the Synchronization of SysEP into the PEP/ Crane Series**

The Figure 5-18 provides a good generic first overview of the synchronization topic. The essence of this representation shows the strategic importance for the determination of the product strategy within the development of a system as well as in the development of a product as early as possible. Because the earlier the synchronization decision is determined the more recent the system could be prepared for the product and vice versa.

# 6 Conclusion

On the basis of the stakeholder surveys and workshops, it should be noted that the development efficiency or the development quality of a system development can be derived from several criteria. These process-specific criteria for optimizing the current system development process according to Table 8 range from the discipline on the part of the stakeholders involved, on the relevance of agility in a system development, as well as the measurability with a suitable mature degree model to increase transparency, up to the generation of a process-spanning concept. These criteria are essential for the future treatment of system development and to increase the development quality.

To be able to develop a system efficiently within specified amount of time and under defined resources, it is necessary to generate one overarching process understanding of every involved stakeholder. This will form the basis for a successful system development. Another crucial issue for the optimization of the system engineering process is the management of the system and its interfaces by an overall process leader. Due to the fact that in recent SysEP a lack of synchronization between the systems interfaces was figured out. The efficiency of a SysEP is further closely linked to the transparency within the system engineering process. This means within the development of a system it must be validated on its state of maturity. If a system is finished or realized to a certain degree of maturity, the information basis between the Stakeholders is more detailed and clear. A further important point is the appropriate management of requirements in this case the literature comprises a range of useful characterizations and classifications of how to manage the requirements. The right management of requirements is one of the key performance indicators for an efficient system development, because if the Functional Specification Document is released and after the release a requirement will be changed or implemented, postpone into the FSD, the negative effects could be tremendous regarding the increase of development costs and -time. Therefore, the prioritization of requirements through the Kano model or other models could be a critical success factor in the future for the development of systems.

Based on the Stakeholder surveys the agility relevance is crucial for the development of innovative and complex project with a high degree of fuzziness. This again describes the nebulous state of the idea or the innovation in the initial pre-development phase. Regarding to the Dynamic approach the development within the pre-development phase is based on agile process models. Therefore the fuzziness could be reduced from a high unclear state to a state of robustness. From the point of robustness the use of agile models will switch to the traditional system development model. The Straight model will be used for short-term projects with a low degree of risk and fuzziness within the initial state of the project. This will increase the competitive edge for the development of demand driven projects which must be developed within a short and efficient manner. So the basic idea was to define to process types which could be combined together and each process has their project specific characteristic. Thus the experienced managers are able to decide at first site which system process type is already needed. The decision will build up on the level of fuzziness and the system related criteria (example shown in Table 9)

This has also been shown that specific terms derived from the literature, such as the fuzziness of innovation management, were not enough formulated to be able to define a system in a proper sufficient manner. Further, not all stakeholders could understand what the term fuzziness is related to and how this term is defined in a Palfinger specific way, however, after careful discussion, this complex concept proved to be suitable for distinguishing the two defined system development approaches. That a hybrid version of the new optimized system engineering approach had to be defined especially for the company was already shown after a short run time of the project. A closer look to the literature makes sure that the optimization regarding the actual system engineering process has to be defined with a few guidelines out of the literature but the major definitions were driven and identified by the Stakeholder surveys and workshops. Due to the fact that a change within a large concern which affects the working conditions of hundreds of people is hard to introduce within a short amount of time.

Therefore, as the first step the definition of these two system approaches will be the initial situation for a larger project which will determine those system engineering processes within more detail and based on the “Marktreifer Kran” project will define the Stakeholder process and the relation between

their working interfaces. Further the company will provide the development of a prototype based on these new system engineering approaches.
The following step for the further determination will be the synchronization of both system process approaches with the involved stakeholders and define the stakeholder- related working tasks within the SysEP. This project will lead and coordinated by one overall project manager. A further investigation will lead to the synchronization scenario of the SysEP into PEP. The goal should be the definition and evaluation of overall process landscape and the interfaces between the process. This will be defined at the macro-process-level (Figure 5-3) which is basically the definition of a product portfolio of all PEPs and their integrated systems as well as the determination of the micro-process-level within the SysEP. But the most important basis for the efficient development of systems and products will be the generation of the overarching process thinking within the departments to prevent from territoriality thinking and increase the pull into the same direction.

# 7 Outlook

The results arisen from the master thesis are subsequently elaborated in detail. The synchronization scenario as well as the two system development approaches with the stakeholders-related processes are evaluated more precisely and defined in detail in a process map. In addition to the definition of stakeholder-specific processes and their work packages, another goal is the synchronization between those process interfaces. In the course of further discussions, the basis of an understanding of the current developments in the planning of the product engineering process of the "Marktreifer Kran" project is to be combined with the new system development approaches such as the straight and dynamic approach. The target after the further evaluation of the system approaches will be the standardization of certain stakeholder working tasks to reduce the development time and the required resources and focus on the increase of the development efficiency. To cope with the increase of dynamic market or customer related demands, the integration of flexibility in the form of agile process methods, will according to the stakeholder surveys be crucial for the future of system engineering within the Palfinger development teams. In order to maintain the high standard of competitiveness in the field of premium goods, the flexibility in form of fast reactions and realizations of requirements related to certain market demands is necessary for the future success of the company. Therefore, the implementations of agile process methods or even hybrid models could be the next step for a successful efficient systems engineering.

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## Affidavit:

"I declare on oath that I have written the master thesis with the title" Optimization regarding the system engineering process of mechatronic systems, in consideration of the transparency and the development efficiency ", independently and without the help of others And aids not used, and all literally or professionally collected posts, as such. "

Place, Date

Grießner Bernhard, BSc