University of Applied Sciences Upper Austria

MASTER DEGREE PROGRAM

Innovation and Product Management

Developing a manual for the preparation of recurring experiments with statistical methods for mechanical engineering companies

Master Thesis submitted

for the attainment of the academic degree

Master of Science in Engineering

by

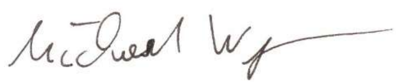
Michael Tobias Wesinger

March 2013

Supervised by

Dr. Gerhard Gietl

I faithfully declare, that I have written this thesis independently and without outside help. I have only used the sources which are quoted in the reference and I have marked the pages taken, either directly or as regards content from the sources.
The thesis was in this or similar style never shown to another board of examiners nor it was published.



....
Michael Wesinger

Wels, 27.02.2013

ABSTRACT

The testing departments of engineering companies have the task to check machines, their assemblies and components to specific requirements, for instance they test prototypes, doing life tests, etc. This extensive process is concerned with a wide range of specific knowledge.

Information for ordered experiments is often gathered from former experiments, project documentations, requirements and performance specifications or is provided only by seasoned engineers.

Based on the fact that the knowledge base between the employees of the testing department differs, it could happen that the experiments for one test object are also different and furthermore the testing results could vary as well.

For this reason the idea of creating a standard test catalog for all employees who are concerned with the testing department arose to provide a knowledge base including all recurring experiments. This knowledge base contains information of the organizing and documentation process from a testing request until the archiving of the test results.

Process models for the standardization of test cases and their documentation for machines, assemblies and components which are used for different machine series and machine generations are generated in this project.

The goal with this project is the creation of a guide for the preparation of recurring test cases for the testing department of a mechanical engineering company. This manual will include on one hand the processes of creating standardized test sequences by using statistical design of experiment and on the other hand a model of how these testing scenarios will be documented in a software system.

Generally, the manual aims the improvement of the administration of the testing department of engineering companies and its related departments and areas.

Design of Experiments (DOE) and Requirements Engineering & Management (RE&M) are the significant topics covered in this project.

KURZFASSUNG

Die Versuchsabteilung von Maschinenbau-Unternehmen hat die Aufgaben Maschinen, deren Baugruppen und Komponenten auf spezielle Anforderungen zu überprüfen. Darunter fallen beispielsweise das Testen von Prototypen, Lebensdauertests, Überprüfungen für die Serienfreigabe, etc. Dieser umfangreiche Versuchsprozess ist mit einer Menge an implizitem Wissen verbunden.

Informationen werden üblicherweise aus früheren Versuchsaufträgen, Projektdokumentation, Pflichtenheften oder Lastenheften entnommen, oder sind gänzlich nur in den Köpfen der erfahrenen Ingenieure vorhanden.

Bei der Versuchsentwicklung unterscheidet sich der Wissenstand einzelner Mitarbeiter von einander, somit kann es vorkommen, dass dasselbe Testobjekt auf mehrere Varianten getestet wird und dadurch unterschiedliche Ergebnisse liefert. Darüber hinaus stellt die Wissensbeschaffung für die Versuchs-Durchführenden einen erheblichen Aufwand dar.

Deshalb entstand die Idee einen Standard Versuchskatalog zu erstellen, welcher unternehmensinterne Standard-Versuchsszenarien beinhaltet und daher den organisatorischen und dokumentarischen Ablauf von der Versuchsauftragsausschreibung bis zum Festhalten der Ergebnisse steuert.

Desweiteren werden Prozessmodelle zur Standardisierung und Dokumentation von Testfällen entwickelt, die für Maschinen, Baugruppen und Komponenten unterschiedlicher Maschinen-Serien und –Generationen anwendbar sind.

Das Ziel dieser Arbeit ist die Erstellung eines Leitfadens für die Generierung von wiederkehrenden Versuchsabläufen für die Versuchsabteilung von Maschinenbau-Unternehmen. Dieser Leitfaden beinhaltet einerseits die Prozesse zur Erstellung der standardisierten Testfälle und andererseits ein Model wie diese Versuche mithilfe eines Software-Systems dokumentiert werden können.

Allgemein zielt der Leitfaden darauf ab, die Organisation von Versuchsabteilungen und der damit verbundenen Bereiche von Maschinenbau-Unternehmen zu verbessern.

„Design of Experiments“ (DOE) und „Requirements Engineering & Management“ (RE&M) sind signifikante Themen die im Zuge dieser Arbeit behandelt werden.

TABLE OF CONTENTS

1 INTRODUCTION

"In an ideal world, testing would be a pretty straightforward process. A test team takes the product requirements, writes a test specification document, reviews the tests, and then runs them all for each version of the product. The team is composed of full-time staff, and everyone knows exactly what is expected of them.

In practice few organizations have that luxury. There is not time to run all the tests on every product version - especially on fix-releases that need to be rolled out quickly. Requirements are constantly changing, and the tests have to be changed in step.

Test staff come and go. There are misunderstandings over who was supposed to run which tests, so some get missed. Management suddenly wants a status update at seven in the evening." [1]

Also, through better recording methods the quantity of information and data recording is rising in testing departments of mechanical engineering companies. The illustration and storage of a high amount of data gets cheaper and easier to effort. By rising data and information quantity its administration gets more and more complex. New administrative concepts must be created to overlook this data flood.

For all these situations the company needs support for the test management. This is the crucial factor for this thesis.

1.1 BACKGROUND AND SIGNIFICANCE

The testing departments of engineering companies have the task to check machines, their assemblies and components to specific requirements like testing the suitability for mass production, testing prototypes, life testing, etc. This extensive process is concerned with a wide range of specific knowledge.

It could occur that the employees of the testing department do not know the necessary testing criteria and procedures.

Information is often gathered from former experiments, project documentations, requirements and performance specifications or is provided only by seasoned engineers.

[1] teamst.org

This project aims to develop a process model for the standardization of test cases and their documentation for machines, assemblies and components which are used for different machine series and machine generations.

Based on the fact that the knowledge base between the employees of the testing department differs, it could happen that the experiments for one test object are also different and furthermore the testing results could vary as well.

For this reason the idea of creating a standard test catalog for all employees who are concerned with the testing department arose to provide a knowledge base including all recurring experiments. This knowledge base contains information of the organizing and documentation process from a testing request until the archiving of the test results.

In small and medium-sized engineering enterprises in Austria intuitive development of experiments is common instead of using statistical methods for the design of experiments. Intuitive experimentation is good for individual testing but for recurring experiments the advantages of statistical design of experiment overlap.

The advantages of statistical design of experiment are the reduction of experimental variations, it helps to determine the important variables that need to be controlled und the unimportant variables that may not need to be controlled and it helps to measure important interactions. Using Design of Experiment reduces the amount of testing cycles of a product or a product part. Because of this it saves money by reducing the costs of testing.

The specific requirements for this project are now to find the system for test planning of mechanical engineering companies to develop a manual for the generation of different recurring experiments.

The manual should include the process from intuitive testing to using statistical design of experiment in the testing department. For the future this manual includes the process, a list of statistic methods and the documentation structure to develop the prospective software tool.

1.2 SCOPE

The proposed research will contribute at both the theoretical and empirical levels to the enhanced understanding of the processes in a testing department of mechanical engineering companies.

The principal theme of the project is the Quality Management in the testing department and how the process of preparing testing sequences works. This topic is related to some important questions: How can experiments be standardized generally? Which opportunities does a mechanical engineering company have to standardize their experiments? What is the current process of developing testing cases and what must be done to improve that process? Which statistic methods are useful for testing in engineering companies?

An important requirement in the testing department and furthermore in the production of machines is the time you need to get results from an experiment. Therefore Design of Experiment (DOE) is a significant issue to shorten the testing time of experiments. For that reason it is a basic topic for the project.

Another relevant key issue is Requirements Engineering & Management (RE&M). For this project Requirements Engineering & Management is used as a system engineering process which covers all of the activities involved in discovering, documenting and maintaining a set of requirements for the experiments of the testing department.

A set of information from different mechanical engineering companies will be gathered and compared by making a Benchmarking. This information should contain the processes of test planning and the documentation structure of the experiments and the test results from the testing department of the different companies.

1.3 THE GOALS AND OBJECTIVES OF THE THESIS

The aim with this project is to create a guide for the preparation of recurring testing cases for the testing department of a mechanical engineering company. This manual will include on one hand the process of creating standardized testing sequences by using statistical design of experiment and on the other hand a model of how these testing scenarios will be documented in a software system.

Moreover, it should not only be a guideline for one specific company but also for mechanical engineering companies in general.

1.3 THE STRUCTURE OF THE THESIS

Chapter 2 “Design of Experiments” and chapter 3 “Requirements Engineering & Management” form the theoretical foundation of this thesis. Chapter 2 covers Design of Experiments with its definitions, principles, methods, processes and the barriers of DOE. Chapter 3 includes amongst others the definitions, the RE Process, Requirements Management and the Validation & Verification of Requirements.

Chapter 4 “Benchmarking” give the theoretical background of the conducted empirical research. Chapter 5 “Empirical Research” describes the methods and processes of the benchmarking and gives the summary of the benchmarking results, including the single analysis and an overall analysis of the surveyed companies.

Chapter 6 "Improving the processes and developing the manual" illustrates the development of the standard test catalog based the principles of reuse. This includes a current example compared to the improved processes for the testing department. Furthermore this chapter also describes the process to create the standard test catalog and the documentation in the test catalog and around the processes.

Chapter 7 "The manual" is a summary of the developed result from chapter 8 without the comments of the derivation and without the comparison to the theoretical part. The manual also includes a few examples for the processes and the documentation for a better understanding.

At the end a conclusion is given in chapter 8 and the references of this work in chapter 9.

2 DOE – DESIGN OF EXPERIMENTS

2.1 DEFINITIONS

What is an Experiment?

"The term experiment is defined as the systematic procedure carried out under controlled conditions in order to discover an unknown effect, to test or establish a hypothesis, or to illustrate a known effect. When analyzing a process, experiments are often used to evaluate which process inputs have a significant impact on the process output, and what the target level of those inputs should be to achieve a desired result (output). Experiments can be designed in many different ways to collect this information."[2]

What is Design of Experiments?

„DOE is a systematic approach to investigation of a system or process."[3]

"More precisely, it can be defined as a series of tests in which purposeful changes are made to the input variables of a process or system so that one may observe and identify the reasons for these changes in the output response."[4]

2.2 WHY DOE?

"With modern technological advances, products and processes are becoming exceedingly complicated. As the cost of experimentation rises rapidly, it is becoming impossible for the analyst, who is already constrained by resources and time, to investigate the numerous factors that affect these complex processes using trial and error methods."[5] Instead, the techniques of "Design of Experiment" give powerful and efficient manners to identify only the so-called "vital few" factors. These factors are adequate to improved quality and productivity to achieve the process or product requirements.

At one-factor-at-a-time experiments a single factor changes over time to study its effect on the product or process. This method is easy to understand but very time consuming when the numbers of factors are rising and it gives no conclusion on the interaction of different factors. Therefore, DOE methods are more efficient than the one-factor-at-a-time method because it

[2] moresteam.com
[3] thequalityportal.com
[4] TANCO et al (2009): P.478
[5] weibull.com

considers not only the effects of single factors but also the interactions between the factors. The effects of interactions are sometimes more important because (…) "the application environment of the product or process includes the presence of many of the factors together instead of isolated occurrences of single factors at different times."[6]

Results from designed experiments and analysis are more reliable and complete than from the one-factor-at-a-time method because it ignores interactions, which could lead to misleading conclusions.

Design of Experiments guarantees that all factors and their interactions are systematically analyzed.[7]

2.3 COMPONENTS OF EXPERIMENTAL DESIGN

Consider the following diagram of a cake-baking process. There are three aspects of the process that are analyzed by a designed experiment:

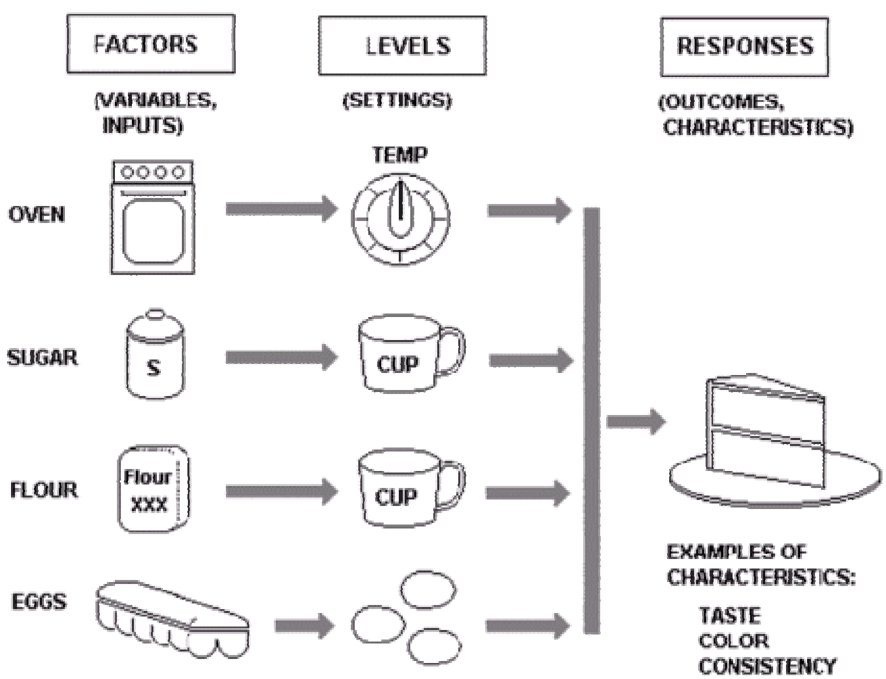


Figure 2.1: Cake-Baking-Process

(Source: http://www.moresteam.com/toolbox/design-of-experiments.cfm

[6] weibull.com

[7] Cf. weibull.com

Factors, or inputs to the process

The inputs can be set as controllable or uncontrollable variables. In the example of Figure 2.1 the controllable factors are the ingredients for the cake and the oven that the cake is baked in. There could be other types of factors as well, like the mixing method or tools, the sequence of mixing, or even the people involved. In general people are defined as a Noise Factor. A Noise Factor is an uncontrollable factor, which creates variability under normal operating conditions but is controllable during the experiment by using blocking and randomization. By using a Fishbone Chart, also called Cause & Effect Diagram, factors can be categorized.[8]

Levels, or settings of each factor

In the examples of figure 2.1 this is the oven temperature setting and the particular amounts of sugar, flour, and eggs chosen for evaluation.[9]

Response, or output of the experiment

In the cake-baking example of figure 2.1, measureable outcomes are the taste, consistency, and appearance of the cake. The factors and their respective levels influence them. Experimenters often desire to avoid optimizing the process for one response at the expense of another. For this reason, important outcomes are measured and analyzed to determine the factors and their settings that will provide the best overall outcome for the critical-to-quality characteristics - both measurable variables and assessable attributes.[10]

2.4 PROCESS MODELS FOR DOE

In DOE they often use a ‘black box’ type to begin with a process model. This process has discrete or continuous input factors, which can be varied by the experimenter and one or more measured output factors.

Often the experimenter must deal with a number of uncontrolled factors that may be discrete. These factors can be for example different machines or operators, and/or factors such as ambient temperature or humidity.[11]

---

[8] Cf. moresteam.com
[9] Cf. moresteam.com
[10] Cf. moresteam.com
[11] Cf. itl.nist.gov

In DOE it is essential to understand the process behind the experiment. “A process is the transformation of inputs into outputs. In the context of manufacturing, inputs are factors or process variables such as people, materials, methods, environment, machines, procedures, etc. and outputs can be performance characteristics or quality characteristics of a product. Sometimes, an output can also be referred to as response. ”[12]
To apply a designed experiment, the experimenter will intentionally vary the input process factors or machine variables in order to measure occurring changes in the output process. The experiments are planned, executed and analyzed to gain certain information in order to improve functional performance of products, to reduce scrap rate or rework rate, to reduce product development cycle time, to reduce excessive variability in production processes, etc.[13]
Figure 2.2 shows an example of a process model (e.g.: an injection molding process) with of six variables of factors, possible inputs and outputs.[14]

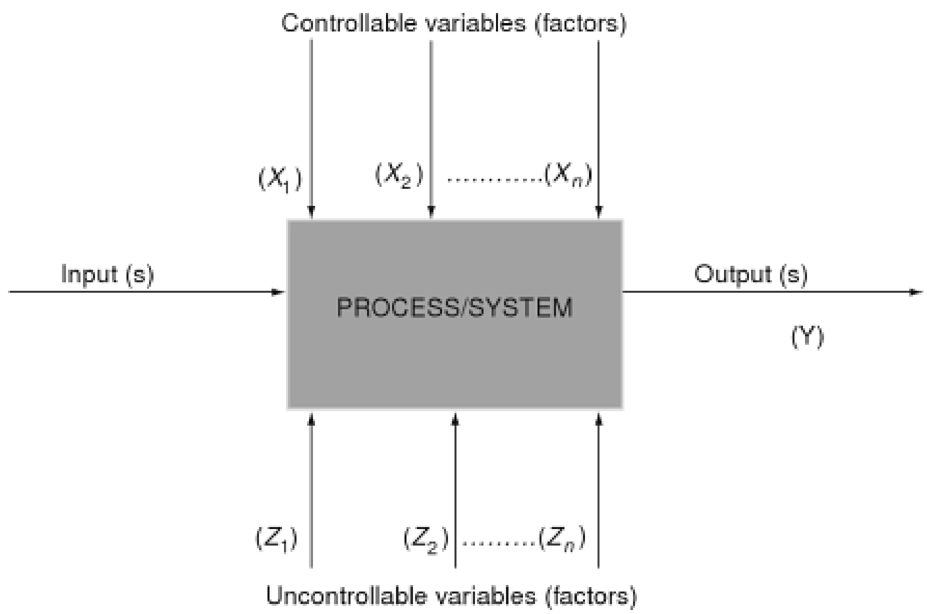


Figure 2.2: Process Model Schematic of DOE (Source: ANTONY (2003): P. 7)

Some of the input factors can be controlled (controllable variables) others are hard or expensive to control with standard conditions during normal production.[15]

In Figure 2.2 Output (s) are characteristics that are measured to evaluate process or product performance. Controllable variables (represented by X’s) can be varied easily during an

[12] ANTONY (2003): P. 6
[13] Cf. ANTONY (2003): P. 6
[14] Cf. ANTONY (2003): P. 6
[15] Cf. ANTONY (2003): P. 7

experiment by the experimenter. Uncontrollable variables (represented by Z's) are difficult or unable to control during an experiment. These factors are the trigger for product performance variability. Optimal settings of X's are essential to minimize the effects of Z's. This is the fundamental strategy of robust design.[16]

2.5 BASIC PRINCIPLES

Replication:

"Replication" and "repeated measurements" are two different principles. For example, four people get one sort of drug. The effects are measured for each person. This results in four independent observations on the drug. This principle is called "replication." On the other hand, if only one person gets a drug four different times and the effects are measured, the results are not independent. This is called "repeated measurements."[17]

Randomization:

At the process of "randomization" the basic objects whereby the experiment is carried out (so-called "experimental units") are allocated randomly to treatments and not through a subjective approach. Randomization leads to unbiased results. Alternatives include subjective approaches whereby biased results will occur.[18]

Blocking:

At the process of "blocking" experimental units are allocated to homogeneous groups in a way to compare the treatments easier with a random allocation of the treatments within every group (or 'block').[19] The experimental conditions in each block are similar and hence, improve the observation. [20]

[16] Cf. ANTONY (2003): P. 7
[17] Cf. DEAN, VOSS (1999): P. 2f
[18] Cf. stats.gla.ac.uk
[19] Cf. stats.gla.ac.uk
[20] Cf. DEAN, VOSS (1999): P. 3

2.6 PURPOSE OF EXPERIMENTATION AND USES OF DOE

DOE deals with questions like "what is the main contributing factor to a problem?", "how well does the system/process perform in the presence of noise?", "what is the best configuration of factor values to minimize variation in a response?" etc.[21]

Designed experiments have many potential uses in improving processes and products, including:

Comparing Alternatives: For a bakery one example is comparing the results and output characteristics form two different types of flour. If the characteristics are similar, they can select the vendor with the lowest-cost, but if there are significant differences, they should select the flour with the better results. The experiments should lead to information to help by the decision-making comparing both cost and quality. [22]

"**Identifying** the **Significant Inputs** (Factors) **Affecting** an **Output** (Response): **separating the vital few from the trivial many**." [23]

Achieving an **Optimal Process Output**. "What are the necessary factors and the levels of those factors, to achieve the optimal taste of a specific cake?"

Reducing Variability. "Is it possible to change the recipe that the outcome is more likely the same?"

Minimizing, Maximizing, or Targeting an Output (Response). "How can the cake be made as moist as possible without disintegrating?" [24]

Improving process or product "**Robustness**" - fitness for use under varying conditions. "Can the factors and their levels (recipe) be modified so the cake will come out nearly the same no matter what type of oven is used?" [25]

Balancing Tradeoffs if more than one "Critical to Quality Characteristics" are required optimize the product. "How can the best tasting cake be produced with the simplest recipe (least number of ingredients) and shortest baking time?" [26]

---

[21] Cf. thequalityportal.com
[22] Cf. moresteam.com
[23] moresteam.com
[24] moresteam.com
[25] moresteam.com
[26] Cf. moresteam.com

2.7 DOE PROCESS

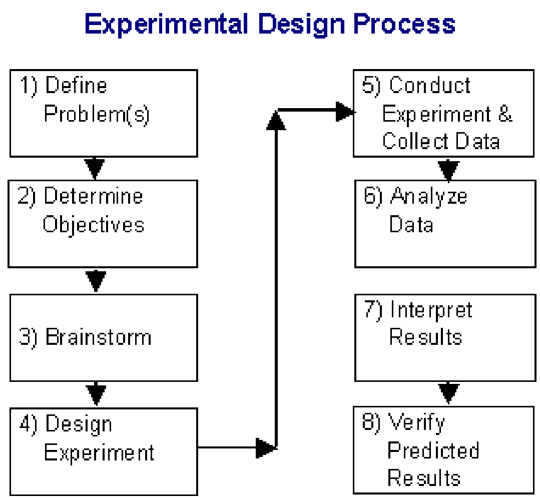


Figure 2.3: Experimental Design Process (Source: moresteam.com)

1) Define Problem

In preparation for the research the following questions will help defining the current situation:

- Who is the customer?
- What are the long-term goals?
- Which (sub-) problems should be solved with the planned implementation?
- How much time and capital are available at the most?
- Who are the stakeholders of the planned research?
- Who is responsible for the project management?
- What do you know about the present problem? [27]

2) Determine Objectives

“Planning an experiment begins with carefully considering what the objectives (or goals) are. The objectives for an experiment are best determined by a team discussion. All of the objectives should be written down, even the "unspoken" ones.

The group should discuss which objectives are the key ones, and which ones are "nice but not really necessary". Prioritization of the objectives helps you decide which direction to go with

[27] Cf. KLEPPMANN (2006): P. 14f

regard to the selection of the factors, responses and the particular design. Sometimes prioritization will force you to start over from scratch when you realize that the experiment you decided to run does not meet one or more critical objectives." [28]

3) Brainstorm - Set process variables

All process variables are set in this process step. The best way to define these process variables including all inputs (factors) and outputs (responses) is done as a brainstorming in a team. The team should

- include all important factors.
- be bold in choosing the low and high factor levels.
- check the factor settings for impractical or impossible combinations.
- include all relevant responses. [29]

Graphical illustrations help defining the variable, following are some important tools listed:

Process flow chart

"The Process Flow chart provides a visual representation of the steps in a process. Flow charts are also referred to as Process Mapping or Flow Diagrams. Constructing a flow chart is often one of the first activities of a process improvement effort, because of the following benefits:

- Gives everyone a clear understanding of the process
- Helps to identify non-value-added operations
- Facilitates teamwork and communication
- Keeps everyone on the same page"[30]

Fishbone Diagram (also Cause & Effect Diagram or Ishikawa Diagram)

"This diagram is used to identify all of the contributing root causes likely to be causing a problem."[31]

---

[28] itl.nist.gov
[29] Cf. itl.nist.gov
[30] moresteam.com
[31] moresteam.com

4) Design Experiment

The choice of an optimal experimental design depends on the objectives, the number of factors, the number of levels for each factor, the desired accuracy of the results and the dimension of random scattering.[32]

Types of designs are listed here according to the experimental objective they meet:

Comparative objective: If you have a *comparative problem*, you need a *comparative design* solution. E.g.: If the observation has one or more factors and the main objective of the experiment to find a prior factor and furthermore, to make a recommendation whether that factor is significant or not.

Screening objective: Choosing or screening out the few important prior effects comparing to the many less important effects is the main objective of the experiment.

Response Surface (method) objective: The experiment is designed in a way to give assessments of interaction and also quadratic effects. Hence, for the observation evaluations of the shape of the response surface can be given. In this case they are called *response surface method (RSM) designs*. [33]

“RSM designs are used to:

- Find improved or optimal process settings
- Troubleshoot process problems and weak points
- Make a product or process more robust against external and non-controllable influences. "Robust" means relatively insensitive to these influences.” [34]

Optimizing responses when factors are proportions of a mixture objective: A *mixture design* is needed if the factors of the observed experiment are proportions of a mixture and the optimum proportions of the factors to maximize or minimize an output are searched.

Optimal fitting of a regression model objective: A *regression design* is needed, if a response as a mathematical function of a few continuous factors should be modeled and special model parameter assessments, like unbiased and minimum variance, are wanted. [35]

[32] Cf. KLEPPMANN (2006): P. 26
[33] Cf. itl.nist.gov
[34] itl.nist.gov
[35] Cf. itl.nist.gov

Design Selection Guideline			
Number of Factors	**Comparative Objective**	**Screening Objective**	**Response Surface Objective**
1	1-factor completely randomized design	_	_
2 - 4	Randomized block design	Full or fractional factorial	Central composite or Box-Behnken
5 or more	Randomized block design	Fractional factorial or Plackett-Burman	Screen first to reduce number of factors

Table 2.1: Design Selection Guideline (Source: http://www.itl.nist.gov/div898/handbook/pri/section3/pri33.htm)

5) Conduct Experiment & Collect Data

Statistic does not replace accuracy. Every measured value is used for the calculation of all effects. Therefore, it affects every conclusion of the test. An undetected mistake can adulterate the results. The single tests of the test plan must be prepared and executed with high diligence.[36]

Preparation

An accurate test preparation ensures an error-free and smooth test execution.

Following steps should be considered:

- Planning of the necessary resources:
  Which equipment, measuring devices, raw material and parts are required? Who and when is the work done?
- Checking of the measurement equipment and processes:
  Are the measuring devises calibrated? Is the measurement spread known and small enough?

[36] Cf. KLEPPMANN (2006): S. 31

- Selection, identification marking and allocation of the parts:
  Are the parts representative? Are the parts similar or are existing differences known as block-factor in the test plan? Are the parts marked to allocate the parts to the test number?
- Definition of the test and measuring process:
  Is the test and measuring process clearly defined? Can it be guaranteed that the environmental requirements and other specifications are as similar as possible for every experiment? Are the most important environmental requirements collected and documented? How to avoid allocation and transmission errors?
- Allocation and briefing of the human resources:
  Is it clearly defined who would do what work? (One task per person) Is it clear for the staff that the defined series of experiments must be followed? Moreover, is it clear that every test result is necessary for the calculation of all effects; therefore, accuracy and consistent procedures are very important?
- Execution of a pilot test:
  Have the pilot test been executed to check the feasibility of the defined factor combinations and to try the test procedure? [37]

Execution

In spite of high accuracy it is possible that unpredicted incidents might occur during the test execution. These incidents could have influence on the test results. Therefore, it is necessary to document all variations and deviations of the test plan beside the test procedure. The actual-values are considers at the analysis, not the must-values.

If it is not possible to keep the environmental conditions constantly, all variations should be documented. Hence, their effects on the results can be identified belated. [38]

[37] Cf. KLEPPMANN (2006): S. 31f

[38] Cf. KLEPPMANN (2006): S. 32

6) Analyze Data

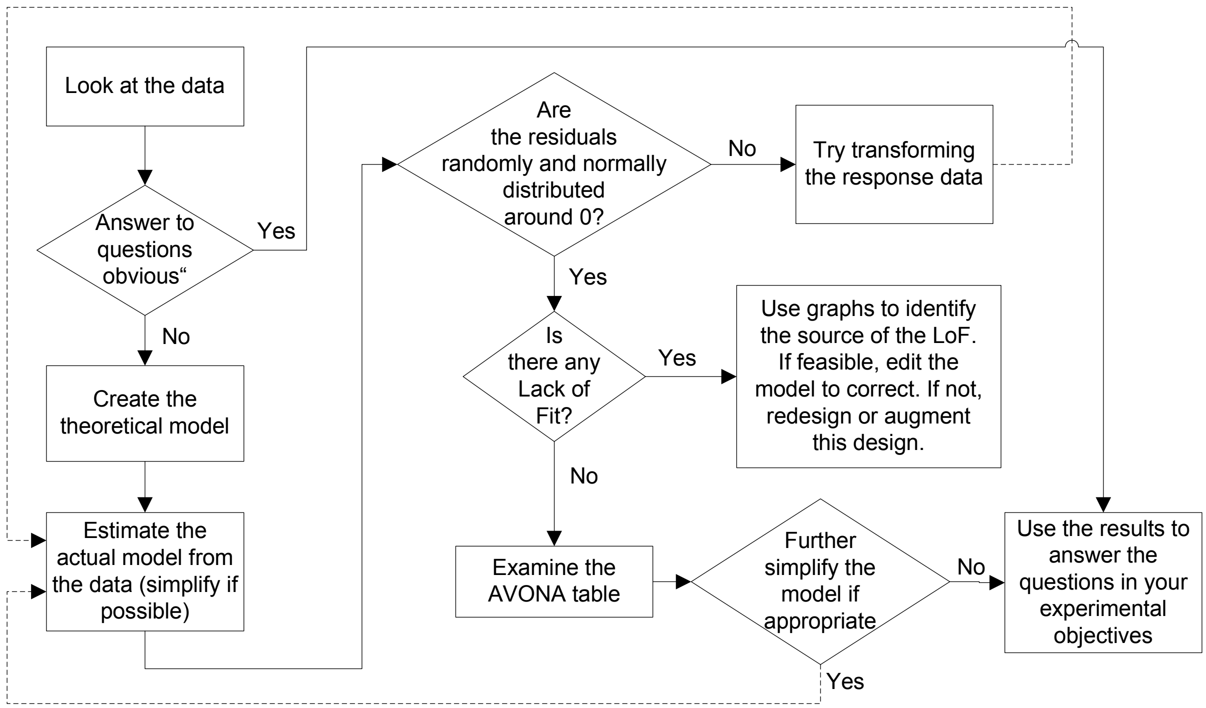


Figure 2.4: Flowchart of DOE Analysis Steps (Source: http://www.itl.nist.gov/div898/handbook/pri/section4/pri41.htm)

DOE Analysis Steps

The following are the basic steps in a DOE analysis.

1. “Look at the data. Examine it for outliers, typos and obvious problems. Construct as many graphs as you can to get the big picture.
    - Response distributions
    - Responses versus time order scatter plot (a check for possible time effects)
    - Responses versus factor levels (first look at magnitude of factor effects)
    - Typical DOE plots (which assume standard models for effects and errors)
        - Main effects mean plots
        - Block plots
        - Normal or half-normal plots of the effects
        - Interaction plots
    - Sometimes the right graphs and plots of the data lead to obvious answers for your experimental objective questions and you can skip to step 5. In most cases, however, you will want to continue by fitting and validating a model that can be used to answer your questions.

2. Create the theoretical model (the experiment should have been designed with this model in mind!).
3. Create a model from the data. Simplify the model, if possible, using stepwise regression methods and/or parameter p-value significance information.
4. Test the model assumptions using residual graphs.
    - If none of the model assumptions were violated, examine the ANOVA.
        - Simplify the model further, if appropriate. If reduction is appropriate, then return to step 3 with a new model.
    - If model assumptions were violated, try to find a cause.
        - Are necessary terms missing from the model?
        - Will a transformation of the response help? If a transformation is used, return to step 3 with a new model.
5. Use the results to answer the questions in your experimental objectives -- finding important factors, finding optimum settings, etc." [39]

7) Interpret Results

The results of the statistical analysis are numerical values for the effects and the width of the confidence range. This leads to statements of the significance of the effects. These results must be made technical interpreted and understandable. Then, arrangements for the improvement will derive from them. [40]

Checklist relating DOE conclusions or outputs to experimental goals or experimental purpose:

- "Do the responses differ significantly over the factor levels?
  (comparative experiment goal)
- Which are the significant effects or terms in the final model?
  (screening experiment goal)
- What is the model for estimating responses?
    - Full factorial case (main effects plus significant interactions)

[39] itl.nist.gov
[40] Cf. KLEPPMANN (2006): S. 36

  - Fractional factorial case (main effects plus significant interactions that are not confounded with other possibly real effects)
  - RSM case (allowing for quadratic or possibly cubic models, if needed)
- What responses are predicted and how can responses be optimized? (RSM goal)
  - Contour plots
  - Settings for confirmation runs and prediction intervals for results" [41]

8) Verify Predicted Results

"This final stage involves validation of the best settings by conducting a few follow-up experimental runs to confirm that the process functions as desired and all objectives are met."[42]

Somebody must verify the forecasts, after the analysis of the experiment is done, to see that they are good. These procedures are called confirmation runs.

Stable processes are objective in an industrial setting. To reach this goal it is necessary to run a test at its optimum settings more than once. Minimum 3 runs are recommended that an estimation of variability at these settings can be given.

Is the time between the actual run of the experiment and the execution of the confirmation runs less than a few hours, then the experimenter should check again the factor that nothing has changes meanwhile.

The environment of the confirmation runs should be as similar as possible to the original conducted experiment.[43]

"For example, if the experiments were conducted in the afternoon and the equipment has a warm-up effect, the confirmation runs should be conducted in the afternoon after the equipment has warmed up. Other extraneous factors that may change or affect the results of the confirmation runs are: person/operator on the equipment, temperature, humidity, machine parameters, raw materials, etc."[44]

[41] itl.nist.gov
[42] weibull.com
[43] Cf. itl.nist.gov
[44] itl.nist.gov

What should be done if the confirmation runs don't obtain the expected results?

1. “check to see that nothing has changed since the original data collection
2. verify that you have the correct settings for the confirmation runs
3. revisit the model to verify the "best" settings from the analysis
4. verify that you had the correct predicted value for the confirmation runs“ [45]

2.8 DOE TYPES & METHODS

The following is a summary of some of the most common DOE types.

Type	Attitude	Remark
Full factorial	All combinations, full orthogonal	High number of tests, effortful best evaluable
Fractional	Half or less number of tests like full factorial, full orthogonal	Mixing of interactions Unsafe of evaluation
Plackett Burmann	Derivation from factorial design. Very low number or tests.	Interactions are not fully confounded
Taguchi	Very low number of tests, multiple fractional full orthogonal	Many interactions mixed with each other and with factors; suitable only for regulation of individual factors
Central Composite Design	The same construction as full factorial plus cross in the middle. Test space like a ball	High number of tests, effortful good evaluable
Box-Behnken	Evaluation for quadratic models. Middle levels in outlet area.	High number of tests, effortful good evaluable
D-Optimal	Very low number of tests, Clear regulation of interactions,	not orthogonal good evaluable
Mixture	Use of factors whose sum must always amount to 100%	not orthogonal, factors dependent on each other good evaluable

Table 2.2: Overview of the design types (Source: Cf. RONNINGER (2012): P. 26)

[45] itl.nist.gov

Good Examples for the following DOE Types and Methods can be found on this link:
URL: http://www.itl.nist.gov/div898/handbook/pri/section4/pri47.htm

2.8.1 One Factor Designs

"These are the designs where only one factor is under investigation, and the objective is to determine whether the response is significantly different at different factor levels. The factor can be qualitative or quantitative. In the case of qualitative factors (e.g. different suppliers, different materials, etc.), no extrapolations (i.e. predictions) can be performed outside the tested levels, and only the effect of the factor on the response can be determined. On the other hand, data from tests where the factor is quantitative (e.g. temperature, voltage, load, etc.) can be used for both effect investigation and prediction, provided that sufficient data are available." [46]

2.8.2 Full Factorial Design

"These designs include all possible combinations of the levels of every factor with the levels of every other factor. The number of experimental runs is a product of the number of levels of each factor."[47]
"It is the advantage of the complete test plan that all interactions can be explained."[48]
Experiments with factors at two levels (2k) are very efficient forms of experimentation, thus they play a special role.[49]

Full factorial designs in two levels
"A common experimental design is one with all input factors set at two levels each. These levels are called `high' and `low' or `+1' and `-1', respectively. A design with all possible high/low combinations of all the input factors is called a full factorial design in two levels." [50]

[46] weibull.com
[47] TANCO et al (2009): P. 493
[48] RONNINGER (2012): P. 27
[49] Cf. TANCO et al (2009): P. 493
[50] itl.nist.gov

If there are k factors, each at 2 levels, a full factorial design has 2^k runs.

Number of Factors	Number of Runs
2	4
3	8
4	16
5	32
6	64
7	128

Table 2.3: Number of Runs for a 2^k Full Factorial (Source: http://www.itl.nist.gov/div898/handbook/pri/section3/pri333.htm)

Table 2.3 shows if the number of factors is greater than 4, then a full factorial design needs a large number of runs and is not very efficient. For more than 4 factors a fractional factorial design or a Plackett-Burman design would be a better alternative.[51]

2.8.3 Fractional Factorial Design

"A factorial experiment in which only an adequately chosen fraction of the treatment combinations required for the complete factorial experiment is selected to be run." [52]
In a full factorial design the number of runs can be very large, although at two level factors. Using a fraction can reduce the number of runs, for instance one half or one fourth of a full factorial.[53]

"The basic purpose of a fractional factorial design is to economically investigate cause-and-effect relationships of significance in a given experimental setting. This does not differ in essence from the purpose of any experimental design." [54]
The possibility of choosing fractions of a full factorial design is given to be more economical, but it must be considered that different factorial designs serve different purposes.[55]

[51] Cf. itl.nist.gov
[52] itl.nist.gov
[53] Cf. TANCO et al (2009): P. 494
[54] itl.nist.gov
[55] Cf. itl.nist.gov

Two Level Fractional Factorial Designs

“This is a special category of two level designs where not all factor level combinations are considered and the experimenter can choose which combinations are to be excluded. Based on the excluded combinations, certain interactions cannot be determined. “[56]

2.8.4 Plackett-Burman Designs

“In 1946, R.L. Plackett and J.P. Burman published their now famous paper "The Design of Optimal Multifactorial Experiments" in *Biometrika* (vol. 33). This paper described the construction of very economical designs with the run number a multiple of four (rather than a power of 2). Plackett-Burman designs are very efficient screening designs when only main effects are of interest.” [57]

Plackett-Burman Designs (…) “are fractional factorial designs that can be used to study up to $k=N-1$ factors at each level of N runs, where N is a multiple of 4. They are designs of resolution III and are used for screening experiments. The alias structure is complex, since each main effect is confounded with fractions of several two-factor interactions.”[58]

“Plackett Burman-test plans have compared with the classical fractional plans the great advantage that interactions among each other and with other factors are not completely confounded.”[59]

A good example for the Plackett-Burman Designs can be found on this link:

URL: http://www.itl.nist.gov/div898/handbook/pri/section3/pri335.htm

2.8.5 Central Composite Design

“These designs consist of a full factorial design or a fractional factorial design of resolution V (2^{k-p}), augmented by 2k star or axial points and center points. A star point has all but one factor setting in the middle of the factor range. The center point is usually replicated several times.”[60]

---

[56] weibull.com

[57] itl.nist.gov

[58] TANCO et al (2009): P. 494

[59] RONNINGER (2012): P. 29

[60] TANCO et al (2009): P. 494

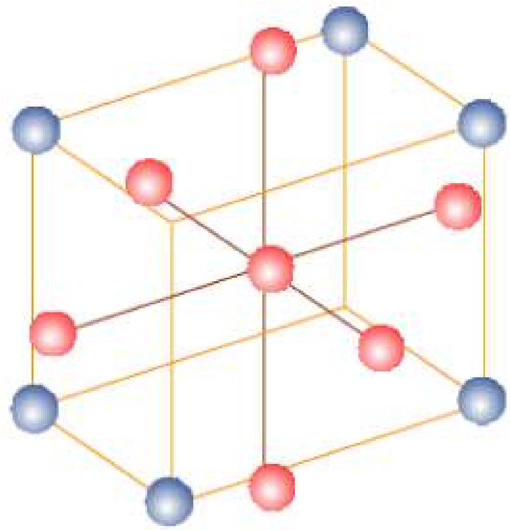


Figure 2.5: Central Composite Design (Source: RONNINGER (2012): P. 29)

“A central composite design always contains twice as many star points as there are factors in the design. The star points represent new extreme values (low and high) for each factor in the design.”[61]

A good example for the Central Composite Designs (CCD) can be found on this link:
URL: http://www.itl.nist.gov/div898/handbook/pri/section3/pri3361.htm

2.8.6 Robust parameter designs - the Taguchi Method

“Genichi Taguchi, a Japanese engineer, proposed several approaches to experimental designs that are sometimes called "Taguchi Methods." These methods utilize two-, three-, and mixed-level fractional factorial designs. Large screening designs seem to be particularly favored by Taguchi adherents. “[62]

“A robust design experiment has two types of factors: control factors and noise factors. The goal of a robust design is to find a setting of control factors that will make the product or process insensitive to sources of noise. These are often a product array, or crossed array, defined as an experimental design of noise factors that is repeated at every treatment combination of an experimental design of control factors.”[63]

[61] itl.nist.gov
[62] itl.nist.gov
[63] TANCO et al (2009): P. 494

"Traditional thinking is that any part or product within specification is equally fit for use. In that case, loss (cost) from poor quality occurs only outside the specification (Figure 2.6 left). However, Taguchi makes the point that a part marginally within the specification is really little better than a part marginally outside the specification.

As such, Taguchi describes a continuous Loss Function that increases as a part deviates from the target, or nominal value (Figure 2.6 right). The Loss Function stipulates that society's loss due to poorly performing products is proportional to the square of the deviation of the performance characteristic from its target value." [64]

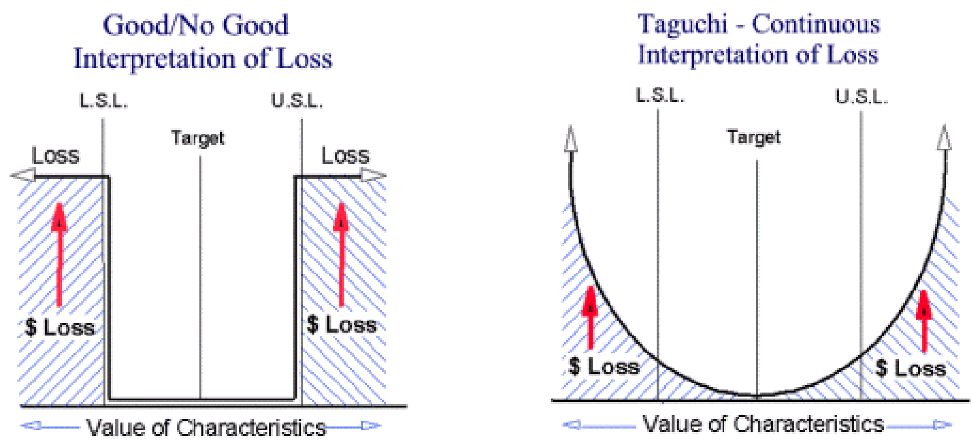


Figure 2.6: Taguchi Loss Function (Source: http://www.moresteam.com/toolbox/design-of-experiments.cfm#taguchi)

"Taguchi adds this cost to society (consumers) of poor quality to the production cost of the product to arrive at the total loss (cost). Taguchi uses designed experiments to produce product and process designs that are more robust - less sensitive to part/process variation." [65]

2.8.7 Box-Behnken designs

The Box-Behnken designs (…) "only have factors of three levels each and can be used to fit a quadratic model. This design is very useful when there are restrictions in the factor space and experimenting in the corner of the cube is unfeasible."[66]

[64] moresteam.com
[65] moresteam.com
[66] TANCO et al (2009): P. 494

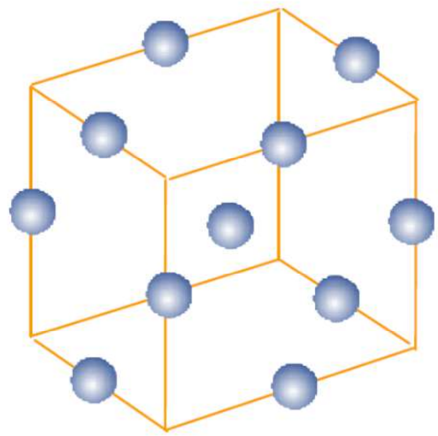


Figure 2.7: Box-Behnken Design for Three Factors (Source: RONNINGER (2012): P. 29)

"The Box-Behnken design is an independent quadratic design in that it does not contain an embedded factorial or fractional factorial design. In this design the treatment combinations are at the midpoints of edges of the process space and at the center. These designs are rotatable (or near rotatable) and require 3 levels of each factor. The designs have limited capability for orthogonal blocking compared to the central composite designs." [67]

A good example for the Plackett-Burman Designs can be found on this link:
URL: http://www.itl.nist.gov/div898/handbook/pri/section3/pri3363.htm

2.8.8 D-Optimal designs

"D-optimal designs are one form of design provided by a computer algorithm. These types of computer-aided designs are particularly useful when classical designs do not apply. Unlike standard classical designs such as factorials and fractional factorials, D-optimal design matrices are usually not orthogonal and effect estimates are correlated."[68]

At D-Optimal plans the aim is preparing test plans with minimum effort. These test plans show the desired effects and interactions definitely. This brings a decisive advantage comparing to fractural design where interactions are confounded with each other partly. [69]

[67] itl.nist.gov
[68] itl.nist.gov
[69] Cf. RONNINGER (2012): P. 34

Advantages of the D-Optimal test plans

- “Free choice for the number of the steps per influence factor. The number of levels can be elected factor by factor differently.
- Free choice of the step distances, which can equidistantly or not be chosen equidistantly.
- Free choice for the distribution of the test points in the n dimensional test room
- Free choice of the mathematical model
- Expansion capability by new influence factors
- Certain attitudes and combinations can be excluded, these are not attainable”[70]

Disadvantages of the D-Optimal test plans

- “The test plan is not orthogonal, however, the deviations are usually only small”[71]

2.8.9 Mixture Experiments

“In a mixture experiment, the independent factors are proportions of different components of a blend. For example, if you want to optimize the tensile strength of stainless steel, the factors of interest might be the proportions of iron, copper, nickel, and chromium in the alloy. The fact that the proportions of the different factors must sum to 100% complicates the design as well as the analysis of mixture experiments.”[72]

Planning a mixture experiment typically involves the following steps

1. “Define the objectives of the experiment.
2. Select the mixture components and any other factors to be studied. Other factors may include process variables or the total amount of the mixture.
3. Identify any constraints on the mixture components or other factors in order to specify the experimental region.
4. Identify the response variable(s) to be measured.
5. Propose an appropriate model for modeling the response data as functions of the mixture components and other factors selected for the experiment.
6. Select an experimental design that is sufficient not only to fit the proposed model, but which allows a test of model adequacy as well.”[73]

[70] RONNINGER (2012): P. 34
[71] RONNINGER (2012): P. 34
[72] itl.nist.gov
[73] itl.nist.gov

2.9 WHY DOE IS NOT USED? - BARRIERS

TANCO et al (2010) describe in their article „Why is not design of experiments widely used by engineers in Europe?" some barriers of Design of Experiments.
Following are the typical barriers listed:

B1: resistance to change

"Since engineers often do OFAT experiments, you must be able to convince practicing engineers that what they have been doing for years can be improved upon. Moreover, most engineers believe that they must do additional work to prove what they already knew."[74]

B2: bad image of statistics

"Many engineers have a negative image of statistics. The word "statistics" often invokes fear and resistance in engineers."[75]

B3: low commitment of managers

"As for any quality improvement initiative, it is essential to have strong managerial commitment while applying DOE. Most managers are unaware of the importance of statistical techniques for process and product improvement."[76]

B4: previous bad experiences with DOE

"Negative experiences with DOE may discourage and limit its use in the future. Experiments may have failed because the appropriate design or analyses were not used. In addition, nontechnical issues such as poor planning or the failure to identify all the factors are sometimes not taken into account."[77]

B5: absence of teamwork skills

"Since experimentation is a team process, its success depends on involving the necessary people who will work as a team. Poor interpersonal relationships and lack of inner communication may cause the project to fail."[78]

---

[74] TANCO et al (2010): P. 1962
[75] TANCO et al (2010): P. 1963
[76] TANCO et al (2010): P. 1963
[77] TANCO et al (2010): P. 1963
[78] TANCO et al (2010): P. 1963

B6: not enough software aid

"Although, nowadays, there are many commercial software products and expert systems to aid in the experimentation, they are not enough to satisfy business needs. Sometimes, they lead to erroneous application of statistical methods, are poor at handling technical features and do not cover all the steps necessary for a DOE project."[79]

B7: lack of methodologies to guide users through experimentation

"The complete methodology needed to implement DOE may be unclear since so much time is devoted to explaining data analysis. Often there are so many unstructured, unorganized and uneven elements that a thorough reorganization is needed for efficient management."[80]

B8: insufficient resources

"Even though many engineers appreciate the power of DOE, they believe that more resources such as time, money and materials are needed to use it."[81]

B9: poor statistical background

"Statistical courses generally focus too much on probability theory and hypothesis testing instead of on problem solving through statistical thinking. Consequently, statistical methods needed for DOE are generally misunderstood and wrongly applied."[82]

B10: absence of theoretical developments to solve real industrial problems1

"Some industrial problems are so complicated, and have so many restrictions that they cannot be solved by using current methods of DOE application."[83]

B11: DOE is not taught to engineers

"Engineers and scientists receive little or no training in designed experiments. Most statistics professors believe that one course is not enough to teach DOE concepts."[84]

[79] TANCO et al (2010): P. 1963
[80] TANCO et al (2010): P. 1963
[81] TANCO et al (2010): P. 1963
[82] TANCO et al (2010): P. 1964
[83] TANCO et al (2010): P. 1964
[84] TANCO et al (2010): P. 1964

B12: poor statistical consultancy

"Consultation often results in creating unrealistic expectations, meaning that problems are not analyzed deeply enough. This is a common complaint about statistical consultation. Moreover, many small and medium enterprises (SME) are unable to pay the high costs of thorough consultation."[85]

B13: statistical jargon is used to explain DOE

"Many references and books are written in statistical terminology or jargon that is obscure to engineers. Obscure explanations make the application of DOE more difficult."[86]

B14: DOE is taught badly

"DOE is not taught well. Many professors lack practical experience with DOE and do not present real case studies in class. Furthermore, students are not encouraged to conduct practical experiments. Moreover, DOE courses are generally incomplete; more than 80% of course content is dedicated to analysis."[87]

B15: publications do not reach engineers

"Engineers, mainly those from SME, do not have access to books and articles that explain details of the technique. Moreover, publications are generally focused on technical problems rather than on the whole experimentation process. Also, few reports of practical experiments are published, and failed experiments are rarely mentioned."[88]

B16: DOE is not widely used because it is a complex tool

"DOE is seen as a difficult technique because of the inherent complexity of the tools, so unless engineers are well educated in statistical methods including DOE, the technique will never become widespread."[89]

[85] TANCO et al (2010): P. 1964
[86] TANCO et al (2010): P. 1964
[87] TANCO et al (2010): P. 1964
[88] TANCO et al (2010): P. 1964
[89] TANCO et al (2010): P. 1964

3 REQUIREMENTS ENGINEERING & MANAGEMENT (RE&M)

This chapter discusses the requirements engineering & management in general. A definition for a requirement will be given as well as for requirements engineering & management in general and especially what it means for this thesis. In addition, requirements engineering & management activities and the phases of the requirements engineering process will be discussed shortly.

3.1 DEFINITIONS

Requirement:
"A statement that identifies a product or process operational, functional, or design characteristic or constraint, which is unambiguous, testable or measurable, and necessary for product or process acceptability (by consumers or internal quality assurance guidelines)."[90]

Requirements Engineering:
"Requirements engineering (RE) can be split into two main areas of activities, requirements development and requirements management. Requirements development concerns activities related to elicitation, analysis, documentation and validation of requirements. It deals principally with the content of the requirements. The purpose of requirements development is to produce and analyze customer, product, and product-component requirements. Requirements development is not within the scope of this thesis."[91]

Requirements Management:
"Requirements management (RM) concerns activities related to controlling and tracking of changes to agreed requirements, relationships between requirements and dependencies between the requirements specifications and between specifications and other project artifacts. Requirements management can be seen as a supportive process, which helps to manage requirements through the product's lifecycle."[92]

[90] IEEE (2005): P.9
[91] HEINONEN (2006): P. 11
[92] HEINONEN (2006): P. 11

Stakeholder:

"A party having a right, share, or claim in a system or in its possession of characteristics that meet that party's needs and expectations."[93]

Other Definition: "An individual, group of people, organization or other entity that has a direct or indirect interest (or stake) in a system."[94]

"A stakeholder's interest in a system may arise from using the system, benefiting from the system (in terms of revenue or other advantage), being disadvantaged by the system (in terms, for instance, of cost or potential harm), being responsible for the system, or otherwise being affected by it.

Stakeholders are legitimate sources of requirements."[95]

3.2 IMPORTANCE & BENEFITS OF RM&E

Why is Requirements Management & Engineering more significant for a certain group of companies comparing to others? Why get the methods and processes of RM&E more significance during the implementation stage?

Requirements management is normally not a difficult problem when small organizations develop a simple product. In that kind of company, the engineers of development department know their customer requirements and needs very well. Through the direct communication they can be easily transferred and integrated in their products and services.

Because of the small group of people involved in this process, the step between customer needs and finished product or service is very short in such case. The communication is principally verbal and the coordination is easy. The product or service complexity is rather simple and the separation of labor is not required. With this situation it is possible to achieve good or acceptable results.[96]

If the growth of the company is faster, its product or service complexity increases mostly as well. When the separation of labor becomes more common as well, the usage of structured methods and processes in requirements management and engineering gets more interesting for the company.[97]

---

[93] IEEE (2005): P.9
[94] HULL, JACKSON, DICK (2011): P. 7
[95] HULL, JACKSON, DICK (2011): P. 7
[96] Cf. HOOD et al. (2008): P. 11
[97] Cf. HOOD et al. (2008): P. 12

"The department for testing and verification management benefits the most from the active use of RM&E methods. The main task of this group is not only to assess the quality of already developed products and systems but also to accompany the whole development process and to verify intermediate results like specifications." [98]

To fulfill this task, it is prerequisite to define the desired state for the planned system. Furthermore, a specification must be established, which describes the difference between the current state and the desired state. These specifications are often neglected and have a low quality, for instance they have gaps, are out of date or missing completely. Requirements Management & Engineering and its specifications are used for verification and to create test cases for the planned system.

If the specifications are missing, drawn-out interviews with the stakeholders or development department can help to develop new test cases, but the quality of them suffer from the bad usage of RM&E.[99]

Supplier and customer as well as departments and individuals can get a different understanding of the planned system within these circumstances. Therefore, an agreement on the final product does not exist and furthermore, every formal declaration of the quality of the system must be put into account.

By using RM&E methods the specification is always up to date, which leads to precise agreement on the final product between all stakeholders. The specification builds the solid base of the product and for the creation of test cases. Changes during the product can be traced and therefore the affected test cases can be adapted to the changes. This avoids unnecessary the efforts and the information value regarding the quality of the system improves.[100]

[98] HOOD et al. (2008): P. 19
[99]Cf. HOOD et al. (2008): P. 19
[100] Cf. HOOD et al. (2008): P. 20

3.3 CHARACTERISTICS OF A GOOD SOFTWARE REQUIREMENTS SPECIFICATION (SRS) FROM IEEE

An SRS should be

a) Correct;

b) Unambiguous;

c) Complete;

d) Consistent;

e) Ranked for importance and/or stability;

f) Verifiable;

g) Modifiable;

h) Traceable.

a) Correct

"An SRS is correct if, and only if, every requirement stated therein is one that the software shall meet. There is no tool or procedure that ensures correctness. The SRS should be compared with any applicable superior specification, such as a system requirements specification, with other project documentation, and with other applicable standards, to ensure that it agrees. Alternatively the customer or user can determine if the SRS correctly respects the actual needs. Traceability makes this procedure easier and less prone to error."[101]

b) Unambiguous

„An SRS is unambiguous if, and only if, every requirement stated therein has only one interpretation. As a minimum, this requires that each characteristic of the final product be described using a single unique term.“[102]

If a term could have multiple meanings because it is used in particular context, the term should be describe in a glossary to make the meaning more specific. The specifications should be unambiguous to both to those who create it and to those who use it. The users and the creators often have a different background and furthermore there requirements descriptions are different.[103]

[101] IEEE (1998): P. 4
[102] IEEE (1998): P. 4f
[103] Cf. IEEE (1998): P. 5

c) Complete

„An SRS is complete if, and only if, it includes the following elements:

a) All significant requirements, whether relating to functionality, performance, design constraints, attributes, or external interfaces. In particular any external requirements imposed by a system specification should be acknowledged and treated.

b) Definition of the responses of the software to all realizable classes of input data in all realizable classes of situations. Note that it is important to specify the responses to both valid and invalid input values.

c) Full labels and references to all figures, tables, and diagrams in the SRS and definition of all terms and units of measure.“[104]

d) Consistent

"Consistency refers to internal consistency. If an SRS does not agree with some higher-level document, such as a system requirements specification, then it is not correct." [105]

Internal consistency: "An SRS is internally consistent if, and only if, no subset of individual requirements described in it conflict.

The three types of likely conflicts in an SRS are as follows:

a) The specified characteristics of real-world objects may conflict.

b) There may be logical or temporal conflict between two specified actions

c) Two or more requirements may describe the same real-world object but use different terms for that object. For example, a program's request for a user input may be called a "prompt" in one requirement and a "cue" in another. The use of standard terminology and definitions promotes consistency." [106]

e) Ranked for importance and/or stability

"An SRS is ranked for importance and/or stability if each requirement in it has an identifier to indicate either the importance or stability of that particular requirement.

Typically, all of the requirements that relate to a (software) product are not equally important. Some requirements may be essential, especially for life-critical applications, while others may be desirable. Each requirement in the SRS should be identified to make these differences clear and explicit." [107]

---

[104] IEEE (1998): P. 5f
[105] IEEE (1998): P. 6
[106] IEEE (1998): P. 6
[107] IEEE (1998): P. 6f

Degree of stability

"One method of identifying requirements uses the dimension of stability. Stability can be expressed in terms of the number of expected changes to any requirement based on experience or knowledge of forthcoming events that affect the organization, functions, and people supported by the software system.

Degree of necessity

"Another way to rank requirements is to distinguish classes of requirements as essential, conditional, and optional.

a) Essential: Implies that the software will not be acceptable unless these requirements are provided in an agreed manner.

b) *Conditional:* Implies that these are requirements that would enhance the software product, but would not make it unacceptable if they are absent.

c) *Optional:* Implies a class of functions that may or may not be worthwhile. This gives the supplier the opportunity to propose something that exceeds the SRS." [108]

f) Verifiable

"An SRS is verifiable if, and only if, every requirement stated therein is verifiable. A requirement is verifiable if, and only if, there exists some finite cost-effective process with which a person or machine can check that the software product meets the requirement. In general any ambiguous requirement is not verifiable. Non-verifiable requirements include statements such as "works well," "good human interface," and "shall usually happen." These requirements cannot be verified because it is impossible to define the terms "good," "well," or "usually." The statement that "the program shall never enter an infinite loop" is non-verifiable because the testing of this quality is theoretically impossible.

If a method cannot be devised to determine whether the software meets a particular requirement, then that requirement should be removed or revised." [109]

g) Modifiable

"An SRS is modifiable if, and only if, its structure and style are such that any changes to the requirements can be made easily, completely, and consistently while retaining the structure and style. Modifiability generally requires an SRS to

[108] IEEE (1998): P. 7
[109] IEEE (1998): P. 7

a) Have a coherent and easy-to-use organization with a table of contents, an index, and explicit cross-referencing;
b) Not be redundant (i.e., the same requirement should not appear in more than one place in the SRS);
c) Express each requirement separately, rather than intermixed with other requirements.
Redundancy itself is not an error, but it can easily lead to errors. Redundancy can occasionally help to make an SRS more readable, but a problem can arise when the redundant document is updated. For instance, a requirement may be altered in only one of the places where it appears. The SRS then becomes inconsistent.
Whenever redundancy is necessary, the SRS should include explicit cross-references to make it modifiable." [110]

j) Traceable
"An SRS is traceable if the origin of each of its requirements is clear and if it facilitates the referencing of each requirement in future development or enhancement documentation. The following two types of traceability are recommended:
a) *Backward traceability (i.e., to previous stages of development).*
This depends upon each requirement explicitly referencing its source in earlier documents.
b) *Forward traceability (i.e., to all documents spawned by the SRS).*
This depends upon each requirement in the SRS having a unique name or reference number.
The forward traceability of the SRS is especially important when the software product enters the operation and maintenance phase. As code and design documents are modified, it is essential to be able to ascertain the complete set of requirements that may be affected by those modifications." [111]

3.4 THE REQUIREMENTS ENGINEERING PROCESS

"In general terms, the RE process can be thought of as a series of activities consisting of articulating the initial concept, problem analysis, feasibility and choice of options, analysis and modeling and requirements documentation. Each activity may require the use of different techniques."[112]

[110] IEEE (1998): P. 8
[111] IEEE (1998): P. 8
[112] MACAULAY(1996): P. 158

For this thesis this process phases are collected from different sources:

1. Requirements Elicitation
2. Requirements Analysis
3. Requirements Specification
4. Requirements Verification
5. Requirements Validation and Documentation

1. Requirements Elicitation and Validation

Elicitation regards generally the gathering of information. This phase is also described as requirements gathering, requirements capture or, sometimes, requirements acquisition. The three main considerations are:

- What information should be gathered?
- From what source it can be gleaned?
- By what mechanisms or techniques it may be gathered?[113]

Stakeholder identification and finding out their desires are goals of this phase. Some methods for elicitation are plain interviewing techniques, surveys, workshops, scenario creation, etc.[114]

At the beginning the knowledge of the problem is very little. The approach to the first question must be step by step. First, a generalized approach is used for any system. The characteristics of the problems and the problems requiring solution within the system the requirements must be defined. The problems can be defined by analyzing the early elicited information. The selection of elicitation techniques depends on the available source of information and the essential characteristics of the problems.

The stakeholders are the main source of information. Their interests should be obtained precisely.[115]

“So, the sources of input to the elicitation task are several and varied but well understood. The output, on the other hand, is seldom mentioned, to the extent that there is not even a widely used name. Elicitation output will here be referred to as elicitation notes and, indeed, it often is in the form of notes taken during interviews, etc., but it can also encompass audio recordings, video recordings, piles of completed questionnaires and so on. This output is quite distinct from analysis output because it is largely unprocessed, unstructured and may contain

[113] Cf. BRAY(2002): P. 26
[114] Cf. ENGELSMAN (2008): P. 31
[115] Cf. BRAY(2002): P. 27

many irrelevancies and, initially, omissions. Elicitation notes are often regarded as temporary documents which, once used, are destined for the bin. This may well be a mistake as, for purposes of tracing the origin of requirements or for understanding the rationale behind requirements, they can prove useful."[116]

2. Requirements Analysis

Analysis is (…) "the achievement of understanding of and the documentation of the characteristics of that domain and the problems (requiring solution) that exist within that domain", by studying the problem domain. [117]

Requirements Analysis (…) "is the process by which elicited requirements are evaluated for consistency, similarity and scope coverage. Requirements are triaged; that is, placed in 3 separate categories:

a) Must-have

b) Should-have

c) Nice-to-have"

First, the most relevant (must-have) requirements are emphasized and developed in this process. This guarantees that the final product fulfills all of the important requirements, and it is done in the most time and cost efficient way. Other "should-have" and "nice-to-have" requirements can be relegated to future phases.[118]

The characteristics of this task:

- "Analysis concerns (and often models) the problem domain, not the solution system.
- The principal goal is to achieve understanding of the nature of the problem domain and the problems that exist within it.
- In essence (despite overlap and iteration), analysis precedes specification (of the behavior of the solution system)."[119]

(…) "The output from analysis is (or should be) a carefully structured description or model of the relevant characteristics of the problem domain, plus a statement of the requirements (i.e.

[116] BRAY(2002): P. 27
[117] BRAY (2002): P. 24
[118] Cf. blog.deversus.com
[119] BRAY (2002): P. 26

the effects that the solution system should produce in the problem domain in order to solve the problem). This document is sometimes known as the analysis document but the, probably, more common name of requirements document will be adopted here. It should, not be confused with the specification document which defines the required behavior of the solution system.[120]

3. Requirements Specification

Other names for this phase are specification, system requirements specification, requirements definition, functional requirements definition, etc.[121]

Common definitions are:

Specification is (…) "a document that fully describes a design element or its interfaces in terms of requirements (functional, performance, constraints, and design characteristics) and the qualification conditions and procedures for each requirement."[122]

Specification may also be defined as:

"The invention and definition of a behavior of a solution system such that it will produce the required effect in the problem domain."[123]

"Requirements specification is the task of documenting the precise external behavior of the system that is to be built. It takes the features selected during requirements analysis and expands them into considerable detail. The primary purposes of doing this are to ensure that (1) customers and developers have the same understanding of what is to be built, (2) all developers have identical understanding of what is to be built, (3) testers are testing for the same qualities that developers are building, (4) management is applying resources to the same set of tasks that the developers are performing. Traditionally, these requirements have been documented in a software requirements specification. However, more recently there is a trend toward maintaining the requirements in a database or repository of discrete requirements, rather than a formal document."[124]

---

[120] BRAY (2002): P. 26
[121] Cf. BRAY (2002): P. 28
[122] IEEE (2005): P.9
[123] BRAY (2002): P. 27
[124] DAVIS, YOURDON, ZWEIG (2000): P. 4

4. Requirements Verification

Verifying requirements is (...) "proving that each requirement has been satisfied. Verification can be done by logical argument, inspection, modeling, simulation, analysis, expert review, test or demonstration." [125]

"Requirement verification process is somehow a mechanical process of checking documents. Verification has no concern about stakeholders. In this process requirements are verified on standards and imposed conditions such as requirement should be "Concise", "Traceable", "Organized", "Verifiable" and "Conformant to standards". When requirements fulfill these verifications then these requirements are ready for requirement documentation."[126]

5. Requirements Validation and Documentation

Validation: "Ensuring that the set of requirements is correct, complete, and consistent, a model can be created that satisfies the requirements, and a real-world solution can be built and tested to prove that it satisfies the requirements."[127]

"Validation is not a mechanical process of checking documents. It is more an issue of communicating requirements to the stakeholders whose goals those requirements are supposed to meet. The purpose of requirement validation is to give the stakeholders a chance to check early whether the solution proposed will really solve their problems?" [128]

Documentation: Many companies set up their own standard form and content of the requirements document that meets their own needs and purposes. There may be different types of requirements document, for example for the different groups of stakeholders like a market requirements document, a user requirements document and a software requirements document.

An example of general software requirements documentation guidelines is the IEEE Std 610, 1990. This emphasizes that a requirements document should contain statements which are unambiguous, complete, verifiable, consistent, modifiable, traceable and usable during the operation and maintenance phases.[129]

---

[125] BAHILL, HENDERSON (2004): P. 2
[126] scarpedia.com
[127] BAHILL, HENDERSON (2004): P. 2
[128] scarpedia.com
[129] CF. MACAULAY(1996)

3.5 REQUIREMENTS MANAGEMENT

Requirements Management (RM) describes the principles and methods to store specifications and other information in a manner that any involved person is able to find any information these person needs.

Professional Requirements Management tends to meet the needs of many different (involved) people at the same time.

Structures are the frame of any administration. Good frameworks are stable, bad frameworks are dangerous. Standard structures are approved, flexible and discretionary.

Developing Object-IDs are the first and most important step to a professional Requirements Management. Without Object-IDs it is just management of whole documents and not the management of requirements.

Requirements Management enfolds all necessary actions for structuring requirements, preparing them for different cases, changing them consistently and for implementing these requirements. [130]

3.5.1 Reasons for professional Requirements Management

All challenges of Requirements Management derive from two basic assumptions:

1. *Requirements change over time*
2. *Requirements have further uses*

Requirements change over time

It does no matter how precise requirements are collected, documented and verified stakeholders will change, delete, add or displace the requirements.

The requirements documentation must be structured in a way that changes in any form are not a big deal. [131]

Requirements have further uses

The collections of the requirements are never just for one person. Other people than the author of the requirements will read, understand and work with them. These people see the requirements from different points of few. They want to use, interpret, evaluate, adapt, test,

[130] Cf. RUPP (2009): P.343f
[131] Cf. RUPP (2009): P.345

convey, implement or use the requirements for further processes. If the specification structure makes sense for one person does not mean that it makes sense for others. [132]

RM gets more important …

- the higher the number of requirements.
- the longer the lifetime of the product.
- the more changes are expected.
- the higher the number of involved people in the Requirements Engineering Process.
- the worse the accessibility or the involvement of the stakeholders.
- the higher the quality claim of the system.
- the higher the re-usage of the requirements, products or processes.
- the more complex the development process is.
- the more inhomogeneous the stakeholder opinions are. [133]

3.5.2 Appearance of professional Requirements Management

Professional Requirements Management covers useful tasks and methods, which are based on the reasons that are named above to accomplish the derived challenges.
The first task is to develop how the analysis of the requirements should proceed and what administrative tasks are necessary to support it.
The **Requirements Engineering Concept** is the central artifact and documents all processes, methods, tools, rolls and procedures that are needed for the analysis of the requirement. Hence, a central task of the Requirements Management is developing a Requirements Management Concept, maintain it and control its appliance.
Good Requirements Management…

- rises the satisfaction of all stakeholders.
- brings a better communication to the involved people.
- makes the supervision of complex projects during every phase easier.
- reduces project cost and time.
- increases the quality of requirements, specifications, products and processes. [134]

[132] Cf. RUPP (2009): P.346
[133] Cf. RUPP (2009): P.348
[134] Cf. RUPP (2009): P.346f

3.5.3 Tasks of professional Requirements-Management

The tasks of RM are:

- exchange of information
- sequence control
- administration of inner correlation
- analysis and project control

Exchange of information – Who delivers what to whom at which time?

The more people are involved in a project, the more requirements are exchanged. Any person involved in the process must know, which state of which requirement he/she gets from whom at which point in time, where he/she finds this requirement and furthermore, when, where and to whom he/she must deliver the requirement. [135]

If data are stored decentralized and spread out, an unmanageable chaos can occur easily. A schematic of centralized versus decentralized information source is shown in Figure 3.1.

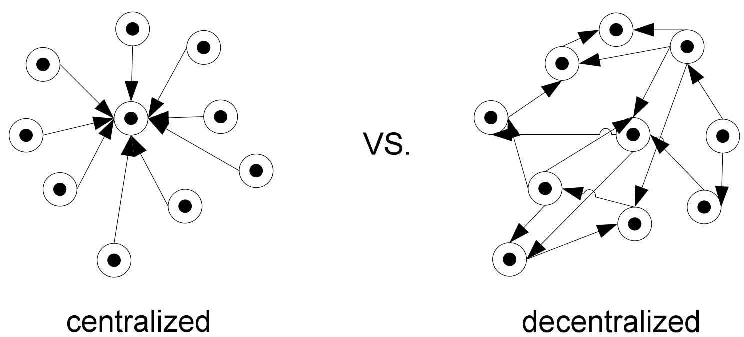


Figure 3.1: Centralized vs. decentralized data/information source (Source: own graphic)

Task: The requirements engineering concept should provide all needed specification content in a centralized manner to the involved people. They have read or write access to the relevant requirements.

Involved Stakeholder: Everybody, who is concerned directly with the specification.

Effect on Stakeholders: The access to specification content is accelerated and the number of failures through inconsistent requirements is reduced.[136]

Sequence control - Who may do what at which time?

Not all information must be provided in the same way to everybody at every point in time. It is important to control who may change or allow a change of what information at which point

[135] Cf. RUPP (2009): P.349

[136] Cf. RUPP (2009): P.350

in time. Sometimes it is also important to control the read access, for instance at safety critical projects.

Task: The requirements engineering concept should show the relevant sequences for the specification of the project. Furthermore, it should offer everybody involved in that project just as many access rights which are necessary for its current working stage.

Involved Stakeholder: Everybody, who is concerned directly with the specification.

Effect on Stakeholders: The number of failures which occur through changes of non-authorized people will be reduced.[137]

Administration of inner correlation – What is connected in which way?

The complexity of the correlations in the requirements collection should not be underestimated, even if the apparent range of the collection is straightforward. Requirements are in connection to other requirements, to older or canceled versions, to external documents, to connected guidelines or to contents of other requirement collections.

This is even more important if single requirements should be re-worked and the engineer should know which contents are concerned from this change.

Task: The requirements engineering concept should show and manage any possible correlation between requirements and to other content.

Involved Stakeholder: Everybody involved in the project.

Effect on Stakeholders: The number of failures which might occur through missing correlations will be reduced.[138]

Analysis and project control

Operative goal must also be adhered beside the actual product development in every development project. Therefore important aids are methods for control and monitoring of the product progress. This means that professional requirements management supports the project management.

Task: The requirements engineering concept must enable that the managed requirements can be statistically analyzed in a way to deliver established statements of the project progress.

Involved Stakeholder: Project manager, accountant.

Effect on Stakeholders: The expenditure of time to establish precise statistical data about the project progress will be reduced.[139]

---

[137] Cf. RUPP (2009): P.350
[138] Cf. RUPP (2009): P.351

3.6 REQUIREMENTS VALIDATION & VERIFICATION

Validation – "Am I building the right product?"

Verification – "Am I building the product right?"

Common Definitions:

Validation: "(A) The process of evaluating a system or component during or at the end of the development process to determine whether it satisfies specified requirements. (B) The process of providing evidence that the system, software, or hardware and its associated products satisfy requirements allocated to it at the end of each life cycle activity, solve the right problem (e.g., correctly model physical laws, implement business rules, and use the proper system assumptions), and satisfy intended use and user needs." [140]

Verification: "(A) The process of evaluating a system or component to determine whether the products of a given development phase satisfy the conditions imposed at the start of that phase. (B) The process of providing objective evidence that the system, software, or hardware and its associated products conform to requirements (e.g., for correctness, completeness, consistency, and accuracy) for all life cycle activities during each life cycle process (acquisition, supply, development, operation, and maintenance); satisfy standards, practices, and conventions during life cycle processes; and successfully complete each life cycle activity and satisfy all the criteria for initiating succeeding life cycle activities. Verification of interim work products is essential for proper understanding and assessment of the life cycle phase product(s)." [141]

"This is the final phase of the requirements engineering process. It involves scrutinizing the documents generated during the specification sub-phase and ensuring their relevance and validity. This must be done by all interested parties (which may include the users of the system, financiers of the system and Deversus as the developer) so they are in agreement with the proposed system's behavior, especially in the case of the Use Case document and prototypes. "[142]

---

[139] Cf. RUPP (2009): P.351
[140] IEEE (2012): P. 11
[141] IEEE (2012): P. 11
[142] blog.deversus.com

“For validation the easy to use techniques like document reviews are suitable to use. If more detailed validation is required scenarios or scenarios combined with prototyping are well accepted techniques. For verification the easiest and best way is to organize an acceptance test.” [143]

“The purpose of Validation and Verification is to help the development organization build quality into the system during the life cycle.

Validation and Verification processes provide an objective assessment of products and processes throughout the life cycle. This assessment demonstrates whether the requirements are correct, complete, accurate, consistent, and testable. The V&V processes determine whether the development products of a given activity conform to the requirements of that activity and whether the product satisfies its intended use and user needs. The determination includes the assessment, analysis, evaluation, review, inspection, and testing of products and processes.” [144]

[143] ENGELSMAN (2008): P. 31
[144] IEEE (2012): P. viii

4 BENCHMARKING

This chapter presents some basic definitions, the motivation for using benchmarking, the different types of benchmarking plus the pros and cons of each type, and the benchmarking process.

4.1 DEFINITION BENCHMARKING

Here are some possible definitions of the term benchmarking:

“Benchmarking is a strategic and analytic process of continuously measuring an organizations products, services, and practices against a recognized leader in the studied area.”[145]

“Benchmarking is an improvement process used to discover and incorporate best practices into your operations. Benchmarking is the preferred process used to identify and understand the elements (causes) of superior or world-class performance in a particular work process.”[146]

“Benchmarking can be defined as a systematic process for securing continual improvement through comparison with relevant and achievable internal or external norms and standards.”[147]

4.2 THE AIM OF A BENCHMARKING

”The overall aim of benchmarking is to improve the performance of an organization as measured against its mission and objectives. Benchmarking implies comparison – either internally with previous performance and desired future targets, or externally against similar functions. Benchmarking is a management tool already in use in both the public and private sector organizations.”[148]

[145] KRAFT (2011): P. 7
[146] DAMELIO (1995): P. 1
[147] MALANO, BURTON (2001): P. 1
[148] MALANO, BURTON (2001): P. 1

"Benchmarking can greatly enhance an organization's performance. Researching and comparing a core business process to the best-in-class can yield dramatic benefits in a reasonably short length of time."[149]

The process benchmarking aims to detect the strength and weaknesses of internal processes, furthermore, to find their reasons to clarify the room for improvement.[150]

"Some of the reasons why organizations use benchmarking are …

… to accelerate process improvement. Incremental change is often slow to produce result that people can see. Leaders are more likely to implement a major change in work processes because benchmarking demonstrates that it has been done successfully by others.

… to forecast industry trends. Because it requires the study of industry leaders, benchmarking can provide numerous indicators on where a particular business might be headed, which ultimately may pave the way for the organization to take a leadership position.

… to discover emerging technologies. The benchmarking process can help leaders uncover technologies that are changing rapidly, newly developed, or state-of-the-art.

… to stimulate strategic planning. The type of information gathered during a benchmarking effort can assist an organization in clarifying and shaping its vision of future.

… to enhance goal-setting. Knowing the best practices in your business can dramatically improve your ability to know what goals are realistic and attainable."[151]

4.3 TYPES OF BENCHMARKING

Four types of benchmarking are defined,

"**Internal benchmarking** is comparison between departments, units, subsidiaries, or countries within the same company or organization.

Competitive benchmarking is direct comparison of own performance/results against the best real competitors, i.e., that manufacture the same product or deliver the same service.

[149] KRAFT (2011): P. 16
[150] Cf. WAGNER (2001): P. 253
[151] KRAFT (2011): P. 16

Functional benchmarking is comparison of processes or functions against non-competitor companies within the same industry or technological area.

Generic benchmarking is comparison of own processes against the best processes around, regardless of industry."[152]

4.3.1 Internal Benchmarking

Internal benchmarking compares similar functions or processes of different units within corporations to detect room for improvement. If the best performance is identified, this can be used as a basic scale for other units.

Internal benchmarking is often used as an entry to external a benchmarking.[153]

Pros and Cons of internal benchmarking:

Pros

+ most cost efficient
+ relatively easy
+ low cost
+ fast
+ good practice/training with benchmarking process
+ information sharing
+ easy to transfer lessons learned
+ common language
+ gain a deeper understanding of your own process
+ makes a great starting point for future benchmarking studies

Cons

– fosters mediocrity
– limits options for growth
– low performance improvement
– can create atmosphere of competitiveness
– not much of a stretch
– internal bias
– my not yield best-in-class comparisons[154]

4.3.2 Competitive Benchmarking

“Competitive benchmarking is an extension of competitor analysis where instead of focusing on the industry average, focus is on the best competitors. Due to problems regarding sharing of sensitive information between competitors and the legal and ethical limitations connected

[152] ANDERSEN, PETTERSEN (1996): P. 6
[153] Cf. LINSS (2002): P. 365 & WAGNER (2001): P. 254
[154] KRAFT (2011): P. 18

to this type of benchmarking, competitive benchmarking is often seen as superficial and too focused on key figures."[155]

This most obviously form of comparison gathers information about products, workflows, production processes and economic data of competitors. This gives the opportunity to improve the productivity and thereby the market position of the own enterprise. Similar to the internal benchmarking it is possible to reach a high range of comparability. It might be problematic to accomplish this form of benchmarking because companies are not interested in giving their knowledge and their secret of success to direct competitors.[156]

Pros and Cons of competitive benchmarking

Pros	**Cons**
+ know your competition better	– difficult legal issues
+ comparing like processes	– threatening
+ possible partnership	– limited by "trade secrets"
+ useful for planning and setting goals	– may provide misleading information
+ similar regulatory issues	– may not get best-in-class comparisons
	– competitors could capitalize on your weakness
	– relatively low performance improvement[157]

4.3.3 Functional Benchmarking

"In functional benchmarking, benchmarking partners can be customers, suppliers, or other companies within the same industry or technological area. It is often easy to get in touch with such companies and the problems facing these companies are often similar."[158]

Through the comparison the own company learns from similar areas or areas of unrelated industries to find innovative solutions for the own business.[159]

[155] ANDERSEN, PETTERSEN (1996): P. 6
[156] Cf. LINSS (2002): P. 365 & WAGNER (2001): P. 255
[157] KRAFT (2011): P. 19
[158] ANDERSEN, PETTERSEN (1996): P.6
[159] Cf. LINSS (2002): P. 365

Pros and Cons of functional benchmarking

Pros	Cons
+ provides industry trend information	– diverse corporate cultures
+ quantitative comparisons	– great need for specificity
+ many common business functions	– “not invented here” syndrome
+ better improvement rate	– takes more time than internal or competitive benchmarking
	– must be able to visualize how to adapt the best practices
	– common functions can be difficult to find[160]

4.3.4 Generic benchmarking

“Finding companies in totally unrelated industries that perform similar processes as oneself might sometimes require a solid portion of creativity. The same goes for transferring knowledge from one industry to another. Still, the potential for identifying new technologies or practices that will lead to breakthroughs is highest in generic benchmarking. One example is the spread of bar coding from industry to industry.”[161]

Pros and Cons of generic benchmarking

Pros	Cons
+ high payoff	– high cost
+ noncompetitive/nonthreatening	– difficult concept
+ broad, new perspective	– can be difficult to identify best-in-class
+ innovative	– takes a long time to plan
+ high potential for discovery	– known world-class companies are inundated with requests
+ examines multiple industries	– quantum changes can bring high risk and escalate fear[162]
+ can compare to world-class organizations in your process	

4.4 THE BENCHMARKING PROCESS

There are a lot of different benchmarking processes in use. Most of them have similar phase and just a few differences. For this project I chose the “Department of Navy Benchmarking

[160] KRAFT (2011): P. 20
[161] ANDERSEN, PETTERSEN (1996): P.7
[162] KRAFT (2011): P. 21

Model". The following figure shows the "Department of Navy Benchmarking Model" with its four phases und 10 steps.

4.4.1 Overview of the Department of the Navy Benchmarking Model

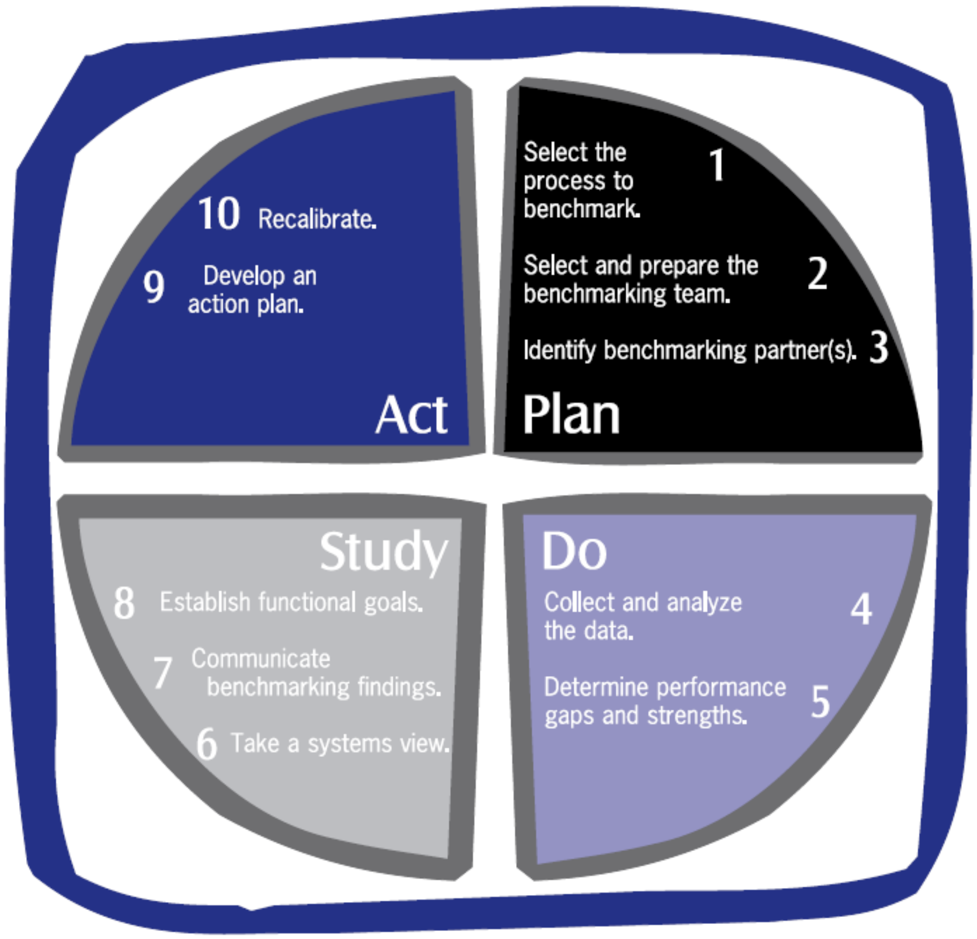
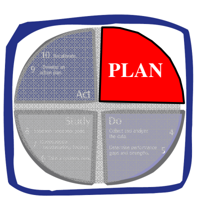


Figure 4.1: The Department of Navy Benchmarking Model (Source: KRAFT (2011): P. 24)



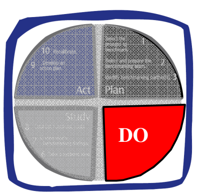
THE PLAN PHASE

- **Step 1: Select the process to benchmark**
  - List possible significant processes for benchmarking and select one that supports a specific strategic goal. Articulate the purpose and expectations of the benchmarking initiative.
  - Charter a team of process owners. Identify internal and external customers of the process along with their needs, expectations, and any performance measures. Identify all process owners. Ensure support of top managers.

- Identify the type of benchmarking the benchmarking team is to use (Internal, Competitive, Functional, Generic)
- Identify the goal(s) and desired level of improvement.[163]

- **Step 2: Select and prepare the benchmarking team**
  - Charter a cross-functional benchmarking team and provide guidance, such as membership, priorities, proposed timelines for completion of benchmarking study, any desired outputs or outcomes, any critical success factors, type(s) of benchmarking.
  - Clarify roles and responsibilities in the team
  - Flowchart the process to be benchmarked and know how the process currently works.[164]

- **Step 3: Identify benchmarking partner(s) from best-in-class**
  - Research information sources for best practices.
  - Examine networks, libraries, periodicals, articles, research projects, watchdog groups, industry experts, award winners, and public domain.
  - Prepare a list of companies/organizations to possibly benchmark.
  - Rank the potential partners (approximately 5 to 15).
  - If necessary, interview potential partners via mail and/or telephone.
  - Prioritize candidates according to how well they match your benchmarking criteria.
  - Select final partner(s) (approximately 1 to 5). Concentrate on recognized leaders. Evaluate advantages/disadvantages of possible site visit(s).[165]

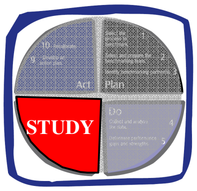


THE DO PHASE

- **Step 4: Collect and analyze the data**
  - Determine the data collection plan and method. Determine what will be measured (productivity, accuracy, responsiveness, speed, product stability, process financial contribution, product availability, product quality, asset utilization, dependability, capacity, service, etc.).
  - Determine how the data will be collected (via mail, e-mail, fax, telephone or face-to-face interviews, survey data, publications, other media, library, databases).
  - Assign roles and responsibilities for data collection.
  - Collect data and organize for analysis. Summarize findings in a report.[166]

[163] CF. KRAFT (2011): P. 25
[164] CF. KRAFT (2011): P. 26
[165] CF. KRAFT (2011): P. 26-27

- **Step 5: Determine performance gaps and strengths**
    - Analyze performance gaps and strengths. Determine reasons for gaps between units being compared.
    - Project any future competitive gaps.
    - Summarize analysis into report form.[167]



THE STUDY PHASE

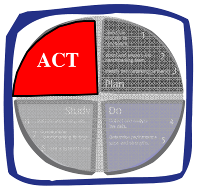
- **Step 6: Take a systems view**
    - Study the Benchmarking Team's report in a broader context. Ensure a common understanding of the theory and actual practice of the process.
    - Analyze the performance gaps.
    - Look at any possible impact on other management and operational processes.[168]

- **Step 7: Communicate benchmarking findings.**
    - Communicate final benchmarking report and findings to all appropriate levels of the organization.
    - Determine the different audiences and methods to most effectively communicate the report (graphics, statistics, flowchart of the .to-be. model, etc.).
    - Evaluate what customers and/or suppliers need to be informed and supportive.
    - Obtain acceptance/buy-in/support from all levels.
    - Collect and analyze any input/feedback.[169]

- **Step 8. Establish functional goals.**
    - Write functional goals based on best practices.[170]

---

[166] CF. KRAFT (2011): P. 28
[167] CF. KRAFT (2011): P. 28
[168] CF. KRAFT (2011): P. 29
[169] CF. KRAFT (2011): P. 30
[170] CF. KRAFT (2011): P. 30



THE ACT PHASE

- **Step 9. Develop an action plan, implement procedures, and monitor progress**.
    - Develop suggestions for how to:
        1. implement changes needed to achieve results.
        2. measure results.
        3. monitor feedback.
    - Get top-level approval of the action plan.
    - Celebrate successes.[171]

- **Step 10. Recalibrate.**
    - Monitor the benchmarked process.
    - Repeat cycle.[172]

[171] CF. KRAFT (2011): P. 31
[172] CF. KRAFT (2011): P. 32

5 EMPIRICAL RESEARCH

5.1 PROCESS OF THE RESEARCH

The process of the research described in dependence on the Department of the Navy Benchmarking Model and was adapted to our needs for this project.

The phases *Plan* and *Do* are explicated in this chapter describing our course of action within this Benchmarking.

The Phase *Study* and *Act* will be specified throw the following chapters 6 and 7.

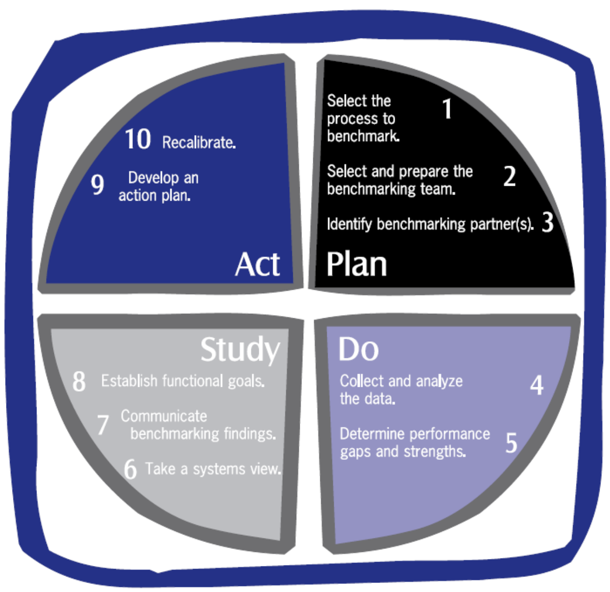
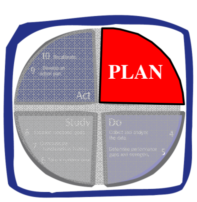


Figure 5.1: The Department of Navy Benchmarking Model (Source: KRAFT (2011): P. 24)



THE PLAN PHASE

- **Step 1: Select the process to benchmark**

The significant processes for this benchmarking are the processes around the testing department of mechanical engineering companies.

These processes include the order of tests, the development of tests, the realization of tests, the documentation of tests and the storage of test-related documents.

The process-related people and process owners are the employees of the research and development department, the department of mechanical engineering and the testing department.

As the type of the benchmarking a Functional benchmarking is the best choice. It is a comparison of processes or functions against non-competitor companies within the same industry or technological area.

The goals of the benchmarking are the optimization of the processes in the testing department, to give an overview of the organization of the testing department of different companies in different fields, to find room for improvement of the current situation and to find a best in practice example of testing departments.

- **Step 2: Select and prepare the benchmarking team**

A colleague of the company and me built the benchmarking team. We had a flat hierarchy and both of us were responsible for the whole benchmarking.

The Process of the current situation is described in chapter 6.1 Example of a current situation

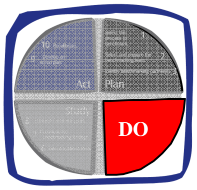
- **Step 3: Identify benchmarking partner(s) from best-in-class**

Criteria for benchmarking partners:

It was important that the benchmarking partners come from different industries. We wanted companies of mechanical engineering and mechatronics, (e.g. vehicle construction, machine tools manufacturing), composites and plastics, and some testing institutes. The companies should do a lot of testing.

I asked different Professors from University and colleagues within the company about potential benchmarking partners. By an Internet research of the recommended organizations I confined the number of benchmarking partners to 10 companies. Then we rank those companies by their importance for this project by comparing their qualities to the defined criteria.

I contact the potential interview partners via E-Mail and made appointments for the interviews.



THE DO PHASE

- **Step 4: Collect and analyze the data**

With a small group of 4 people we developed a questionnaire for the benchmarking. The questionnaire includes 5 main parts: the processes, used methods, documentation, used software and used standards.

I determined to collect the information by face-to-face interviews. We decided that the two of us would both participate in the interviews.

Instead of 10 interviews we only made 7 because some of the companies were not poised to help us.

After every face-to-face interview I summarized the answers of the interview and wrote final protocols, which are found in chapter 5.2 “Single Analysis of the Interviews”.

- **Step 5: Determine performance gaps and strengths**

We compared the results of the interviews to the current process and documented everything important in the final analysis described in chapter 5.3 “Overall Analysis of the interviews“.

5.2 SINGLE ANALYSIS OF THE INTERVIEWS

In this part the single analysis of the surveyed companies are summarized.

In terms of confidentiality the interviewed companies are named company 1 to company 7.

5.2.1 Company 1

- **Process**

The testing department subordinates the development department (engine development).

Experiments are conducted in every stage of development. The development of new engines is based on existing engines, whereat the dimensioning of the components takes place before. Then they start with the planning of the experiments.

The testing department exclusively plans experiments and inspections.

All developments are operated as projects. In the course of these projects all experiments are planned. The instructing engineer of the development department gives basic concepts of quantity and course of actions of the experiments to the executing test engineer. The test engineer then makes the time and resource planning for the experiment.

The test client and the test executer arrange the interface between each other with a requirements specification document. The specification document includes customer requirements and requirements from the sales department. In respect of these requirements the engineers develop the components and plan the tests.

The processes of the experiments are standardized and default within the company. The experiment processes are stored in a software system. There the single steps and operations are roughly described. The project management software system includes the assignment descriptions (e.g.: build-up and process steps of long time tests). Also the operations and resource planning is done in the project management software system. The project manager together with the project team does the complexity planning.

The project management software system is commercialized software, which was adapted for the company.

The static and dynamic test procedures, which are also used for the product acceptance procedure, are advanced or adjusted to the new product requirements.

After the test determination the project team members review and discuss the results of the experiment.

Generally they differ between standardized experiments and special measurements.

The engineers of the product development use the results of the standardized experiments for further findings. Apart from the standardized test they also execute special experiments for different applications, for instance for the proving of the new measurement equipment or processes.

Sometimes new product requirements need new measurement techniques or equipment. (e.g.: for a better accuracy, etc.)

Measurement equipment and measuring methods are normally reused.

If new measurement equipment or test procedures for special experiments work well, they could get standardized test and thus part of the test procedure catalog. The test procedure catalog is a collection of standardized testing procedures. Also the procedures of special tests are saved for a possible later reuse.

For standardized experiments they use a consistent engine test stand, which get more and more advanced for new product developments. Some of the standardized tests are based on

legal regulations. All standardized tests run fully automatically, just the parameterization is done previously.
The test catalog for the test programs is similar for every engine test stand. The executor must only choose the needed program and adjust the right parameters before the program start.
The test results are stored in a database. These data are available to everybody in the company. Though, to understand the data the testing requirements must be known. Not all of the basic conditions are saved in the database. Therefore a second software system is in use, in which the hardware information (build-up of the engine test stand, status of the test object) is stored.
To observe all information of an executed test the employees have to look at two different software systems.
Some R&D projects are contracted to technical universities. The universities execute the test on their own engine test stands.
Some suppliers also get test assignments for development projects.

- **Methods**

The company uses intuitive test planning for the development of special experiments and for the apprenticeship of new employees.
Statistical Design of Experiment (DOE) is used to optimize products. This method brings a good time saving and is used to find the optimum solution for a problem earlier in time.
Specified conditions test are used to reduce the testing time of long time experiments. One used method is called Thermoshock-testing. This method uses loads over the defined limit of the product. After the test cycle the engine is filled with coolant to find weaknesses faster.
At shortening the testing time for life cycle test it is rough to draw conclusions from reality. Therefore it is important to execute measurements under real terms and conditions.
Downtime is always a critical topic. Standards for long-term test are for instance temperature level test and endurance test programs.
Other long-term tests are testing with excessive load. Simulations normally do these kinds of tests. By the reason of software simulations the life of assembly parts is highly exhausted.
The load at assembly test stands is considerably higher than in real life situations.
Destructive test are done with single assemblies or components but not with the whole product (engine).

- **Documentation**

Endurance test reports include the runtimes of the tests, the assemblies, defects and failures, evidence of single components, the used program, all alternations and the shape of the single parts after the endurance test. Therefore they create a uniform protocol.
All analysis is standardized and the final results are documented. The protocol is created with Conjerto and saved as a PDF-file.
The documentation for the final approval is defined by legal regulations. Scripts in Conjerto create the protocols automatically.

- **Software**

Test planning and project planning: Clarity (with interface to MS Project), MS Project for scheduling.
Test execution: Tornado for the engine test stands. Bosh Inca for control units.
For development operations: Concerto and Inca.
Documentation: Concerto and Word. Final protocols are saved in a database.
For product optimization: Cameo
For Analysis: Concerto and MATHLAB
All documents and reports are saved in an Intragroup Database.

- **Legal regulations, Norms and Standards**

All legal regulations, standards and norms are based on the automobile industry.
Furthermore the company has also some intragroup standards, which are advanced repeatedly.

5.2.2 Company 2

- **Process**

The testing engineers of the testing department plan and execute the experiments and tests. Company extern clients assign approximately 70-80% of all experiments. The rest is in-house development. The majority of the tests are during the prototype stage. There are also tests for the product support.
The process from the test order until the result is the following:
Request/Order – feasibility testing – create a proposal – planning the test stand – conception of the test stand – set-up of the test stand – test execution – writing a test report.

For the test planning they don't differ between single tests and recurring tests. A test scenario catalog is not in use. All testing orders were planned individually.

A certain degree of reuse arises from the usage of the testing equipment and the load transmitting elements (hydraulic cylinder, vibrating plate, etc.). Test set-ups (e.g.: mounting of the testing objects) are highly different and mostly planned individually. Sometimes they are used again.

The clients who order the experiments mostly plan the tests on their own. The clients normally defaults the specific details about the test set-up and the test execution.

Every test engineer plans and develops his experiments individual based on his experience. The clients pretend most of the test details and specifications. The team and department heads check and release the created testing proposals.

A permanently consultation between test client and executer exists during the whole testing process.

Less experienced engineers can exchange with more experienced engineers for the planning of new experiments. For the test engineers another way of gathering information about experiments is to look at old test report in the company intern database.

After finishing an experiment the executing test engineer creates a report in MS Word, then sends the report to the test client and also saves it in the test report database. The database is accessible and useable for every employee.

A test is completed if all specifications from the client are fulfilled or rather the test-report is finalized.

In the area of research and development the company gives project to Universities, but the testing department directly don't.

- **Methods**

The testing department uses following methods for the test planning:

- Intuitive test planning, based on experiences
- Weibull-Analysis, for the appraisal of experiments
- Log-Normal Distribution, for planning the lotsize and testing loads
- Woehler curve, a program used to find the woehler line.
- Fatigue strength analysis

For statistical design of experiment they use in-house programmed software.

The test engineers use specific test tracks and overloaded test tracks to reduce the execution time for life tests. These tests are planned to simulate as many as possible scenarios of the reality. By using the Woehler line it is possible to draw conclusions to the lifetime of the products. The achieving lifetime is given from the client. All parts, which are not relevant for the lifetime, are removed before the test.

- **Documentation**

The test engineers save the finished test reports on a database, called report achieve. All test reports are provided with keywords. This makes it easier to find the right reports in the system. The test engineers define the keywords on their own. There is no default guideline for the definition of the keywords. Most of the test engineers search for the author and the title of the test reports.

A test report includes the following content:
A summery on the first page, then the problem description, the set-up of the test stand, all iterations of the test stand (further developments and revisions) and the specifications of the test stand, following by the results, at the end a conclusion and if necessary further procedures.
The reports are mainly created with MS Word.

- **Software**

Test planning: in-house self develop software and MS Excel
Test execution: test stand software by MTS, in-house developed software for analysis, MATLAB for simulations.
Documentation: test reports with MS Word and/or Excel
Storage: “report manager”, database with search function for an easy finding of saved reports. At the storage of the test report they add keywords to the reports. There are no default standards for the assignment of the keywords.

- **Legal regulations, Norms and Standards**

ISO/TS16949 – Third edition
DIN 17025 Accreditation for testing facilities

5.2.3 Company 3

- **Process**

Client for tests is the engineering design department.

The test engineers of the testing department plan the experiments together with the respective design engineer. Then these tests are executed on the planed test stand. The testing department plans the experiments and executes these experiments in the real environment. The test engineers are allocated to the different product categories.

The interface between test client and test executor depends on the size of the test project. Small projects are done only by an oral agreement. More extensive projects are discussed and planned in a team. Then the responsible engineer writes an informal Word-File about the project details from the team meeting. These Word-Files are written individually and do not have a default structure. Hence, there is no default testing order in use.

All test processes are planned and proceed individually. They do not have predefined procedure to plan and execute experiments. Therefore a test procedure catalog does not exist.

Also the time planning is base on experienced data. By the reason that most of the tests are destructive inspection, they cannot forecast how long the testing time will be.

The test planning in each case is intuitive planning of the responsible engineer. Most of the tests are field test (done in the real environment), thus the test planning depends on the weather forecast.

For every test they make an own documentation. The tests are planned as a project. The details about the actions and tests are stored electronically in the file-structure of the appropriate product.

- **Methods**

In principle all test are planned individually based the experience of the test engineers. They don't use statistical methods or programs for test planning or calculations.

Most of the tests are long run field tests. Test customers do the test runs. There are test runs with 16 or over 24 hours.

The probabilities sampling and number of tests are chosen based on experienced data (e.g. from previous product series).

- **Documentation**

The responsible test engineer saves the data and documents of the completed test electronically in a standardized file structure on the database of the testing department.
A standardized protocol-master does not exist.
The experiences and findings are documented of the single test runs.

- **Software**

IMC FAMOS is use for acquisition and editing of the measured data at the test stands.

5.2.4 Company 4

- **Process**

Just external clients order test (e.g.: single component test or norm testing). The test planning takes place in the company together with the engineers of the external client.
Normally the managers of the external clients contact Company 4 to clarify the cost-benefit ratio, to set the basic requirements and to clarify the feasibility.
After the placement of order the test engineers of Company 4 define the goals with the design engineers of the client and clarify the details of the experiments.
The main tests are single component tests for prototypes, norm tests and prototype test with the finished prototype.
At norm tests the main requirements are defined by the appropriate norm. The clients define the test specifications and documentation.
The test engineers plan some special tests together with the engineers of the client, where they define the specific requirements by a team meeting.
The test processes don't follow default procedures. The processes for the tests are planned and executed individually.
Also at the test planning Company 4 don't have defined procedures to plan the experiments. Thus every new test is planned individually.
The time planning of the experiments is based on experienced data. Many test are destructive experiments, therefore they cannot forecast how low a test runs.
They generally deference between norm tests and individual tests. At norm test they have reusable test set-ups. A standardized frame is used for a fast test set-up. Individual test are always planned new from scratch. Hence, they do not use a standardized test procedures catalog.

- **Methods**

The test are planned intuitively and based on experiences. Statistical methods or programs of statistical design of experiment or calculations are not in use.

Continuous tests are running sometimes for more then a week. The test stands are controlled via remote maintenance. Special methods to reduce the testing time are not in use.

The probability sampling and the choice of the number of test are based on experienced data.

- **Documentation**

The testing engineers save the testing data on a special database. The structure of the database is order related. The data are sorted by test order via MS Access. Every test order has its own folder structure. The test engineers manage the database and the folder system.

- **Software**

They use a simple MS Outlook Calendar for the time and resources planning for every test stand. For the staff planning they use MS Excel.

At the test stands the company uses IMC FAMOS for the data measurement and analysis.

- **Legal regulations, Norms and Standards**

The costumers define the norms and standards. E.g.: EN 60068, EN 61373

5.2.5 Company 5

- **Process**

The test development and planning happens in the research and development department. The engineers of the R&D department plan the experiments together with the test engineers.

All test are solely done in the testing department in the company.

The R&D and the design department order the test. The majority of the tests are in the prototype stage. Single component test may happen in earlier stages.

Test client and test executor arrange verbally about the performed tests or by a simple informal Word-Document. A default test order is not in use. Most of the tests are principally chosen from a default test scenario catalog, which is already known by the test executor.

New tests are planned in team meetings with the heads of the development, the design and the test department together with the project manager of the appropriate project.

The project managers of the individual projects select the diverse test from the standard test scenario catalog and decide if more tests are necessary. The standard tests from the test catalog are adapted to the new requirements for each project.

The head of the testing, the developing and the design department do the controlling of the test results together with the project manager of the appropriate project.

The project managers make the time planning for the test on their own, mainly by using MS Project.

The standard test scenario catalog is divided into 3 categories: functional test (whole product and single parts), life test, and community type approval.

The whole tests with process, build-up, measurement instruments, etc. are re-used. New test are also documented as a report and saved in the project folder of the appropriate project. If the new test is re-used it will get part of the standard test catalog.

The test executor summarizes the measured data after finishing a test in a test protocol. The test protocols are saved digitally in a folder structure on the drive of the testing department.

All employees of the testing department, all project managers and all heads of the different departments have access to the test protocols. Due to the fact that the tests of the standard catalog are consistent, it is possible to compare the protocols to find differences or failures.

For community type approval sometimes the company sometimes work together with external testing facilities. Those external testing facilities execute the standard tests, which cannot be done in the company. Therefore the interface between the companies is done by a written order, which includes all the specific measurement requirements of the standard test.

- **Methods**

As written above new test are developed by a team meeting, intuitively and based on experiences. Special methods of the test planning, like statistical design of experiment or similar are not in use.

For the reduction of the testing time of life test they determine the load collectives of the products. Then they decide a higher load. Then the experiments are done with the higher load for the whole product or single components.

They don’t use special methods for the probability sampling. The main principle is “as less prototypes as necessary”.

- **Documentation**

The test protocols of the finished experiments are sorted after product and then after function and component. On the database the company uses a basic folder structure.

The test protocols follow a default structure. The topics are: starting base, short description of the experiment, Requirements and goals, build-up of the test stand, results, conclusion and further activities.

Every prototype also has an individual documentation about its life cycle. This life cycle documentation includes all done experiments, all rebuilding, all changes and all component tests until its maturity phase. The described tests in the document are linked to the protocols of the finished test. The life cycle description is a simple table in a MS Word-Document.
All protocols are normally created in MS Word or MS Excel.

- **Software**

For the test execution and measurement they use following programs: IMC FAMOS, Almeno, AMR, LabView.
The documentation is done via MS Word and MS Excel.

- **Legal regulations, Norms and Standards**

EU Typengenehmigung Fahrzeugbau - permission for a type of vehicle for the European Union
LUF Land und Forstfahrzeug – Standards for agriculture and forestry vehicles.
LKW Typengenehmigung - permission for truck standardization

5.2.6 Company 6

- **Process**

The planning of the tests is done in the different projects by the project team. The test clients are manly from the simulation department. Then the testing department executes the tests.

In company 6 they use a default form for test orders. These test orders describes the requirements, the kind of test (life test, static test, dynamic test, etc.), the load cycles, the impact points of the load and a time and cost estimate. The test client defines the system boarders and the specific requirements of the tests. The testing department only plans the realization of the tests.

Process of the test planning:
There are no standard tests. Every test is planned individually. Though, some tests cases repeat over time. E.g.: static tests, life tests, climate tests, lightning strike tests, etc. Then the test stand can be re-used but the test processes are still planned new.

Every experiment is newly planned and executed. They don't differ between one-time experiments and re-useable experiments. Every test is therefore a one-time experiment.
The reason for this is that every product is individual and therefore every test must be individual. Of course, Test equipment, test build-ups and measurement equipment are re-used. A standardized test catalog is not in use.

The test planning is principally base on the size of the test and its demand. Normally the responsible test engineer develops a concept for the experiment. Then the test engineers discuss and rework this concept in a team meeting. For larger experiments the test engineers develop the concept for the test together in a brainstorming. After the conception the engineers discuss the experiment with the test client, to finalize or rework the test concept (iterative process).

Time planning:
The test engineers estimate the length of their test on their own. The time planning in the project does the project manager.

Documentation:
Everything from the raw material to the point of the finished product must be documented. (E.g.: Requirements, test-definitions, process, additions, test build-up, test set-down, etc.) Then all data are documented and saved digitally in the project folder of the company server. The testing department uses a MS Word-template for the testing protocols.

Some of the tests are given to external testing facilities. They decision which facility they take is based on the short-term availability of the external testing facilities.

The interface between the external firm and the testing department of company 6 is done by a default test order. The external testing center provides the raw data of the done experiment. The responsible test engineer creates the protocol and gives it to the test client.

- **Methods**

The testing department does not use any statistical methods for design of experiments. All tests are planned intuitively and based on experience. Thus, they don't have software programs for design of experiment.

The test client (mostly the simulation department) normally provides the processing time and the load cycles for the experiments. Thus, the testing department doesn't do any calculations for this. Therefore, the test client is responsible for the usage of specific methods for the reduction of the testing time.

- **Documentation**

The documented information of a protocol is:

Introduction, rough description, test object, requirements (why and what is tested), used equipment (what do they need for the test), test process, ambience conditions, data report (calculations, etc.), test data (raw data), measured data, rough analysis (plausibility analysis), summery and conclusion. The test client itself does the further analysis.

The protocols are saved electronically on the project drive or sometimes on the drive of the testing department.

All necessary tests are listed in an MS Excel-File. All saved data is linked to the projects on the project drive.

The test protocols are also saved in SAP. There an identification number and some key words are added to these protocols. SAP has the advantage of a good search function.

- **Software**

All test are linked to projects, therefore they use MS Project as a planning tool.

The used software programs for the test execution are: HBM Messtechnik, Catman, IMC Famos

- **Legal regulations, Norms and Standards**

There are countless company intern norms. External norms depend on the specific requirements of the product and the customer requirements.

5.2.7 Company 7

- **Process**

The testing department is a part of the development and construction design department. In the development department every product area is allocated to a responsible person.
Every of these responsible persons plan the needed experiments for their product and assign the testing engineers with the execution of the tests. He also helps with the execution of the experiments.
For the planning of new products the responsible person writes the requirements specification to fit the norms and the customer requirements. The needed Experiments are scheduled in the work breakdown structure. The interface between the test executer and the test initiator is just an informal verbal agreement because the initiator often helps doing the experiments.
Every test is planned individually because of the product variety. A reuse of test scenarios is just rarely possible. Hence, they don't use a test scenario catalog.
Some experiments are done in extern testing institutions. The interface to the external testing institution is a test order including the specific requirements of the performed test.

- **Methods**

The test planning is intuitive. For the reduction of the testing time they use a load cycle, which is base on experiences and used if required.

- **Documentation**

After completing the test they write a test report. For the test report a master document exists. The topics in the document are the goals of the test, the buildup of the test, the execution process, the results and a conclusion. All reports are saved in the intranet of the company ordered by a folder structure of the different products.

- **Software**

The testing department uses the following programs: NI LabView, Mathcad, MS Excel

- **Legal regulations, Norms and Standards**

Different norms: e.g. EN1028 for pumps, EN1846 for vehicles, etc.

5.3 OVERALL ANALYSIS OF THE INTERVIEWS

- **Process**

The testing department in the corporate structure:

Some of the Companies have a self-organized testing department. Metaphorically speaking the testing department serves as a service provider for other departments, like the development or the design department.

At other companies the testing division is integrated in the development department. Therefore the developers also function as test engineers.

At those companies where the testing department is separated from the development or design department, it makes sense to define an interface between the test client and the test executer. Therefore, most of the companies use a standard test order, which is provided by the test client for the test executer. This test order is not always a strict instruction. At some companies it is the base of an iterative process.

The advantages of a standard test order are:

- A clear structured and consistent blank
- Requirements of the experiments are clearly defined
- Structured and consistent description for the development of tests
- Traceability of completed experiments
- Comparability of the test orders

At some of the consulted companies they do not use a written test order. An oral agreement between test client and test executer is enough.

Process for test planning:

Independently from the different branches there was no consistent process found due the questioning.

Following examples were given for test planning:

- Brainstorming within a Team,
- Brainstorming of the head of departments,
- Individual employees develop their test for their projects and discuss it with their colleagues, the test clients or their supervisor.

Difference between one-time test and re-used tests (test catalog):

The difference between one-time test and re-used tests is based on the particular branch of the company and their products.

Just a few companies use a standard test catalog. A standard test catalog is mainly use by firm with similarities in their product lines and/or between different generations of the products.

Advantages of a standard test catalog:

- Similar re-useable test scenarios for the individual test objects or object groups.
- Structuring of the performing tests to the individual component or product
- Conformability and traceability of the performing tests
- Knowledge preservation and storage
- Encyclopedia for test scenarios
- Comparability of the individual tests
- Reproducibility of the individual tests

Following are some reasons why the companies do not use a test catalog:

The majority of the tests are one-time tests because the test components vary too much. Some companies produce mainly individual products, therefore they need different test cases for the different products.

- **Methods**

Methods for the test planning:

The majorities of the interviewed companies plan their experiments intuitively and based on experience. A few companies use statistic methods for the design of experiments and the further development of their products. One reason therefore is high amount of influencing and disturbance variables of their engineering systems.

Methods for the reduction of the testing time of long-term tests:

Most of the companies run their test with higher load cycles to reduce the testing time of long-term tests. Most of the higher loads are based on experience.

Just a few of the interviewed companies do statistical calculations for the planning of life cycle test. These firms use the Woehler-Line for their calculations.

- **Documentation**

Most of the companies create a test protocol and save it on the drive of the development or testing department or on the project drive.

Some companies use a special program or database for the storage of the protocols. For instance SAP, Microsoft SharePoint Server, or other adapted programs.

Advantages of a special program or database:

- Mostly better search function
- Search function also for the content of the protocols and not only of the title and author.
- Defining key words to make the searching easier
- Individual system structure
- Structuring after different criteria's. (E.g.: components, prototypes, functions, sections, etc.)

The majority of the companies document their testing data in the form of a test protocol. Some crated a standardized protocol blank.

Documented content in a protocol:

These are again based on the branch of the individual firms.

Here one example:

Basic situation, rough description of the test, goals, set-up of test stand, measured data, conclusion and further arrangements

Software for the documentation:

The protocols are mainly created in MS Word, MS Excel and MS PowerPoint for additional information. Some firms have adapted programs for their needs and can directly create protocols right after the test run as PDF-Files from the program.

- **Software**

For test planning and project planning: MS Project, MS Outlook (for time planning).

For development reasons: self programmed software, for automobile industry – AVL Cameo, Inca, etc.

For documentation: MS Word, MS Excel, MS PowerPoint

For test execution and analysis: NI LabView, Mathcad, MATLAB, IMC FAMOS, AVL Concerto

- **Legal regulations, Norms and Standards**

Of this questioning was only one general norm interesting: DIN 17025 Accreditation of testing facilities.

6 IMPROVING THE PROCESSES AND DEVELOPING THE MANUAL

This Chapter describes the improvement of the processes and the development of the manual on base of Requirements Engineering and Management, Design of Experiment and the Benchmarking. First an example of a current situation from a mechanical engineering company is given. Then the problems of this situation and the corresponding vision and goal are described. Following the processes behind the test catalog and the procedure to develop the test catalog are shown. At the end of the chapter the structures of the documentation are given.

6.1 EXAMPLE OF A CURRENT SITUATION

This part describes which kinds of experiments are relevant for this thesis and how they are integrated in the development process.

The testing activities are roughly divided into two superior categories, one-time tests and reusable tests.

The reusable tests scenarios are especially relevant for this project. These tests could be for example life tests, test for series-production readiness, accuracy tests, prototype and functional model tests, temperature and energy consumption tests, component and part evaluation tests, etc.

One-time tests or software tests are less relevant for this project. One-time test must also be documented because they can become reusable tests in the future.

The relevant tests are mainly in the late phase of the development process (e.g.: prototype phase, test for maturity phase) and after production as part of the series support service (e.g.: evaluation tests for the change of components or parts). Quality inspection tests are also less mandatory for this project.

The following illustration shows the area of the development process, in which relevant tests mainly occur.

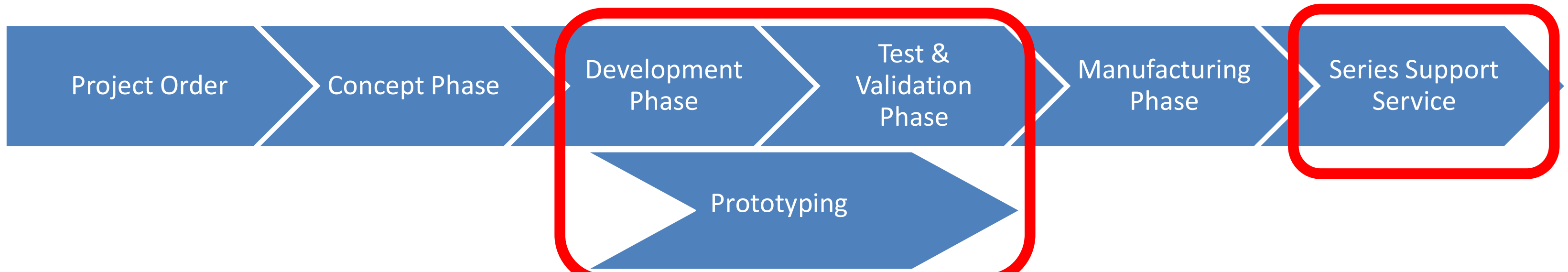


Figure 6.1: Scope in the Product Development Process (Source: own graphic)

The "testing program" – Software example for the test administration

The "testing program" is a software tool based on MOSS (Microsoft SharePoint Server). It is for the administration of the activities in the testing department.

The "testing program"…

- Includes test orders, test processes and test protocols of different experiments.
- Is used to organize tests and for test timing.
- Is in use for different departments
- Is used to assign the tests to the single test executors.
- Is used to store knowledge and insights about the executed tests.

The following part describes a current process example behind the ”test program” and for the administration of the experiments.

6.1.1 Current process for test planning and conduction

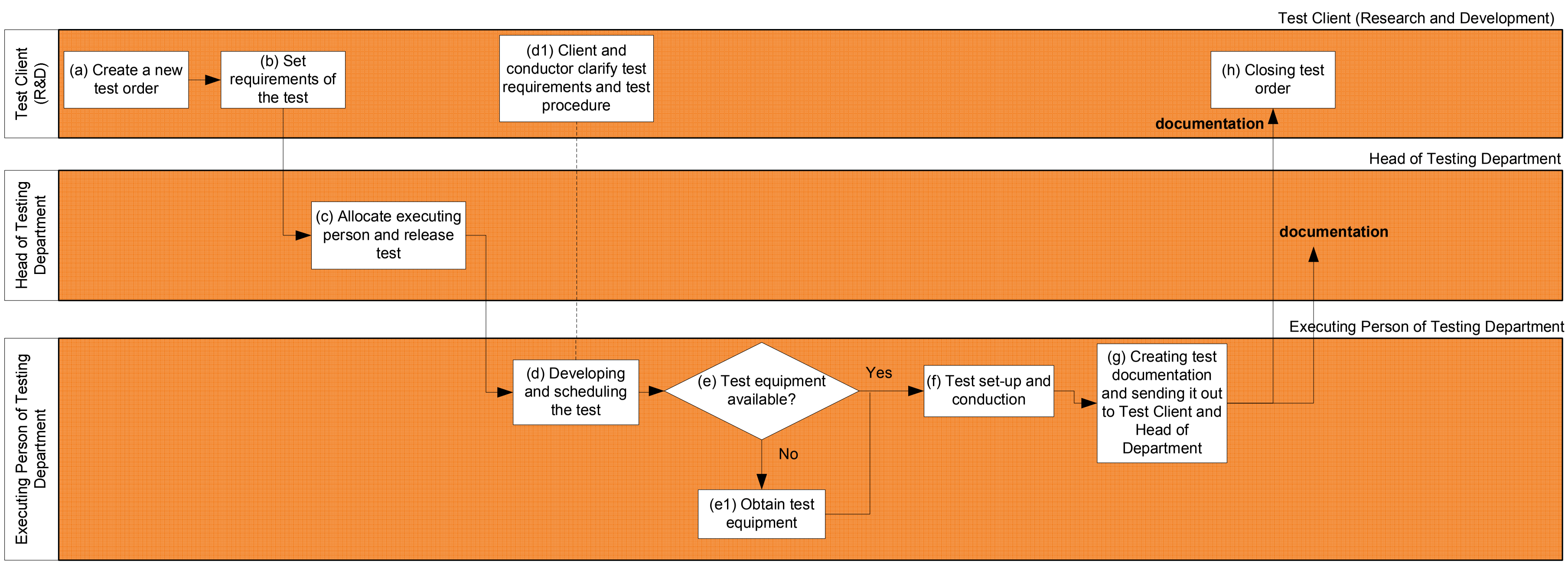


Figure 6.2: Current process of the testing department (Source: own graphic)

(a) Create Test Order

Normally employees of the development department give test orders. The test client defines the goals of the test and gives a description of the test procedure. The test order includes the title of the experiment, the ID of the test, the name of the test client, the name of the conducting person, the due date, the estimated work load, a description of the experiment, instructions for safety at work, the status of the experiment, the goal of the experiment, the status of the goals and the consequences of the test.

(b) Set requirements of the test

This is part of the test order where the goals, specification and requirements of the experiment are defined.

(c) Allocate executing person release test

The head of the testing department confirms the given test orders in this part. If there were no test executor allocated to a test order, the head of department assigns somebody for the test. The head of the testing department can also change the test executor if somebody else fits better for a particular job.

(d) Developing and scheduling the test

In this part the test executor plans and schedules his given test and talks to the test client for further details of the test requirements. The planning of the tests happens according to the test order and the intuitive considerations and the experience of the test executor. Then the actual experiment results from the specifications from the test client and the experience of the test executor.

(d1) Client and conductor clarify test requirements and test procedure

If necessary the test executor has a consultation with the test client to clarify the specifications and requirements of the ordered experiment.

(e) Availability of the test equipment

In this phase the test engineer checks for the planning of the test if the necessary test equipment and other needed machines are available at the time when the test should be conducted. If applicable the needed test equipment must be supplied and/or reserved.

(f) Conducting the test

In this part the test engineer actually conducts the experiment and records the measured data, which are necessary to fulfill the test goal.

(g) Create test documentation

After the test execution the test engineer creates a documentation of the conducted experiment and sends it to the test client.

(h) Closing the test order

After receiving the test protocol the test client closes the test order. Both the test client and the head of the department check if the results of the experiment seem correct.

Test documentation

Every test engineer creates his test documentation individually according to his test order. For the analysis of the experiment and its conclusion the test engineers can use different program according to the requirements of the test. Therefore, the test documentation can vary as well. Generally the test documents are created via MS-Office programs, mainly MS Word. Thus, a protocol blank exists for the documentation of the test.
The protocol blank for the test documentation is structured in the following points:

1. Test and measure set up
2. Test conduction
3. Test results
4. Conclusion

6.2 PROBLEM DISCUSSION

Based on the fact that many companies make no difference between recurring and one-time experiments, for these companies every test is a single-test. Most of the conducted test of these companies cannot be compared because the test procedures differentiate from each other. This occurs due to the fact that every test engineer creates his experiments based on his knowledge, experience and order from the client. These important factors like the experience of the engineers can vary from one to the others. Since the experiments differentiate among one another, even if the test objects and criteria are similar, every test can be seen as unique, therefore it is hardly possible to compare similar tests for example from one product

generation to another. The results of the benchmarking approve and support this assumption. This leads to the case that beneficial knowledge is not used or gets lost over time.
Hence, the vision of a test catalog for standard test cases has arisen.

6.3 VISION AND GOALS

Through the problem of the current situation and results of the benchmarking the idea of a “standard test catalog” came up.
Through discussions with other organizations during the benchmarking some questions emerged. Why should a company develop a standard test catalog? What are the benefits of such a catalog?
The quantity of information and data recording is rising in testing departments of mechanical engineering companies through better recording methods. Also the illustration and storage of a high amount of data gets cheaper and easier. By rising data and information quantity its administration gets more and more complex.
This standard test catalog and its process behind guarantee a continuing improvement of the testing department and its processes. Through an optimal administration of the experiments the created knowledge can be used more efficient. A good administration of the test cases guarantees comparability, reproducibility and redundancy free storage.
The development of standardized test scenarios is one possibility to improve the management of the testing.
The defined test cases of the standard test catalog are like a toolbox for the testing department, whereby the engineers can easily choose from a set of standard experiments. These experiments are outstanding from continuous improvement.

Advantages of a standard test catalog:

- Similar reusable test scenarios for the individual test objects or object groups.
- Structuring of the performing tests to the individual component or product
- Conformability and traceability of the performing tests
- Knowledge preservation and storage
- Encyclopedia for test scenarios
- Comparability of the individual tests
- Reproducibility of the individual tests

The following graphic shows the position off the standard test cases of the test catalog. Standard test cases are the optimum connection between the test requirements and the test objects on a basis of reuse.

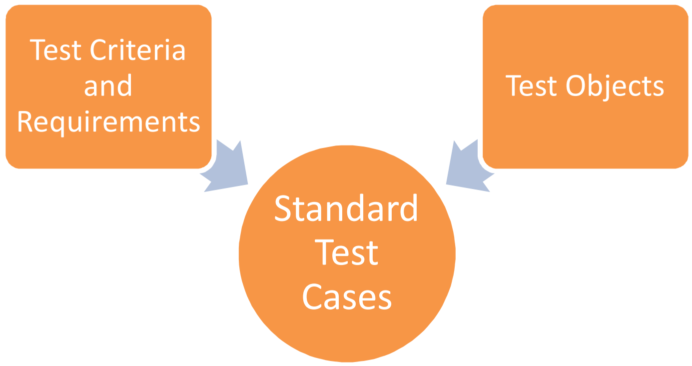


Figure 6.3: Position of the Standard Test Cases (Source: own graphic)

6.4 PRINCIPAL OF REUSE

The principal of re-use is often applied in Software Engineering. In Software Engineering many things can be reused, for example, designs, requirements specifications, procedures, modules, applications, ideas, design patterns, architectures. Components are artifacts that can be identified clearly in software systems. The primary intention in reusing components is that a component can be taken and integrated into a software system.[173]

"Software components and software reuse complement each other perfectly. Using software components to build software systems almost automatically leads to software reuse. (But the use of software components is not sufficient for software reuse.) And trying to reuse software almost automatically evolves in the composition of software out of components."[174]

6.4.1 Benefits of Software Reuse

Reuse has a positive influence on quality, costs, as well as productivity. The following part elaborates on quality improvements and effort reduction in more detail.

[173] Cf. SAMETINGER (1997): P.2
[174] SAMETINGER (1997): P.4

- **Quality Improvements**

Reuse results in improvements in quality, productivity, performance and reliability.

Quality: Continued error fixing from reuse to reuse yields to higher quality for reused components.[175]

Productivity: A productivity gain is achieved due to less developing time for an experiment. This leads to less testing efforts, yields to overall savings in cost by saving labor. “When reuse is being installed, productivity may decrease shortly due to increased learning effort and the need to develop reusable components. This temporary decrease in productivity should easily be compensated by a long-term increase.”[176]

Performance: “Extensive reuse can be worth the effort invested in optimizations. This may yield better performance of a reused component than might be practical for a component that is developed and used only once.”[177]

Reliability: Using optimized components gains the reliability of a system. Hence, the continuous use of a component increases the chance of finding errors.[178]

- **Effort Reduction**

Reuse brings a reduction in redundant work and hence, development time, furthermore, this leads to a shorter time to market. Documentation, costs and team sizes can be reduced as well.

Redundant work, development time: Developing systems from scratch yield in redundant work. By using reusable parts redundant work can be avoided. This results in less development and less associated time and costs.[179]

Time to market: Using reusable components will reduce the developing time and furthermore, this will result in a reduced time to market.[180]

Documentation: Reusing components reduces the amount of documentation to be written. The documentation of the component is created ones and hence, only the changes of the components must be documented in the future.[181]

Team size: “Large development teams suffer from a communication overload. Doubling the size of a development team does not result in doubled productivity.” [182] The more components

[175] Cf. SAMETINGER (1997): P.11
[176] SAMETINGER (1997): P.12
[177] SAMETINGER (1997): P.12
[178] Cf. SAMETINGER (1997): P.12
[179] Cf. SAMETINGER (1997): P.12f
[180] Cf. SAMETINGER (1997): P.13
[181] Cf. SAMETINGER (1997): P.13
[182] SAMETINGER (1997): P.13

can be reused, the less team members are needed. This leads to better communication and increased productivity.

- **Other Benefits**

Expertise sharing is an additional benefit of the reuse principal.

Expertise sharing: "Good designs can only be learned from good designers."[183] Reuse supports this perfectly when engineers study the designs of excellent peers in order to improve their design skills.

6.5 REUSE IN THE MANUAL

The main principal for the manual is:

"Reuse and continuous improvement of test cases, instead of new developing the same experiments again and again!"

In the manual reuse is divided into three categories. Graphic 6.X shows the three cases, which are described in the following part.

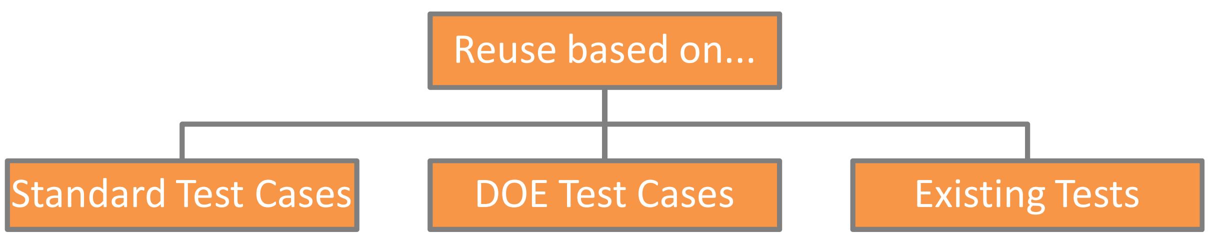


Figure 6.4: Reuse categories in the manual (Source: own graphic)

6.5.1 Reuse based on standard test cases (without DOE)

Standard test cases are tests which can be used more often during product development. For example one experiment must be executed in every generation of a machine or a test occurs in different machine series, than these tests should be part of the standard test catalog. The standard test cases will be developed based on the stored test protocols and the knowledge of test and developing engineers. The process of using standard test cases in the company is illustrated in 6.6.2 "The process behind the standard test catalog and the administration of the

[183] SAMETINGER (1997): P.14

experiments". The process of developing these experiments is described in 6.6.3 "Procedure to develop the standard test catalog".

6.5.2 Reuse based on standard test cases with DOE

DOE test cases are similar to the standard test case but these tests are more complex that the use of Design of Experiments is recommended. Thereby the engineers select possible test cases whereby DOE is useful. The process of using DOE test cases in a company is shown in 6.6.2 "The process behind the standard test catalog and the administration of the experiments". The process of developing these experiments is described in 6.6.3 "Procedure to develop the standard test catalog".

6.5.3 Reuse based on existing tests

Hereby the test protocols of the conducted test which are no standard or DOE tests are stored in a test protocol pool. These tests are one-time tests or new tests which are not defined as a standard test at the beginning. Every protocol is provided with keywords to make it easier to find and categorized by test object and test criteria. The engineers can search for the protocol on the basis of keywords, test objects or test criteria. If a test is needed for another application the engineers can simply copy and modify the existing experiment.

The process of using these one-time or new tests is shown in 6.6.2 "The process behind the standard test catalog and the administration of the experiments". The process of developing these experiments is described in 6.6.3 "Procedure to develop the standard test catalog".

6.6 IMPROVEMENT OF THE PROCESSES

In this part the improvement of the processes behind the standard test catalog, the administration of the experiments and how the standard test catalog can be created.

Again a good administration guarantees comparability, reproducibility and redundancy free storage of the test cases.

6.6.1 Development of the processes behind the standard test catalog

Every process starts with a test order from a developing engineer. A main difference to the current process is the split up in the three types of experiments. The processes are based on the reuse principals. Figure 6.5 shows the three types of experiments. The following part describes the administrative processes behind these three experimental types.

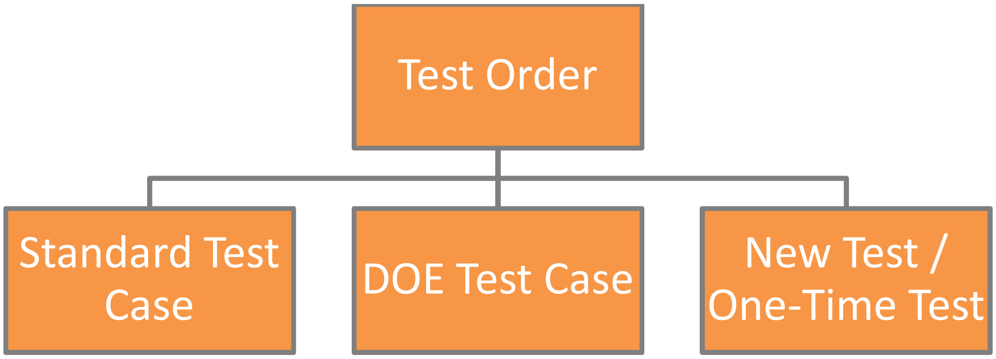


Figure 6.5: Break down of the test order (Source: own graphic)

The three processes “Process for Standard Test Cases”, “Process for DOE Test Cases” and “Process for One-time & New Tests” are divided into 3 layers of responsibility. The first layer is for the “Test Client (R&D)”. The Test Client is any engineer of the developing department who orders an experiment. The next layer is the “Head of Testing Department”. The Head of Testing Department is responsible for the allocation of the executing person, to define the appointed time and to release tests. The third layer is the “Executing Person of Testing Department”. The executing person can be any engineer of the testing department and is responsible for planning and conducting its allocated experiments.

The process behind the standard test catalog and administration of the experiments is a combination of the “Experimental Design Process” (DOE Process), the results of the benchmarking and own consideration. Following the “Experimental Design Process” is shown again to make the comparison to the developed process easier.

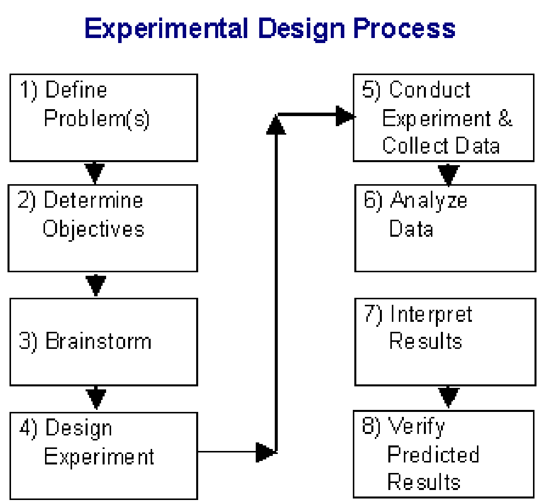


Figure 6.6: Experimental Design (DOE) Process (Source: moresteam.com)

6.6.2 The process behind the standard test catalog and the administration of the experiments

First the processes are shown graphically. Then the steps of the process behind the standard test catalog and the administration of the experiments are described in the following section.

Process for Standard Test Cases

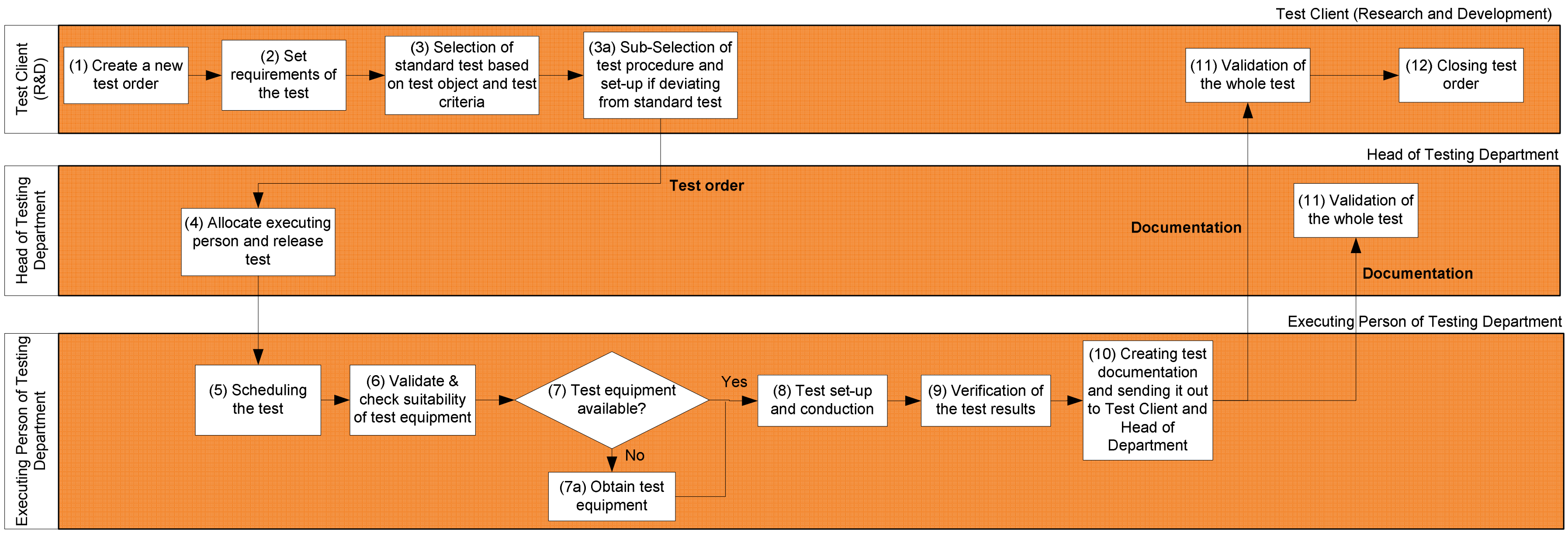


Figure 6.7: Process for Standard Test Cases (Source: own graphic)

Process for DOE Test Cases

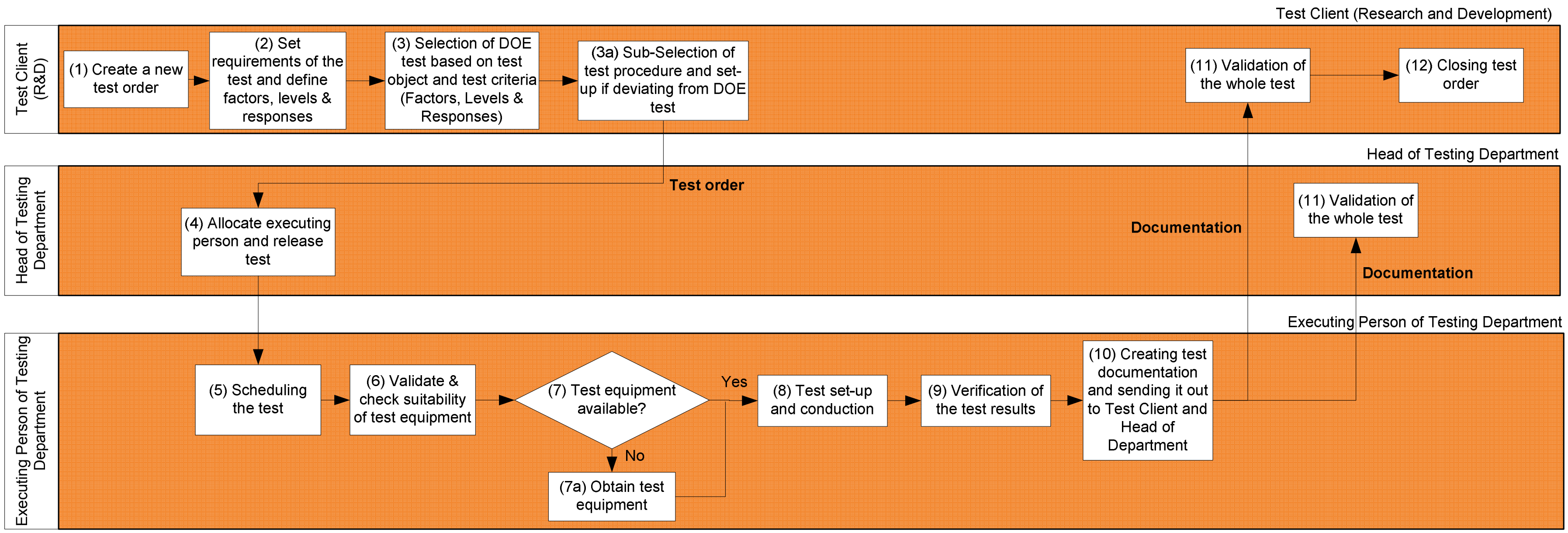


Figure 6.8: Process for DOE Test Cases (Source: own graphic)

Process for One-time & New Tests

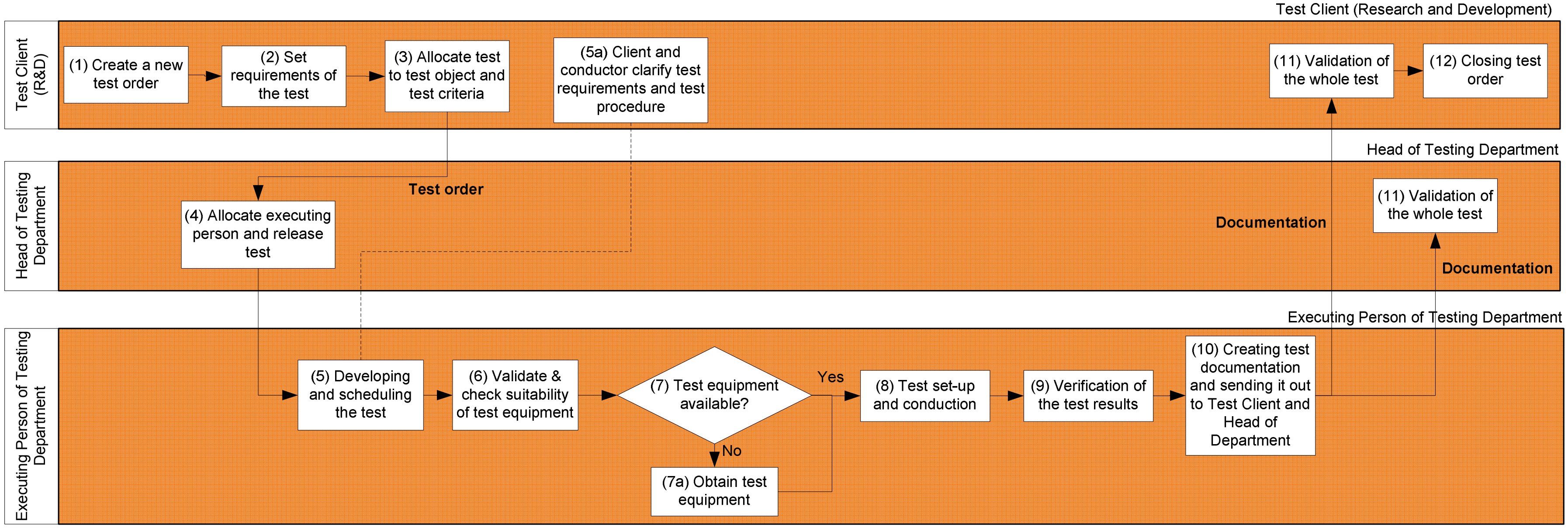


Figure 6.9: Process for One-time & New Tests (Source: own graphic)

(1) Create a new test order

The test client of the developing department orders a test by filling out the test order blank. The test order blank is described in Table 6.2 "Test order blank". In the test order the goals of the tests must be defined.

The test client must select between Standard, DOE or New/One-Time Test. The further process depends on the selection.

Comparing to the DOE Process this phase is similar to the "Define Problem(s)" stage.

(2) Set requirements of the test

The test client gives all necessary requirements for fulfilling the experiment in the test order. For the DOE test also the factors, levels and responses must be defined. The goal of this stage is a list of all requirements of the experiment. Comparing to the DOE Process this phase is similar to the "Determine Objectives" stage but also includes parts of the "Brainstorm" stage.

(3) Selection of standard test based on test objects and test criteria

The test client chooses the needed standard test from the test catalog based on the test object and the test criteria. Furthermore, he should define the measurement values for the standard experiment.

(3) Selection of DOE test based on test objects and test criteria (factors, levels & responses)

The test client chooses the needed DOE test from the test catalog based on the test object and the test criteria. Furthermore, he should define the measurement values for the standard experiment.

(3) Allocate test to test objects and test criteria

The test client allocates the test to the test objects and the test criteria.

Comparing to the DOE Process phase (3) is similar to the "Brainstorm" stage.

(3a) Sub-Selection of test procedure and set-up if deviating from standard test

If there are more types or versions of the experiment or the experiment set-up the test client need to define it more precise to eliminate all lacks of clarity. When it is not clear which test is the correct one, a consultation with the conducting test engineer is recommended.

(3a) Sub-Selection of test procedure and set-up if deviating from DOE test

If there are more types or versions of the DOE experiment or the test set-up the test client need to define it more precise to eliminate all lacks of clarity. When it is not clear which test is the correct one, a consultation with the conducting test engineer is recommended.

(4) Allocate executing person and release test (for One-time & New Tests)

The head of the testing department confirms and release the given test orders in this part. Furthermore, he allocates an executing person from the testing department to the experiment, in case the test client has not done this. The head of the testing department can also change the test executor if somebody else fits better for a particular job.

(5) Scheduling the test

In this part the test executor plans and schedules his allocated experiment.

(5) Developing and scheduling the test (for One-time & New Tests)

If the test is not a standard experiment from the test catalog the executing test engineer develops the test based on the given requirements, test objects and test criteria and schedules his allocated experiment to his work schedule. Test is created due to the knowledge, experience and intuition of the test engineer and the test client.

(5a) Client and conductor clarify test requirements and test procedure

If the test requirements are not clear the executing test engineer contacts the test client to clarify the specifications.

Stage (5) and (5a) are similar to the "Design Experiment" Phase comparing to the Experimental Design Process.

(6) Validate & check suitability of test equipment

The equipment, especially the measuring instruments, should be validated to the following criteria:

Accuracy: Accuracy is (…) "the predicted difference on average between the measurement and the true value. Accuracy is also known as bias." [184]

[184] toolingu.com

Precision: Precision is (…) "the degree to which an instrument will repeat the same measurement over a period of time." [185]

Repeatability: Repeatability is defined as "precision under repeatability conditions. Repeatability conditions means conditions where independent test results are obtained with the same method on identical test items in the same laboratory by the same operator using the same equipment with short intervals of time." [186]

Reproducibility: "Reproducibility is defined as precision under reproducibility conditions. Reproducibility conditions means conditions where test results are obtained with the same method on identical test items in different laboratories with different operators using different equipment."[187]

"Also, a different laboratory of necessity means a different operator, different equipment, a different location and under different supervisory control." [188]

Linearity: The amount of error change throughout an instrument's measurement range. Linearity is also the amount of deviation from an instrument's ideal straight-line performance.[189]

Stability: Stability is (…) "the ability of a measuring instrument to maintain constant its metrological characteristics."[190] Metrological characteristic are (…) "distinguishing feature which can influence the results of measurement." [191]

Traceability: Traceability is (…) "the property of the result of a measurement whereby it can be related to appropriate measurement standards, generally international or national standards, through an unbroken chain of comparisons."[192]

[185] toolingu.com
[186] BROWN, TAULER, WALCZAK (2009): P. 56
[187] BROWN, TAULER, WALCZAK (2009): P. 56
[188] LUKO (2009)
[189] toolingu.com
[190] ISO 10012-1:1992: P. 10
[191] ISO 10012:2003: P. 9
[192] ISO 10012-1:1992: P. 10

(7) Test equipment available?

In this phase the test engineer checks if the necessary test equipment and other needed machines are available at the scheduled time.

(7a) Obtain test equipment

If applicable the needed test equipment must be supplied and/or reserved. The test conductor must possibly change the scheduled time, if the equipment is available in that time frame.

(8) Test set-up and conduction

In this part the test engineer actually sets up and conducts the experiment by following the test description including test procedure, test set-up, test equipment, etc. All measured data for the fulfillment of the test goals must be recorded.

Comparing to the DOE Process this phase is similar to the “Conduct Experiment and Collect Data” stage.

(9) Verification of the test results

Hereby the test results must be verified by the test engineer and/or better another test engineer if the measured results are plausible. Verification is the process of providing objective evidence that the conducted experiment is conform to the given test requirements of the test client.

Note: To guarantee a consistent verification the company should define a “Verification Plan”, which includes the correct verification of their conducted experiments.

Comparing to the DOE Process this phase is similar to the “Verify Predicted Results” stage.

(10) Creating test documentation and sending it out to Test Client and Head of Department

After the test execution the test engineer creates a documentation of the conducted experiment in form of a standard test protocol and sends it to the test client and the head of the department to verify the data. The sending out of the documentation is done by uploading the test protocol to the test database. The test protocol blank is described in Table 6.5 „content of test protocol blank”. Furthermore, during the creation of the documentation the test engineer must analyze the data and interpret the measured results.

Stage (5) is similar to the “Analyze Data” and the “Interpret Results” Phase comparing to the Experimental Design Process.

(11) Validation of the whole test

After receiving the test protocol the test client and/or the head of the testing department must validate the conducted experiment. Therefore they must check if the used method was correct and if the experiment brought the needed and correct results. The validation guarantees if the executed test satisfies the specified requirements of this experiment and of the product.

Validation is the process of providing evidence that the experiment satisfies requirements allocated to its end product and solve the right problems.

Note: To guarantee a consistent validation the company should define a "Validation Plan", which includes the correct validation of their conducted experiments.

(12) Closing test order

Finally after a positive validation of the experiment the test client closes the test order.

6.6.3 Procedure to develop the standard test catalog

The procedure to develop the standard test catalog is developed on the basis of the Requirements Engineering Process and the Tasks of professional Requirements-Management. The RE process is described in Chapter 3.4 "The Requirements Engineering Process".

The Requirements Engineering Process:

1. Requirements Elicitation
2. Requirements Analysis
3. Requirements Specification
4. Requirements Verification
5. Requirements Validation and Documentation

Figure 6.10 shows the procedure to develop the standard test. Following the steps of the procedure a described more detailed.

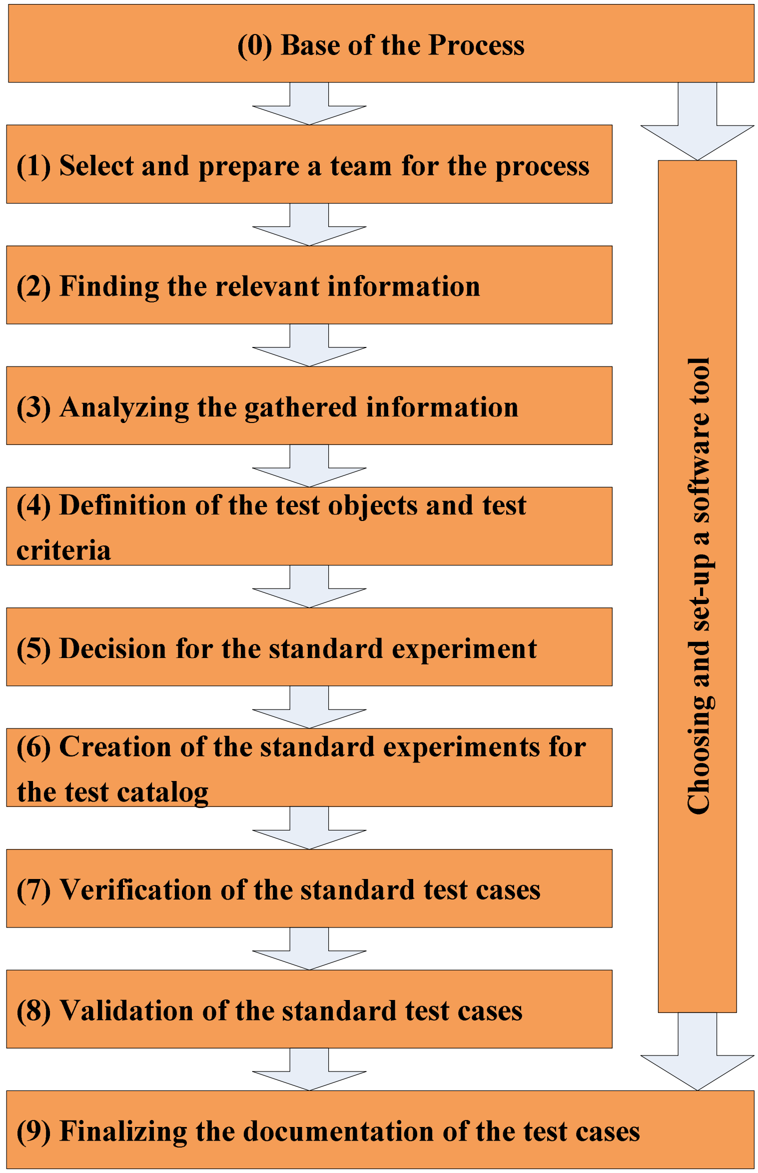


Figure 6.10: Procedure to develop the standard test catalog (Source: own graphic)

(0) Base of the Process

Will to change, Existing test protocols and documentation, knowledge of the test engineers and developer (R&D engineers)

(1) Select and prepare a team for the process

The goal of this phase is to define a team who is responsible for creating the standard test catalog. The head of the team is one responsible person who gets support from the managers and the head of the departments. The team members should include minimum one person of every related department (R&D, testing department, possibly product line service and product management). One DOE expert is also needed for this procedure for developing the Standard

DOE test cases. If there is no DOE expert in the company somebody should be hired or an employee should be trained in Design of Experiments. The team members may not work fulltime on this project.

(2) Finding the relevant information

Comparing to Requirements Elicitation of the RE process at the beginning of the process is the gathering of information. Therefore the head of the team should define:

- What information should be gathered? (e.g.: structure of the test objects, product structure, test criteria, etc.)
- From what source it can be gleaned? (e.g.: test protocols, service instructions, knowledge of the test and R&D engineers, etc.)
- Who are the stakeholders of the process? (e.g.: head of the departments, test engineers, R&D engineers, etc.)
- By what mechanisms or techniques it may be gathered? (e.g.: interview, questioning, survey, etc.)
- Does the company use Design of Experiment and is there a DOE expert in the company? (e.g.: who is the DOE expert, etc.)
- Which software is used to order experiments and which is used to store the information of experiments? (e.g.: creation of protocols, storage of test protocols, etc.)

The goal of this phase is to get an overview of which information sources are in the company and what information need to be obtained.

(3) Analyzing the gathered information

The goal of this phase is to achieve understanding of the nature of the problem domain and the problems that exist within it. The team members get an overview of the frame and the size of the project. For instance to find out how many test are concerned with this topic.

The output from this analysis is a carefully structured model (document) of the relevant characteristics of the problem. Comparing to the RM tasks exchange of information is part of this stage.

(4) Definition of the test objects and test criteria

In this part the team members should define test objects and their test criteria. This information can be find on one hand by analyzing stored test protocols and test orders and on the other hand by asking the test and R&D engineers. Comparing to the RE process this phase is related to Requirements Specification.

The goal of this phase is a pool of all test objects and test criteria and their relations to each other. For instance for the test objects the structure of the produced machines can be listed. Hereby the hierarchy of the machine parts and assemblies must be clear. Then an allocation of the test criteria to the test objects can be done. These lists of objects and criteria are not fixed lists it can expand over time, if new criteria yield in the future. Table 6.1 shows a few examples for test object and allocated test criteria.

Test object	Test criteria
Switching box	Maximum temperature
Robot 1	Maximum speed axis 1 Maximum speed axis 2 Maximum speed axis 3
Motor 1	Maximum power
Robot grabber 1	Maximum grabber force

Table 6.1: Examples for test object and allocated test criteria (Source: own illustration)

(5) Decision for the standard experiment

After analyzing and defining the test objects and criteria the project team defines which experiments will be part of the standard test catalog. Furthermore they need to classify which are standard test cases and DOE test cases.

The goal of this phase should be a list of the standard experiments and the DOE experiments which should be described for the standard test catalog. The development of the structure of the relationship between the tests is also part of this stage. This structure is important for the storage of the test cases in a software tool.

Comparing to the RE process this phase is also related to Requirements Specification.

(6) Creation of the standard experiments for the test catalog

In this phase the tests are actually design. To get the right information survey the test and R&D engineers to create the standard test cases. Other sources of information are protocols and documentation of conducted experiments. In chapter 6.7 “Developing the documentation” table 6.3 describes the content of standard test case blank and table 6.4 shows the content of DOE test case blank.

Comparing to the RE process this phase is somehow related to Requirements Documentation.

(7) Verification of the test cases

The goal of the verification phase is checking if the developed experiments are conforming to the defined requirements. Therefore, other engineers than the developer of the experiments much verify the standard and DOE test to guarantee a four-eyes principle.

Comparing to the RE process this phase is related to Requirements Verification. Verification hereby means: “Am I developing the experiments right?”

(8) Validation of the standard test cases

Validation ensuring that the test cases are correct, complete, and consistent, satisfies the product requirements. It is an issue of communicating requirements to the stakeholders.

The goal of the test case validation is to check if the test cases fulfill the requirements of the product. The purpose of the test validation is to give the stakeholders a chance to check early whether the solution proposed will really solve their problems. This means that the experiments must actually be conducted to see if they fulfill the given specification.

Comparing to the RE process this phase is also related to Requirements Validation. Validation in this case means: “Am I developing the right experiments?”

(9) Finalizing the documentation of the test cases

In this phase the project team finally put the verified experiment descriptions in the software tool. Chapter 6.7.2 “Standard Test Cases” and 6.7.3 “DOE Test Cases” describes the content of standard test case blank and the DOE test cases blank for the documentation in the standard test catalog. Comparing to the RE process this phase is related to Requirements Documentation.

Choosing and set-up a software tool

Parallel to the development of the standard test catalog a software tool for the storage of the test must be set-up. Ideal is a software tool with what the engineer are used to. This could be any existing content management system (CMS) or document management system (DMS). Also PLM (Product Lifecycle Management) Systems can be used.

Following are some examples for possible software solutions:

- Product Lifecycle Management Software: OpenPLM, Aras PLM, etc.
- Microsoft SharePoint Server

- Content Management Systems: Dropal (Open source), Joumla (Open source), Word Press (Open source), Nuxeo (Open Source), etc.
- Issue and Project Tracking Software: Jira, etc.
- Document Management system,

Structure of the Software

The structure of the software corresponds from the different documentation blanks and its relation to each other.

The centre of the software structure is the test order. Beside the test order are the "Test Protocol Pool" and the "Standard Test Catalog". The test protocol pool includes all test protocols. When a test is conducted the protocol is stored in this pool and connected to its test order by a link. Test protocol can also be part of new test orders. Therefore the test description of the new order includes a link to the test protocol. This test will then be copied and modified regarding to the new test requirements. The standard test catalog includes all standard test cases and DOE test cases. When a standard test is applicable for a new test order the test description of the new order includes a link to the necessary test of the standard test catalog.

Furthermore, the tests and the test order a connected via the test objects and test criteria.

These objects and criteria are collected in lists. Both lists of the test objects and the test criteria are created in (4) Definition of the test objects and test criteria of the "procedure to develop the standard test catalog" in chapter 6.6.3.

The following graphic shows the software structure in a simplified way.

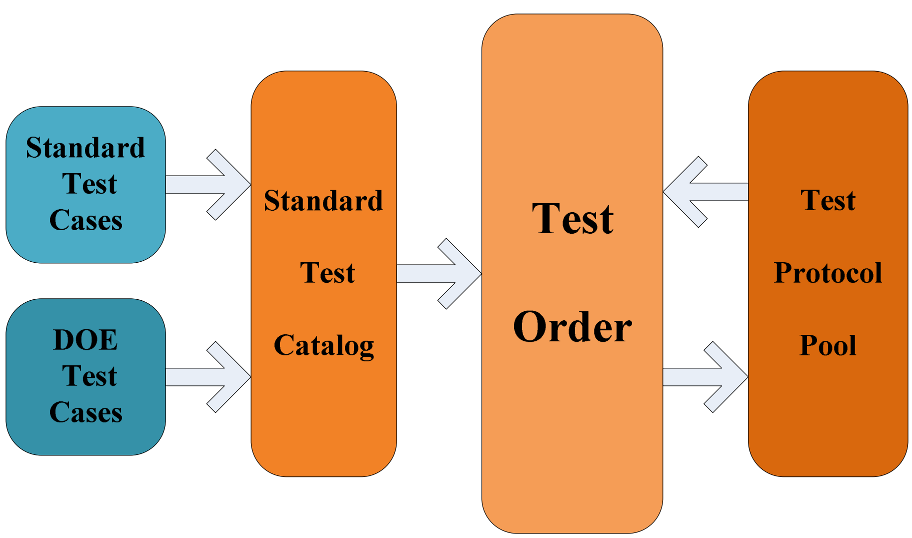


Figure 6.11: Software Structure (Source: own graphic)

6.7 DEVELOPING THE DOCUMENTATION

The resulting documentation is a combination from the results of the benchmarking and own considerations.

The documentation consists of four parts

- Test order
- Standard test documentation
- DOE test documentation
- Test protocols

6.7.1 The Test Order

The test order is the interface between test client and test conductor.

The test client commissions the experiment by setting up a test order. The test conductor is one of the test engineers of the testing department. This test engineer receives the test order.

The more detailed and coherent a test order is the more understandable and comprehensible it is. This leads to less time needed for the test engineer to check the details of a test with the developer (test client) because most of the details are already in the test order.

The following table describes the content of the test order document.

Content of the Test Order Blank:

Name	Description
Title	Describes the title of the experiment
Test-ID	This is a unified number to identify an ordered test.
Test Client	The person who orders the test. (developer)
Test Conductor	The person of the testing department who will conduct the test.
Due date	Date when the test must be conducted. At this date the test client should get the results of the experiment and should close the test order.
Estimated number of work days (effort)	This is the estimated workload measured in work days of the experiment.
Test object	List of the test objects for this test
Test criteria	List of the test criteria for this test
Measured variables (Test requirements)	List of the measured variables of the experiment
Test description	For new/one-time tests the test client describes the test here or refers to link to older experiments from the experiment pool. If it is a standard or DOE test a link to necessary test in the standard test catalog should be given.
Instruction for safety at work	Here are possible safety-instructions given and if a safety analysis is necessary.
Test status (Project status)	Describes the current status of the test. Examples for different status: • In Preparation (client) • Ordered / Requested (client) • In Process (conductor) • Declined (conductor) • Work completed (conductor) • Canceled (conductor) • Closed (client)
Goals	Describes the goals of the experiment.
Goals achievement status	If there are more goals, here are the states of the different goals listed. Examples for different states: • fulfilled • partly fulfilled • critical • unknown • not fulfilled
Goal achievement comment	Here the status of the goals can be commented.
Conclusion and Consequences	After the protocol of the test is done, this describes further instructions and/or gives important findings during the experiment.

Table 6.2: Test order blank (Source: own illustration)

6.7.2 Standard Test Cases

For the documentation of the standard test cases and the DOE test cases only a minimum-set of the content is given. The further content of the test cases should be specified according to the products of a company and there requirements. Consider the more content is documented the more confusing does the documentation get. Hereby applies: “keep it should and simple”

Minimum-Set of the content of standard test case blank for the standard test catalog

Name	Description
Title	Describes the title of the experiment
Test-ID	This is an unified number/name to identify a test
Test objects	List of the test objects for this test
Test criteria	List of the test criteria for this test
Test Equipment	This is the needed equipment (machines, measuring devices, tools, etc.) for the experiment
Output Data	This is the estimated output the executing person will get form this test. This can be for instance a list of the measured variables of the experiment.
Test description	Description of the experiment: including test & measurement set-up, test & measurement procedure, applicability, limitations, strength/weaknesses (by comparing to other similar experiment), advantages/disadvantages (by comparing to similar experiments)
Version	Version of the experiment, for instance described by a Version number like 1.0, 1.1, 2.0, …
Creator	The person who described the given experiment
Verifier	The person who has verified the given experiment
Validator	The person who has validated the given experiment

Table 6.3: Minimum-set of content of standard test case blank (Source: own illustration)

6.7.3 DOE Test Cases

Minimum-Set of the content of DOE test case blank for the standard test catalog

Name	Description
Title	Describes the title of the experiment
Test-ID	This is a unified number/name to identify a test.
Test objects	List of the test objects for this test
Test criteria	List of the test criteria for this test
Measured variables (Test requirements)	List of the measured variables of the experiment (Factors, Level, Responses)
DOE Method	Brief description of the used DOE Method
Test Equipment	Needed equipment (machines, measuring devices, tools, etc.) for the experiment
Output Data	This is the estimated output the executing person will get form this test. This can be for instance a list of the measured variables of the experiment.
Test description	Description of the experiment: including test & measurement set-up, test & measurement procedure, applicability, limitations, strength/weaknesses (by comparing to other similar experiment), advantages/disadvantages (by comparing to similar experiments)
Version	Version of the experiment, for instance described by a Version number like 1.0, 1.1, 2.0, …
Creator	The person who described the given experiment
Verifier	The person who has verified the given experiment
Validator	The person who has validated the given experiment

Table 6.4: Minimum-Set of content of DOE test case blank (Source: own illustration)

6.7.4 Test Protocol

A test protocol must include its test order or must be connected to its test order. The following content is a completion. The real protocol consists of the test order and the protocol to get all the information. If the test is from the standard test catalog the test procedure and set-up must not be described again.

Content of the test protocol blank for the storage of the conducted experiments

Name	Description
Title	Describes the title of the experiment
Test-ID	This is a unified number/name to identify a test
Standard Test (Yes/No)	Yes/No answer if the test is from the standard test catalog. If Yes, the link to the standard test from the catalog must be provided.
Test objects	List of the test objects
Test criteria	List of the test criteria
Measured variables	List of the measured variables of the experiment (Factors, Level, Responses)
Creator	The person who created the protocol
Goals	Describes all goals of the experiment
Test Equipment	Needed equipment for the experiment (machines, measuring devices, tools, etc.)
Test description	Description of the experiment: including test & measurement set-up, test & measurement procedure, applicability, limitations, strength/weaknesses (by comparing to other similar experiment), advantages/disadvantages (by comparing to similar experiments)
Test results	Collection of the test results
Interpretation and conclusion	Interpretation and conclusion of the test results
Further arrangements	If further arrangements are necessary they are described here

Table 6.5: Content of test protocol blank (Source: own illustration)

7 THE MANUAL

7.1 SCOPE OF THE MANUAL – WHO CAN USE IT?

The manual is made for mechanical engineering companies, which do a lot of testing. “A lot of testing means” that these companies develop, plan and/or conduct experiments in their company. The numbers of experiments in this case are not priory the crucial factor, but there should be an amount where the company can actually profit from a software supported form of administration. Also electrical or other engineering companies can use and profit from this Manual.

7.2 THE GOAL OF THE MANUAL – WHY IS IT USED?

This manual aims to improve the administration of the testing department of engineering companies and its related departments and areas.

The improvement includes the administrational processes of the department and the correlated areas, the documentation of the test procedures and test cases, and furthermore the structure of a supporting software system for the storage of the test cases and other documentation.

The reason why such a manual is necessary for some companies is, that more and more information is documented and therefore the documentation of experiments and measurements gets wider and more variegated and hence, more complex.

By using modern measurement software more information can be measured, charted and documented.

Hence, the administration of this high load of information and data gets more complex as well and it must be managed more carefully, to make sure that the data can be re-used for further applications. The information management of some companies is not adapted to the high data quantity. Hence, measured data gets lost and is useless for other applications. Sometimes experiments of the past must be repeated because the finding of the measured data needs more time than repeating the whole experiment.

Through an optimal administration of the experiments the created knowledge can be used more efficient.

A good administration of the test cases guarantees comparability, reproducibility and redundancy free storage.

The vision of the standard test catalog is described in the following chapter 7.3.

7.3 VISION: "THE STANDARD TEST CATALOG"

Through the given challenges stated in the chapter before and results of a benchmarking the idea of a "standard test catalog" came up.

The standard test catalog contains standard test cases based on the principles of reuse. The principles of reuse are given in the following chapter 7.4 "PRINCIPLES OF REUSE IN THE MANUAL". These standard test cases are like another toolbox for the testing department.

The standard test catalog and its process behind guarantee a continuing improvement of the testing department and its processes.

The development of standardized test scenarios is one possibility to improve the management of the testing.

7.4 PRINCIPLE OF REUSE IN THE MANUAL

The main principal for the manual is:

"Reuse and continuous improvement of test cases, instead of new developing the same experiments again and again!"

In the manual reuse is divided into three categories. Graphic 6.X shows the three cases, which are described in the following part.

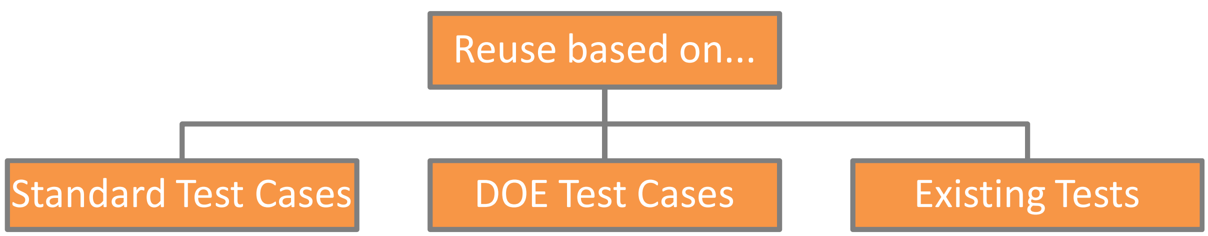


Figure 7.1: Reuse categories in the manual (Source: own graphic)

7.4.1 Reuse based on standard test cases (without DOE)

Standard test cases are tests which can be used more often during product development. For example one experiment must be executed in every generation of a machine or a test occurs in different machine series, than these tests should be part of the standard test catalog. The standard test cases will be developed based on the stored test protocols and the knowledge of test and developing engineers. The process of using standard test cases in the company is illustrated in 7.5 "The process behind the standard test catalog and the administration of the experiments". The process of developing these experiments is described in 7.6 "Procedure to develop the standard test catalog".

7.4.2 Reuse based on standard test cases with DOE

DOE test cases are similar to the standard test case but these tests are more complex that the use of Design of Experiments is recommended. Thereby the engineers select possible test cases whereby DOE is useful. The process of using DOE test cases in a company is shown in 7.5 "The process behind the standard test catalog and the administration of the experiments". The process of developing these experiments is described in 7.6 "Procedure to develop the standard test catalog".

7.4.3 Reuse based on existing tests

Hereby the test protocols of the conducted test which are no standard or DOE tests are stored in a test protocol pool. These tests are one-time tests or new tests which are not defined as a standard test at the beginning. Every protocol is provided with keywords to make it easier to find and categorized by test object and test criteria. The engineers can search for the protocol on the basis of keywords, test objects or test criteria. If a test is needed for another application the engineers can simply copy and modify the existing experiment.

The process of using these one-time or new tests is shown in7.5 "The process behind the standard test catalog and the administration of the experiments". The process of developing these experiments is described in 7.6 "Procedure to develop the standard test catalog".

7.5 THE PROCESSES BEHIND THE STANDARD TEST CATALOG AND THE ADMINISTRATION OF THE EXPERIMENTS

First the processes are shown graphically. Then the steps of the process behind the standard test catalog and the administration of the experiments are described in the following section.

Process for Standard Test Cases

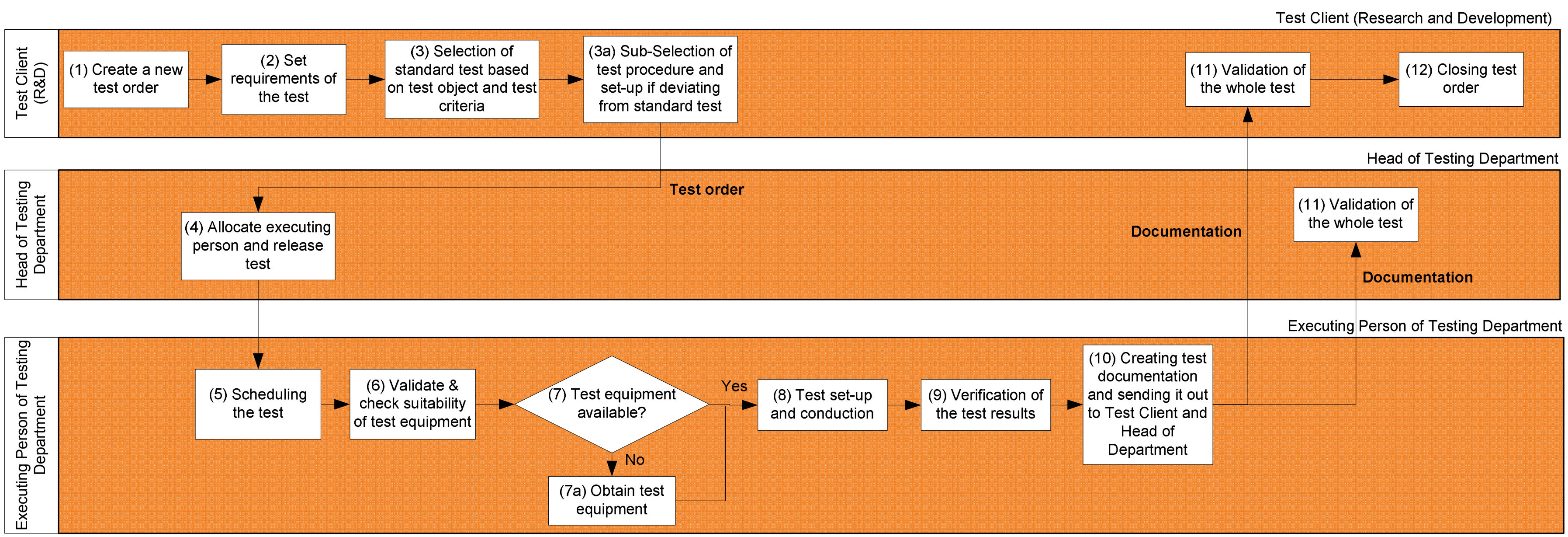


Figure 7.2: Process for Standard Test Cases (Source: own graphic)

Process for DOE Test Cases

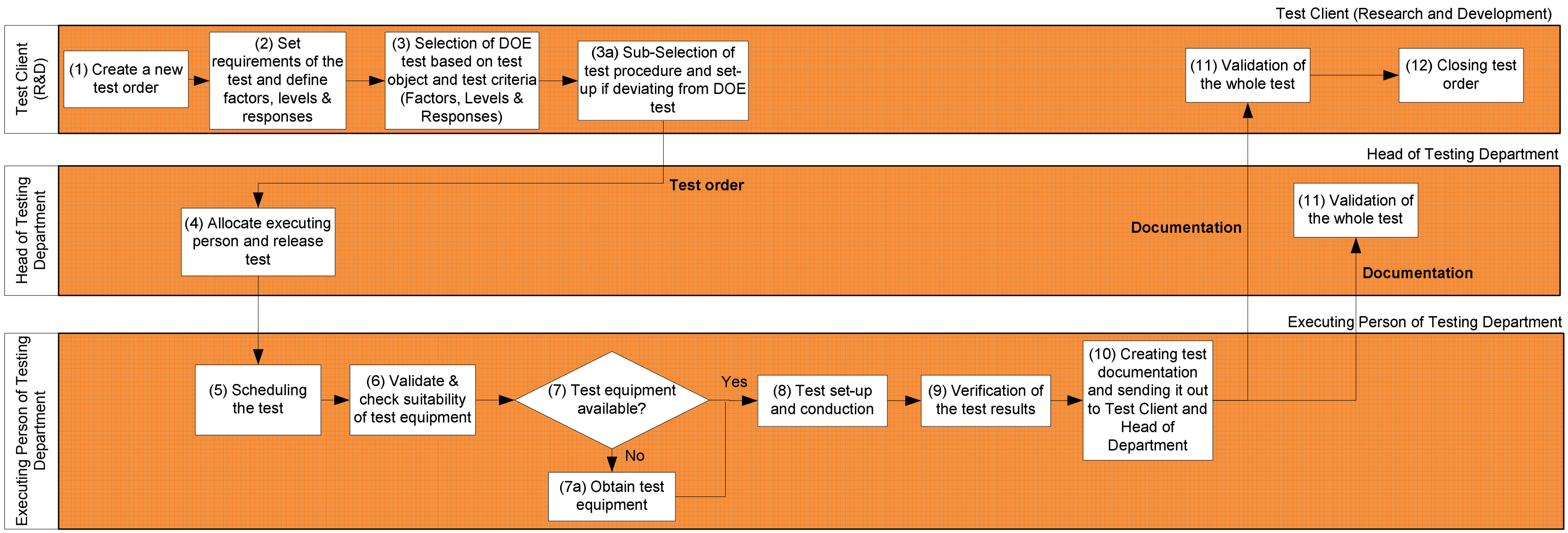


Figure 7.3: Process for DOE Test Cases (Source: own graphic)

Process for One-time & New Tests

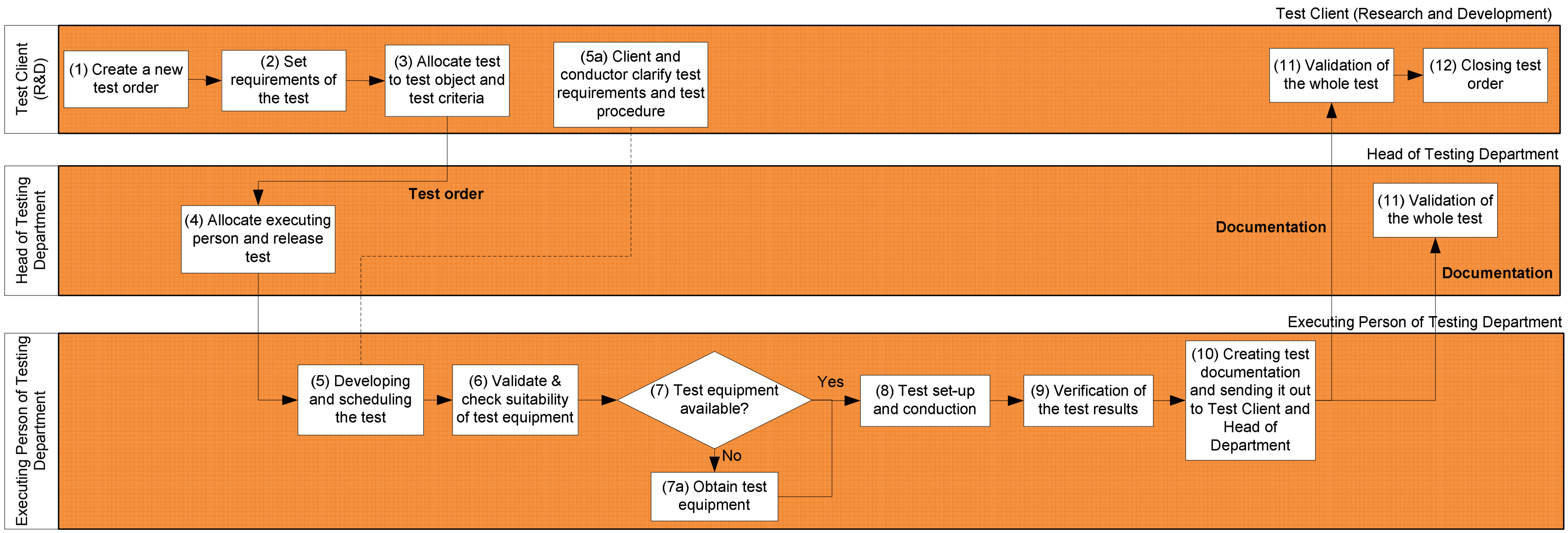


Figure 7.4: Process for One-time & New Tests (Source: own graphic)

(1) Create a new test order

The test client of the developing department orders a test by filling out the test order blank. The test order blank is described in Table 7.2 “Test order blank”. In the test order the goals of the tests must be defined. The test client must select between Standard, DOE or New/One-Time Test. The further process depends on the selection.

(2) Set requirements of the test

The test client gives all necessary requirements for fulfilling the experiment in the test order. For the DOE test also the factors, levels and responses must be defined. The goal of this stage is a list of all requirements of the experiment.

(3) Selection of standard test based on test objects and test criteria

The test client chooses the needed standard test from the test catalog based on the test object and the test criteria. Furthermore, he should define the measurement values for the standard experiment.

(3) Selection of DOE test based on test objects and test criteria (factors, levels & responses)

The test client chooses the needed DOE test from the test catalog based on the test object and the test criteria. Furthermore, he should define the measurement values for the standard experiment.

(3) Allocate test to test objects and test criteria

The test client allocates the test to the test objects and the test criteria.

(3a) Sub-Selection of test procedure and set-up if deviating from standard test

If there are more types or versions of the experiment or the experiment set-up the test client need to define it more precise to eliminate all lacks of clarity. When it is not clear which test is the correct one, a consultation with the conducting test engineer is recommended.

(3a) Sub-Selection of test procedure and set-up if deviating from DOE test

If there are more types or versions of the DOE experiment or the test set-up the test client need to define it more precise to eliminate all lacks of clarity. When it is not clear which test is the correct one, a consultation with the conducting test engineer is recommended.

(4) Allocate executing person and release test (for One-time & New Tests)

The head of the testing department confirms and release the given test orders in this part. Furthermore, he allocates an executing person from the testing department to the experiment, in case the test client has not done this. The head of the testing department can also change the test executor if somebody else fits better for a particular job.

(5) Scheduling the test

In this part the test executor plans and schedules his allocated experiment.

(5) Developing and scheduling the test (for One-time & New Tests)

If the test is not a standard experiment from the test catalog the executing test engineer develops the test based on the given requirements, test objects and test criteria and schedules his allocated experiment to his work schedule. Test is created due to the knowledge, experience and intuition of the test engineer and the test client.

(5a) Client and conductor clarify test requirements and test procedure

If the test requirements are not clear the executing test engineer contacts the test client to clarify the specifications.

(6) Validate & check suitability of test equipment

The equipment, especially the measuring instruments, should be validated to the following criteria:

Accuracy – Accuracy also known as bias is the difference between the measurement and the true value on average.

Precision – Precision is the grade to which an instrument will repeat the same measurement over a period of time."

Repeatability – Repeatability is defined as accuracy under repeatability conditions. Repeatability conditions are conditions where independent test results are received with the same method on identical test items in the same laboratory by the same operator using the same equipment with short intervals of time.

Reproducibility – Reproducibility is defined as accuracy under reproducibility conditions. Reproducibility conditions are conditions where test results are received with the same method on identical test items in different laboratories with different operators using different equipment. A different laboratory also means a different operator, different equipment, a different location and under different supervisory control. [193]

Linearity – Linearity is the amount of deviation from the ideal straight-line performance of a measuring instrument.

Stability – Stability is the ability of a measuring instrument to maintain constant its metrological characteristics. Metrological characteristic are distinguishing features which can influence the results of measurement.

Traceability – Traceability is the property of the result of a measurement whereby it can be related to appropriate measurement standards, generally international or national standards, through an unbroken chain of comparisons.[194]

(7) Test equipment available?

In this phase the test engineer checks if the necessary test equipment and other needed machines are available at the scheduled time.

(7a) Obtain test equipment

If applicable the needed test equipment must be supplied and/or reserved. The test conductor must possibly change the scheduled time, if the equipment is available in that time frame.

(8) Test set-up and conduction

In this part the test engineer actually sets up and conducts the experiment by following the test description including test procedure, test set-up, test equipment, etc. All measured data for the fulfillment of the test goals must be recorded.

(9) Verification of the test results

Hereby the test results must be verified by the test engineer and/or better another test engineer if the measured results are plausible. Verification is the process of providing objective evidence that the conducted experiment is conform to the given test requirements of the test client.

Note: To guarantee a consistent verification the company should define a "Verification Plan", which includes the correct verification of their conducted experiments.

[193] Cf. BROWN, TAULER, WALCZAK (2009): P. 56 & toolingu.com & LUKO (2009)
[194] ISO 10012-1:1992: P. 10 & ISO 10012:2003: P. 9

(10) Creating test documentation and sending it out to Test Client and Head of Department

After the test execution the test engineer creates a documentation of the conducted experiment in form of a standard test protocol and sends it to the test client and the head of the department to verify the data. The sending out of the documentation is done by uploading the test protocol to the test database. The test protocol blank is described in Table 7.9 „content of test protocol blank". Furthermore, during the creation of the documentation the test engineer must analyze the data and interpret the measured results.

(11) Validation of the whole test

After receiving the test protocol the test client and/or the head of the testing department must validate the conducted experiment. Therefore they must check if the used method was correct and if the experiment brought the needed and correct results. The validation guarantees if the executed test satisfies the specified requirements of this experiment and of the product.
Validation is the process of providing evidence that the experiment satisfies requirements allocated to its end product and solve the right problems.
Note: To guarantee a consistent validation the company should define a "Validation Plan", which includes the correct validation of their conducted experiments.

(12) Closing test order

Finally after a positive validation of the experiment the test client closes the test order.

7.6 PROCEDURE TO DEVELOP THE STANDARD TEST CATALOG

The procedure to develop the standard test catalog is based on the Requirements Engineering Process. This procedure contains of 10 steps. A software tool for the storage and the administration of the standard test catalog must be chosen and set-up parallel to the 10 steps. Figure 7.5 shows the procedure to develop the standard test. Following the steps of the procedure a described more detailed, first the 10 steps and after this the details about the software tool.

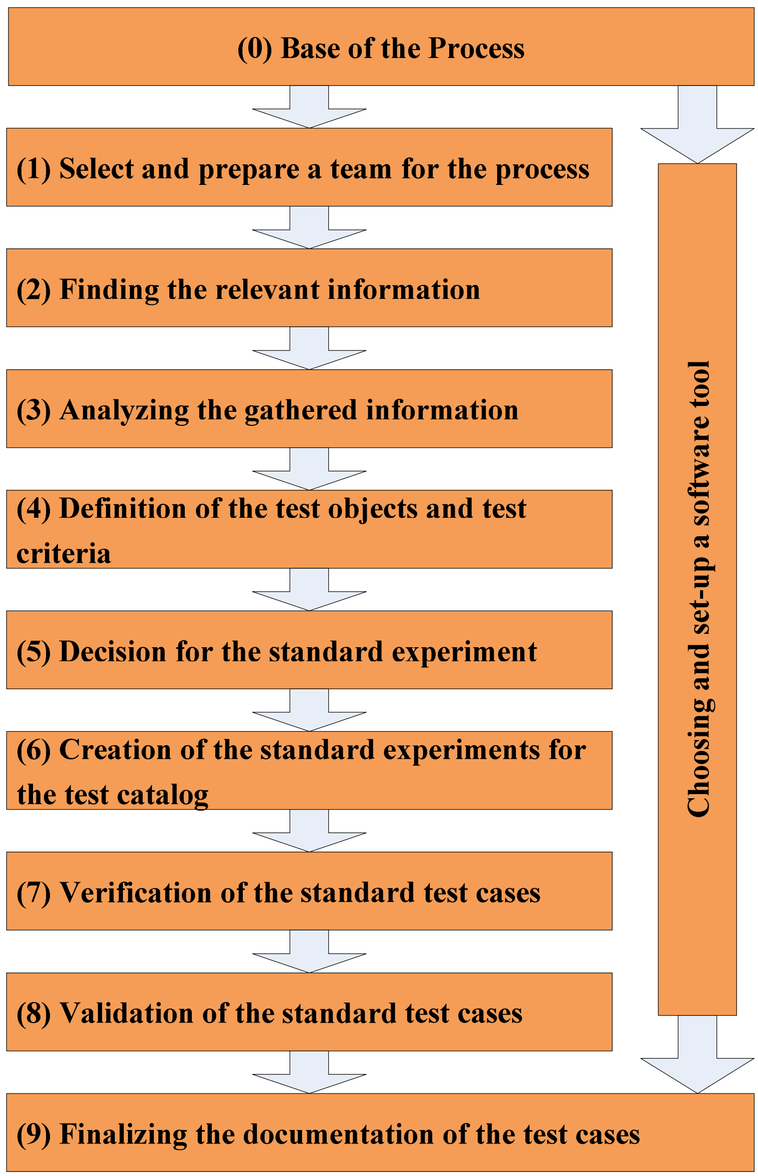


Figure 7.5: Procedure to develop the standard test catalog (Source: own graphic)

(0) Base of the Process

Will to change, Existing test protocols and documentation, knowledge of the test engineers and developer (R&D engineers)

(1) Select and prepare a team for the process

The goal of this phase is to define a team who is responsible for creating the standard test catalog. The head of the team is one responsible person who gets support from the managers and the head of the departments. The team members should include minimum one person of every related department (R&D, testing department, possibly product line service and product management). One DOE expert is also needed for this procedure for developing the Standard DOE test cases. If there is no DOE expert in the company somebody should be hired or an employee should be trained in Design of Experiments. The team members may not work fulltime on this project.

(2) Finding the relevant information

Comparing to Requirements Elicitation of the RE process at the beginning of the process is the gathering of information. Therefore the head of the team should define:

- What information should be gathered? (e.g.: structure of the test objects, product structure, test criteria, etc.)
- From what source it can be gleaned? (e.g.: test protocols, service instructions, knowledge of the test and R&D engineers, etc.)
- Who are the stakeholders of the process? (e.g.: head of the departments, test engineers, R&D engineers, etc.)
- By what mechanisms or techniques it may be gathered? (e.g.: interview, questioning, survey, etc.)
- Does the company use Design of Experiment and is there a DOE expert in the company? (e.g.: who is the DOE expert, etc.)
- Which software is used to order experiments and which is used to store the information of experiments? (e.g.: creation of protocols, storage of test protocols, etc.)

The goal of this phase is to get an overview of which information sources are in the company and what information need to be obtained.

(3) Analyzing the gathered information

The goal of this phase is to achieve understanding of the nature of the problem domain and the problems that exist within it. The team members get an overview of the frame and the size of the project. For instance to find out how many test are concerned with this topic.

The output from this analysis is a carefully structured model (document) of the relevant characteristics of the problem.

(4) Definition of the test objects and test criteria

In this part the team members should define test objects and their test criteria. This information can be find on one hand by analyzing stored test protocols and test orders and on the other hand by asking the test and R&D engineers.

The goal of this phase is a pool of all test objects and test criteria and their relations to each other. For instance for the test objects the structure of the produced machines can be listed. Hereby the hierarchy of the machine parts and assemblies must be clear. Then an allocation of the test criteria to the test objects can be done. These lists of objects and criteria are not fixed lists it can expand over time, if new criteria yield in the future. Table 6.1 shows a few examples for test object and allocated test criteria.

Test object	**Test criteria**
Switching box	Maximum temperature
Robot 1	Maximum speed axis 1 Maximum speed axis 2 Maximum speed axis 3
Motor 1	Maximum power
Robot grabber 1	Maximum grabber force

Table 7.1: Examples for test object and allocated test criteria (Source: own illustration)

(5) Decision for the standard experiment

After analyzing and defining the test objects and criteria the project team defines which experiments will be part of the standard test catalog. Furthermore they need to classify which are standard test cases and DOE test cases.

The goal of this phase should be a list of the standard experiments and the DOE experiments which should be described for the standard test catalog. The development of the structure of the relationship between the tests is also part of this stage. This structure is important for the storage of the test cases in a software tool.

(6) Creation of the standard experiments for the test catalog

In this phase the tests are actually design. To get the right information survey the test and R&D engineers to create the standard test cases. Other sources of information are protocols and documentation of conducted experiments. In chapter 6.7 "Developing the documentation" table 6.3 describes the content of standard test case blank and table 6.4 shows the content of DOE test case blank.

(7) Verification of the test cases

The goal of the verification phase is checking if the developed experiments are conforming to the defined requirements. Therefore, other engineers than the developer of the experiments much verify the standard and DOE test to guarantee a four-eyes principle. Verification hereby means: "Am I developing the experiments right?"

(8) Validation of the standard test cases

Validation ensuring that the test cases are correct, complete, and consistent, satisfies the product requirements. It is an issue of communicating requirements to the stakeholders.

The goal of the test case validation is to check if the test cases fulfill the requirements of the product. The purpose of the test validation is to give the stakeholders a chance to check early whether the solution proposed will really solve their problems. This means that the experiments must actually be conducted to see if they fulfill the given specification. Validation in this case means: "Am I developing the right experiments?"

(9) Finalizing the documentation of the test cases

In this phase the project team finally put the verified experiment descriptions in the software tool. Chapter 7.6.2 "Standard Test Cases" and 7.6.3 "DOE Test Cases" describes the content of standard test case blank and the DOE test cases blank for the documentation in the standard test catalog.

Choosing and set-up a software tool

Parallel to the development of the standard test catalog a software tool for the storage of the test must be set-up. Ideal is a software tool with what the engineer are used to. This could be any existing content management system (CMS) or document management system (DMS). Also PLM (Product Lifecycle Management) Systems can be used.

Following are some examples for possible software solutions:

- Product Lifecycle Management Software: OpenPLM, Aras PLM, etc.
- Microsoft SharePoint Server
- Content Management Systems: Dropal (Open source), Joumla (Open source), Word Press (Open source), Nuxeo (Open Source), etc.
- Issue and Project Tracking Software: Jira, etc.
- Document Management system,

Structure of the Software

The structure of the software corresponds from the different documentation blanks and its relation to each other.

The following graphic 7.6 shows the software structure in a simplified way.

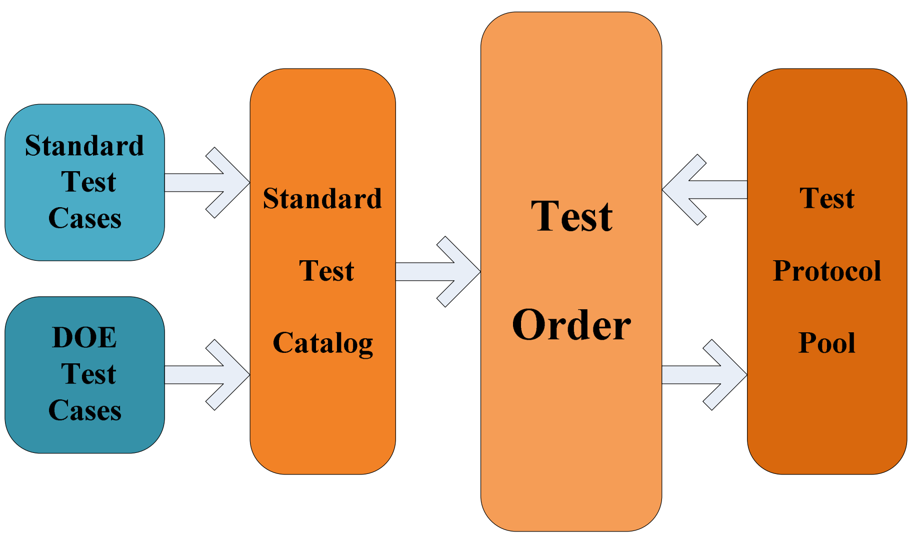


Figure 7.6: Software Structure (Source: own graphic)

The centre of the software structure is the test order. Beside the test order are the "Test Protocol Pool" and the "Standard Test Catalog". The test protocol pool includes all test protocols. When a test is conducted the protocol is stored in this pool and connected to its test order by a link. Test protocol can also be part of new test orders. Therefore the test description of the new order includes a link to the test protocol. This test will then be copied and modified regarding to the new test requirements. The standard test catalog includes all standard test cases and DOE test cases. When a standard test is applicable for a new test order the test description of the new order includes a link to the necessary test of the standard test catalog. Furthermore, the tests and the test order a connected via the test objects and test criteria. These objects and criteria are collected in lists. Both lists of the test objects and the test criteria are created in (4) Definition of the test objects and test criteria of the “procedure to develop the standard test catalog” in chapter 7.5.

7.7 THE DOCUMENTATION

The documentation consists of four parts

- The Test order
- Standard test cases
- DOE test cases
- Test protocols

The given documentation blanks are only recommendations for the documentation of the different contents during this process. The blanks are described in form of tables including the name of the data array in the actual list and des description of this data array.

7.7.1 The Test Order

The test order is the interface between test client and test conductor.

The test client commissions the experiment by setting up a test order. The test conductor is one of the test engineers of the testing department. This test engineer receives the test order. The more detailed and coherent a test order is the more understandable and comprehensible it is. This leads to less time needed for the test engineer to check the details of a test with the developer (test client) because most of the details are already in the test order.

The following table describes the content of the test order document.

Content of the Test Order Blank:

Name	Description
Title	Describes the title of the experiment
Test-ID	This is a unified number to identify an ordered test.
Test Client	The person who orders the test. (developer)
Test Conductor	The person of the testing department who will conduct the test.
Due date	Date when the test must be conducted. At this date the test client should get the results of the experiment and should close the test order.
Estimated number of work days (effort)	This is the estimated workload measured in work days of the experiment.
Test object	List of the test objects for this test
Test criteria	List of the test criteria for this test
Measured variables (Test requirements)	List of the measured variables of the experiment
Test description	For new/one-time tests the test client describes the test here or refers to link to older experiments from the experiment pool. If it is a standard or DOE test a link to necessary test in the standard test catalog should be given.
Instruction for safety at work	Here are possible safety-instructions given and if a safety analysis is necessary.
Test status (Project status)	Describes the current status of the test. Examples for different status: • In Preparation (client) • Ordered / Requested (client) • In Process (conductor) • Declined (conductor) • Work completed (conductor) • Canceled (conductor) • Closed (client)
Goals	Describes the goals of the experiment.
Goals achievement status	If there are more goals, here are the states of the different goals listed. Examples for different states: • fulfilled • partly fulfilled • critical • unknown • not fulfilled
Goal achievement comment	Here the status of the goals can be commented.
Conclusion and Consequences	After the protocol of the test is done, this describes further instructions and/or gives important findings during the experiment.

Table 7.2: Test order blank (Source: own illustration)

Example of a new test order

Name	Description
Title	Checking the maximum temperature in the control box
Test-ID	2013-000123
Test Client	Max Mustermann
Test Conductor	Michael Wesinger
Due date	2013-03-15
Estimated number of work days (effort)	2 work days
Test object	Control box
Test criteria	Temperature
Measured variables	Temperature over time → Temperature profile (table & graph)
Test description	A temperature profile of the control box of machine X should be created. *Standard Test T1-12:* “Temperature profile of the control box” The measurement period is 5 minutes. Run cycle tests of Machine X and take the temperature in the control box and outside surrounding temperature every 5 minutes. A cycle consists of 50 machine runs using a high performance program “H1” to reach a higher temperature in a shorter time comparing to a standard run. The measuring sensor of one fluke thermometer should be placed in the control box. The fluke thermometer itself should be outside the control box and the door of the control box must be closed during the whole experiment. Maximum temperature allowed is 80°C then the machine shuts down.
Instruction for safety at work	No specific safety instruction necessary
Test status	• In Preparation (client)
Goals	Goal 1: temperature profile (table and graph) Goal 2: the maximum temperature reached during the test run
Goals achievement status	Goal 1: not complied Goal 2: not complied
Goal achievement comment	
Conclusion and Consequences	

Table 7.3: Example of a new test order (Source: own illustration)

Example of a test order after test conduction

Name	Description
Title	Checking the temperature profile in the control box
Test-ID	2013-000123
Test Client	Max Musterman
Test Conductor	Michael Wesinger
Due date	2013-03-15
Estimated number of work days (effort)	2 work days
Test object	Control box
Test criteria	Temperature
Measured variables	Temperature over time → Temperature profile (table & graph)
Test description	A temperature profile of the control box of machine X should be created. *Standard Test T1-12:* "Temperature profile of the control box" The measurement period is 5 minutes. Run cycle tests of Machine X and take the temperature in the control box and outside surrounding temperature every 5 minutes. A cycle consists of 50 machine runs using a high performance program "H1" to reach a higher temperature in a shorter time comparing to a standard run. The measuring sensor of one fluke thermometer should be placed in the control box. The fluke thermometer itself should be outside the control box and the door of the control box must be closed during the whole experiment. Maximum temperature allowed is 80°C then the machine shuts down.
Instruction for safety at work	No specific safety instruction necessary
Test status	• Closed (client)
Goals	Goal 1: temperature profile (table and graph) Goal 2: the maximum temperature reached during the test run
Goals achievement status	• Goal 1: complied • Goal 2: complied
Goal achievement comment	
Conclusion and Consequences	The Temperature reached the maximum temperature within 1 hour and the machine shut down. For further test a cooling system is necessary in the control box.

Table 7.4: Example of a test order after test conduction (Source: own illustration)

7.7.2 Standard Test Cases

For the documentation of the standard test cases and the DOE test cases only a minimum-set of the content is given. The further content of the test cases should be specified according to the products of a company and there requirements. Consider the more content is documented the more confusing does the documentation get. Hereby applies: "keep it should and simple"

Minimum-Set of the content of standard test case blank for the standard test catalog

Name	Description
Title	Describes the title of the experiment
Test-ID	This is an unified number/name to identify a test
Test objects	List of the test objects for this test
Test criteria	List of the test criteria for this test
Test Equipment	This is the needed equipment (machines, measuring devices, tools, etc.) for the experiment
Output Data	This is the estimated output the executing person will get form this test. This can be for instance a list of the measured variables of the experiment.
Test description	Description of the experiment: including test & measurement set-up, test & measurement procedure, applicability, limitations, strength/weaknesses (by comparing to other similar experiment), advantages/disadvantages (by comparing to similar experiments)
Version	Version of the experiment, for instance described by a Version number like 1.0, 1.1, 2.0, …
Creator	The person who described the given experiment
Verifier	The person who has verified the given experiment
Validator	The person who has validated the given experiment

Table 7.5: Minimum-set of content of standard test case blank (Source: own illustration)

Examples of a standard test case

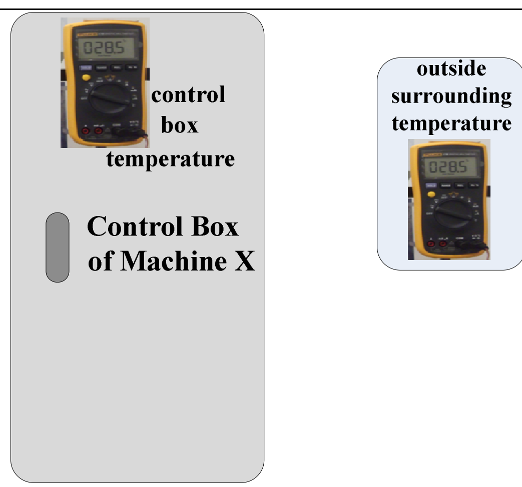
Name	**Description**
Title	Temperature profile of the control box
Test-ID	Standard Test T1-12
Test objects	Control Box
Test criteria	Temperature
Test Equipment	Machine X, Two fluke thermometer,
Output Data	A temperature profile in form of a table and a graph of the temperature over time.
Test description	Test to create a temperature profile of the control box of machine X. Choose the measurement period. (E.g.: every 10 minutes) Choose run cycle program of Machine X. (E.g.: H1, H2 or H3) Program H1 to H3 are high performance programs to reach a higher temperature in a shorter time comparing to a standard run. Place measuring sensor of one fluke thermometer in the control box. The fluke thermometer itself should be outside the control box and the door of the control box must be closed at any time of the whole experiment. The other fluke thermometer should measure the outside surrounding temperature where the machine is placed. Start run cycle program. Read temperature comparing to the measurement period.
	
Version	1.0
Creator	Michael Wesinger
Verifier	Max Musterman
Validator	Franz Musterman

Table 7.6: Examples of a standard test case (Source: own illustration)

7.7.3 DOE Test Cases

Minimum-Set of the content of DOE test case blank for the standard test catalog

Name	Description
Title	Describes the title of the experiment
Test-ID	This is a unified number/name to identify a test.
Test objects	List of the test objects for this test
Test criteria	List of the test criteria for this test
Measured variables (Test requirements)	List of the measured variables of the experiment (Factors, Level, Responses)
DOE Method	Brief description of the used DOE Method
Test Equipment	Needed equipment (machines, measuring devices, tools, etc.) for the experiment
Output Data	This is the estimated output the executing person will get form this test. This can be for instance a list of the measured variables of the experiment.
Test description	Description of the experiment: including test & measurement set-up, test & measurement procedure, applicability, limitations, strength/weaknesses (by comparing to other similar experiment), advantages/disadvantages (by comparing to similar experiments)
Version	Version of the experiment, for instance described by a Version number like 1.0, 1.1, 2.0, …
Creator	The person who described the given experiment
Verifier	The person who has verified the given experiment
Validator	The person who has validated the given experiment

Table 7.7: Minimum-Set of content of DOE test case blank (Source: own illustration)

DOE Types & Methods

Type	Attitude	Remark
Full factorial	All combinations, full orthogonal	High number of tests, effortful best evaluable
Fractional	Half or less number of tests like full factorial, full orthogonal	Mixing of interactions Unsafe of evaluation
Plackett Burmann	Derivation from factorial design. Very low number or tests.	Interactions are not fully confounded
Taguchi	Very low number of tests, multiple fractional full orthogonal	Many interactions mixed with each other and with factors; suitable only for regulation of individual factors
Central Composite Design	The same construction as full factorial plus cross in the middle. Test space like a ball	High number of tests, effortful good evaluable
Box-Behnken	Evaluation for quadratic models. Middle levels in outlet area.	High number of tests, effortful good evaluable
D-Optimal	Very low number of tests, Clear regulation of interactions,	not orthogonal good evaluable
Mixture	Use of factors whose sum must always amount to 100%	not orthogonal, factors dependent on each other good evaluable

Table 7.8: Overview of the design types (Source: Cf. RONNINGER (2012): P. 26)

7.7.4 Test Protocol

A test protocol must include its test order or must be connected to its test order. The following content is a completion. The real protocol consists of the test order and the protocol to get all the information. If the test is from the standard test catalog the test procedure and set-up must not be described again.

Content of the test protocol blank for the storage of the conducted experiments

Name	Description
Title	Describes the title of the experiment
Test-ID	This is a unified number/name to identify a test
Standard Test (Yes/No)	Yes/No answer if the test is from the standard test catalog. If Yes, the link to the standard test from the catalog must be provided.
Test objects	List of the test objects
Test criteria	List of the test criteria
Measured variables	List of the measured variables of the experiment (Factors, Level, Responses)
Creator	The person who created the protocol
Goals	Describes all goals of the experiment
Test Equipment	Needed equipment for the experiment (machines, measuring devices, tools, etc.)
Test description	Description of the experiment: including test & measurement set-up, test & measurement procedure, applicability, limitations, strength/weaknesses (by comparing to other similar experiment), advantages/disadvantages (by comparing to similar experiments)
Test results	Collection of the test results
Interpretation and conclusion	Interpretation and conclusion of the test results
Further arrangements	If further arrangements are necessary they are described here

Table 7.9: Content of test protocol blank (Source: own illustration)

Example of a test protocol

<table>
<tr><th>Name</th><th>Description</th></tr>
<tr><td>Title</td><td>Checking the maximum temperature in the control box</td></tr>
<tr><td>Test-ID</td><td>2013-000123</td></tr>
<tr><td>Standard Test</td><td>Standard Test T1-12: “Temperature profile of the control box”</td></tr>
<tr><td>Test objects</td><td>Control box</td></tr>
<tr><td>Test criteria</td><td>Temperature</td></tr>
<tr><td>Measured variables</td><td>Temperature over time → Temperature profile (table & graph)</td></tr>
<tr><td>Creator</td><td>Michael Wesinger</td></tr>
<tr><td>Goals</td><td>Goal 1: temperature profile (table and graph)
Goal 2: the maximum temperature reached during the test run</td></tr>
<tr><td>Test Equipment</td><td>Machine X, Two fluke thermometer,</td></tr>
<tr><td>Test description</td><td>Standard Test T1-12: “Temperature profile of the control box”:
Test to create a temperature profile of the control box of machine X.
Measurement period: 10minutes
Run cycle program of Machine X: H1
Place measuring sensor of one fluke thermometer in the control box. The fluke thermometer itself should be outside the control box and the door of the control box must be closed at any time of the whole experiment.
The other fluke thermometer should measure the outside surrounding temperature where the machine is placed.
Start run cycle program.
Read temperature comparing to the measurement period.</td></tr>
<tr><td>Test results</td><td>
<table>
<tr><th>Time (minutes)</th><th>Temperature</th><th>Surrounding Temperature</th><th>cycles</th></tr>
<tr><td>0</td><td>26.9</td><td>26.3</td><td>0</td></tr>
<tr><td>10</td><td>43.7</td><td>26.4</td><td>45</td></tr>
<tr><td>20</td><td>55.5</td><td>26.6</td><td>47</td></tr>
<tr><td>30</td><td>64.9</td><td>26.7</td><td>46</td></tr>
<tr><td>40</td><td>71.6</td><td>26.8</td><td>45</td></tr>
<tr><td>50</td><td>77.7</td><td>27.1</td><td>46</td></tr>
</table>
</td></tr>
</table>

	60	80.0	27.2	20
	70	-	-	-
Interpretation and conclusion	The program reached the maximum temperature of 80°C within 60 minutes and the machine shut down.			
Further arrangements	A cooling system must be installed in the control box.			

Table 7.10: Example of a test protocol (Source: own illustration)

7.7.5 Characteristics of a good Requirements Specification

For the creation of the test cases and test orders it is important to consider an optimal requirement specification according to the IEEE Standard.
Here the list of the characteristics of a good Requirements Specification.

A Requirements Specification should be
a) Correct
b) Unambiguous
c) Complete
d) Consistent
e) Ranked for importance and/or stability
f) Verifiable
g) Modifiable
h) Traceable

a) Correct – Correct means that every requirement stated in the requirements specification is one that the product/process shall meet. No tool or procedure exists that ensures correctness. The requirements should be compared with any applicable superior specification, such as a system requirements specification or product requirements specification, with other project documentation, and with other applicable standards, to ensure that it agrees. Alternatively the customer or user can determine the correctness in respect to the actual needs.
b) Unambiguous – Unambiguous means that every requirement stated in the specification has only one interpretation.

c) Complete – Complete means that the test engineer has all that is needed to plan and conduct an experiment.

d) Consistent – The requirement specification should be consistent within itself and consistent to its reference documents. If you call an object "control box" in one place, don't call it "switching box" or "switching unit" in another.

e) Ranked for Importance – Each requirement in the requirement specification must have an identifier to indicate either the importance or stability of that particular requirement.

Typically, all of the requirements that relate to a product/process are not equally important. Each requirement should be identified to make these differences clear and explicit.

f) Verifiable – Verifiable means that there exists some finite cost-effective process with which a person or machine can check that the product meets the requirement. In general any ambiguous requirement is not verifiable. Non-verifiable requirements include statements such as "works well," "good human interface," and "shall usually happen." These requirements cannot be verified because it is impossible to define the terms "good," "well," or "usually."

If a method cannot be devised to determine whether the product meets a particular requirement, then that requirement should be removed or revised. Quantitative requirements should be provided, like: "The temperature in the control box should be less than +70°C" or "The maximum speed of the X-Axis of Robot 1 should be 200mm/s."

g) Modifiable – Modifiable means that any changes to the requirements can be made easily, completely, and consistently while retaining the structure and style. Modifiability generally requires a requirement specification to have a coherent and easy-to-use organization, not be redundant (i.e., the same requirement should not appear in more than one place) and express each requirement separately, rather than intermixed with other requirements. Redundancy itself is not an error, but it can easily lead to errors.

h) Traceable – Traceable means that the origin of each of its requirements is clear and if it facilitates the referencing of each requirement in future development or enhancement documentation. Both Forward and Backward Traceability are recommended types.[195]

[195] Cf. microtoolssinc.com & IEEE (1998): P. 4ff

8 CONCLUSIONS

This thesis has investigated the administration of the testing department and its related areas of engineering companies. The goal of the project was the creation of a manual for the preparation of recurring test cases for the testing department. This included the creation of a standard test catalog and administrative processes of the testing department with its related areas. The manual aims the improvement of the administration of the testing department of engineering companies and its related departments and areas.

The benchmarking approved that most of the asked companies struggle with the topic of test administration as well. They realized that the rising amount of stored data gets difficult to manage.

The theoretical background of Design of Experiments (DOE) and Requirements Engineering & Management (RE&M) were a perfect base for the development of the manual and for the improvement and adjustment of the processes behind the standard test catalog. On one hand the Requirements Engineering Process built the base for the improvement of the processes behind the standard test catalog. On the other hand the procedure to develop the standard test catalog was created based on the Requirements Engineering Process.

The manual provides companies with the basic information for the challenge of test administration. The manual is a general information source which must be adjusted for the specific requirements of every company.

One big topic by following the manual for creating a standard test catalog is the evaluation of a software tool. By choosing the right software for the management of the experiments makes the creation, the storage and finding of test cases easier and saving the knowledge in the long term is guaranteed.

9 REFERENCES

[ANDERSEN, PETTERSEN (1996)] ANDERSEN, Bjørn; PETTERSEN Per-Gaute (1996): The Benchmarking Handbook, Step-by-Step Instuctions, Published by Chapman & Hall, London, UK

[ANTONY (2003)] ANTONY, Jiju (2003): Design of Experiments for Engineers and Scientists, Butterworth-Heinemann, Burlington, MA

[BAHILL, HENDERSON (2004)] BAHILL, Terry A.; HENDERSON, Steven J. (2004): Requirements Development, Verification, and Validation Exhibited in Famous Failures, Systems Engineering, Vol. 8, No. 1, 2005, Wiley Periodicals, Inc., URL: http://acqnotes.com/Attachments/Requirements%20Development,%20Verification,%20and%20Validation%20Exhibited%20in%20Famous%20Failures%20by%20A.%20Terry%20Bahill%20and%20Steven%20J.%20Henderson.pdf, [accessed on February 21, 2013]

[BRAY (2002)] BRAY, Ian (2002): An Introduction to Requirements Engineering, Pearson Education Limited, Essex, United Kingdom

[BROWN, TAULER, WALCZAK (2009)] BROWN, Steven D.; TAULER, Romà; WALCZAK, Beata (2009): Comprehensive Chemometrics: Chemical and Biochemical Data Analysis, Elsevier B. V., Oxford, UK

[CHENEY (1998)] CHENEY, Scott (1998): Benchmarking, Research & Evaluation, ASTD – American Society for Training & Development, Alexandria, Virgina

[CHRISTEL, KANG (1992)] CHRISTEL, Michael G.; KANG, Kyo C. (1992): Issues in Requirements Elicitation, Requirements Engineering Project, Software Engineering Institute, Carnegie Mellon University, Pittsburgh, Pennsylvania. URL: http://www.sei.cmu.edu/library/abstracts/reports/92tr012.cfm, [accessed on July 03, 2012]

[CZITROM (1999)] CZITROM, Veronica (1999): One-Factor-at-a-Time Versus Designed Experiments, The American Statistician, May 1999, Vol. 53, No. 2, Pages: 126 – 131

[DAMELIO (1995)] DAMELIO, Robert (1995): The basics of benchmarking, Productivity Press, Portland, Oregon

[DAVIS, YOURDON, ZWEIG (2000)] DAVIS, Alan M.; YOURDON, Ed; ZWEIG, Ann S. (2000): Requirements Management Made Easy, Omni-Vista, Inc., Colorado Springs, CO

[DEAN, VOSS (1999)] DEAN, Angela M.; VOSS, Daniel (1999): Design and Analysis of Experiments, Springer Verlag, New York

[ENGELSMAN (2008)] ENGELSMAN, Wilco (2008): A method for Requirements Management and modeling, University of Twente, Business Information Technology, Master Thesis

[HEINONEN (2006)] HEINONEN, Samuli (2006) Requirements Management Tool Support for Software Engineering in Collaboration. University of Oulu, Department of Electrical and Information Engineering, Master's Thesis

[HOOD et al. (2008)] HOOD et al. (2008): Requirements Management, The Interface Between Requirements Development and All Other Systems Engineering Processes, Springer-Verlag, Berlin, Heidelberg

[HULL, JACKSON, DICK (2011)] HULL, Elizabeth; JACKSON, Ken; DICK, Jeremy (2011): Requirements Engineering, Third Edition, Springer Verlag, London

[IEEE (1998)] Institute of Electrical and Electronics Engineers (1998): IEEE Recommended Practice for Software Requirements Specifications, IEEE Standard 830-1998 (Revision of IEEE Std 830-1993), Software Engineering Standards Committee of the IEEE Computer, New York.

[IEEE (2005)] Institute of Electrical and Electronics Engineers (2005): IEEE Standard for Application and Management of the Systems Engineering Process, IEEE Standard 1220-2005 (Revision of IEEE Std 1220-1998), Software and Systems Engineering Standards Committee, New York.

[IEEE (2008)] Institute of Electrical and Electronics Engineers (2008): IEEE Standard for Software and System Test Documentation, IEEE Standard 829-2008 (Revision of IEEE Std 829-1998), Software and Systems Engineering Standards Committee, New York.

[IEEE (2012)] Institute of Electrical and Electronics Engineers (2012): IEEE Standard for System and Software Verification and Validation, IEEE Standard 1012-2012 (Revision of IEEE Std 1012-2004), Software and Systems Engineering Standards Committee, New York.

[ISO 10012-1:1992] DIN Deutsches Institut für Normung (1992): ISO 10012-1:1992 - Forderungen an die Qualitätssicherung für Messmittel, Bestätigungssystem für Messmittel. Messprozesse und Messmittel, Beuth Verlag, Berlin

[ISO 10012:2003] DIN Deutsches Institut für Normung (2003): ISO 10012:2003 Messmanagementsysteme - Anforderungen an Messprozesse und Messmittel, Beuth Verlag, Berlin

[KLEPPMANN (2006)] KLEPPMANN, Wilhelm (2006): Taschenbuch Versuchsplanung: Produkte und Prozesse optimieren, 4. Auflage, Carl Hanser Verlag, München, Wien

[KRAFT (2011)] KRAFT, Joan (2011): The Department of the Navy Benchmarking Handbook: A Systems View, Washington, URL: http://unpan1.un.org/intradoc/groups/public/documents/ASPA/UNPAN002509.pdf, [accessed on 2012.05.21]

[LINSS (2002)] LINSS, Gerhard (2002): Qualitätsmanagement für Ingenieure, Carl Hanser Verlag München Wien

[LUKO (2009)] LUKO Stephen (2009: What Are Repeatability and Reproducibility?: Part 3: Their Meaning in Gage r&R Methodology, URL: http://www.astm.org/SNEWS/JA_2009/datapoints_ja09.html, [accessed on February 20, 2013]

[MACAULAY (1996)] MACAULAY, Linda (1996):Requirements for Relquirements Engineering Techniques, Department of Computation, University of Manchester Institute of Science and Technology, pp. 157-164, Proceedings of ICRE ’96, IEEE, Manchester, UK

[MALANO, BURTON (2001)] MALANO, Hector; BURTON, Martin (2001): Guidelines for Benchmarking Performance in the Irrigation and Drainage Sector, iptrid - International Program for Technology Research in Irrigation and Drainage Secretariat, Knowledge Synthesis Report No.5 – August 2001, Food and Agriculture Organization of the United Nations, Rome

[RONNINGER (2012)] RONNIGER, Curt (2012): Design of Experiment, URL: http://www.crgraph.com/Statistics11.pdf, [accessed on July 25, 2012]

[RUPP (2009)] RUPP, Chris & die SOPHISTen(2009): Requirements-Engineering und –Management, Professionelle, iterative Anforderungsanalyse für die Praxis, 5. Auflage, Carl Hanser Verlag, München, Wien

[RYAN (2007)] RYAN, Thomas P. (2007): Modern Experimental Design, John Wiley & Sons, Inc., Hoboken, New Jersey

[SAMETINGER (1997)] SAMETINGER, Johannes (1997):Software Engineering with Reusable Components, Springer-Verlag, Linz, Austria

[TANCO et al (2009)] TANCO et al (2009): Implementation of Design of Experiments projects in industry, APPLIED STOCHASTIC MODELS IN BUSINESS AND INDUSTRY, Appl. Stochastic Models Bus. Ind. 2009; 25: Pages 478–505, John Wiley & Sons, Ltd., TECNUN, University of Navarra, San Sebastian, Spain

[TANCO et al (2010)] TANCO et al (2010): Why is not design of experiments widely used by engineers in Europe? Journal of Applied Statistics Vol. 37, No. 12, December 2010, Pages 1961–1977, Taylor & Francis Group, Department of Industrial Management, TECNUN, University of Navarra, San Sebastián, Spain

[WAGNER (2001)] WAGNER, Karl Werner (2001): PQM – Prozessorientiertes Qualitätsmanagement: Leitfaden zur Umsetzung der ISO 9001:2000, Carl Hanser Verlag München Wien

URLs:

[blog.deversus.com] URL: http://blog.deversus.com/2008/12/requirements-engineering-explained/, [accessed on July 19, 2012]

[itl.nist.gov] http://www.itl.nist.gov/div898/handbook/pri/pri_d.htm, [accessed on July 23, 2012]

[ksi.cpsc.ucalgary.ca] URL: http://ksi.cpsc.ucalgary.ca/KAW/KAW96/herlea/FINAL.html, [accessed on July 19, 2012]

[microtoolssinc.com] URL: http://www.microtoolsinc.com/Howsrs.php, [accessed on July 03, 2012]

[moresteam.com] URL: http://www.moresteam.com/toolbox/design-of-experiments.cfm, [accessed on July 03, 2012]

[scarpedia.com] URL: http://scarpedia.com/general/requirement-validation-vs-requirement-verification/, [accessed on July 03, 2012]

[stats.gla.ac.uk] URL: http://www.stats.gla.ac.uk/steps/glossary/anova.html#block, [accessed on July 23, 2012]

[teamst.org] URL: http://www.teamst.org/, [accessed on February 12, 2013]

[thequalityportal.com] URL: http://thequalityportal.com/q_know02.htm, [accessed on July 03, 2012]

[toolingu.com] URL: http://www.toolingu.com/definition-350300-9245-reproducibility.html, [accessed on February 20, 2013]