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EMPIRICAL INDUSTRIAL STUDY OF THE COOPERATION OF TESTING AND DESIGN DEPARTMENTS

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1. Introduction

"The design process is primarily an information processing operation" [Hubka 1976]. The aim of the design process is to transfer information in the form of requirements into the product characteristics to describe the technical system.

There are both direct characteristics which could be defined by the design engineer, as well as the indirect defined characteristics concluded from characteristics of state. The product properties are defined as the characteristics and their associated values, see [Lindemann 2009]. Weber defines that characteristics can be directly influenced by the designer, while the product properties describe the behaviour of the product. They cannot be directly influenced by the designer [Weber 2005]. Characteristics are the number of teeth and the module of a gear, for example, the load capacity or the durability are product properties. These product properties affect the customer after the realisation through the production. Starting design process planning the design engineer defines characteristics and values widely, while the properties are not defined at all.

This is the paradox of product development [Ehrlenspiel 2013]. The information of the product properties are relevant for the design engineer because they do not always know which effects the defined characteristics will have on the product properties. In order to define the correct characteristics and their values, design engineers have to make the right decision. As a result, it must be ensured that all necessary information is available to the designer, see for example [Ehrlenspiel 2013]. To prevent problems, information on the currently processed product, for example from a previous project, has to be recirculated, see for example [Ehrlenspiel 2013] or [Feldhusen 2013].

As a result, the knowledge level of a current product development is higher than the knowledge level of a previous product development in the same phase of their development processes. Hence, some of the properties can be forecast for certain. The effects of the newly established characteristics on the properties should be identified early. The design engineer needs information about these effects in order to assess them. When the product properties do not conform to the requirements of the product, the design engineer has to change the characteristics. For this identification and analysis of properties, design engineers need short and effective control loops and feedback information about the properties, cf. [Ehrlenspiel 2013]. This allows problems and weaknesses of the product to be recognised earlier. This in turn leads to a reduction of the workload, whilst increasing the options for modifications, cf. Lindemann [2009].

Information about the product properties must be ascertained, in order to evaluate whether the product fulfils the requirements. There are several different methods that can be used, including simulation or testing [Lindemann 2009]. Rodenacker [1970] emphasises the relevance of experiments: "Experimentation is very important for engineering, as all new information concerning a product must be determined by an experiment if it cannot be confirmed in the literature." In this context, simulation, bench testing and field-testing belong to the definition of experimentation. The only difference between all these methods is the analysis model and the environment of each experiment.

The definition of data, information and knowledge is not consistent in knowledge management. There are different definitions, see [Roth 2010], for example. In the context of product development, it is important to concentrate on the information. Additionally, the knowledge and data are also relevant. "The design process is a knowledge-creation and a knowledge-using process" see [Kohler 1990]. Before knowledge can be used, it must be available or applicable. Binz [2011] states that: "Information transfer and decision making play dominant roles in the product development process. Information has to be retrieved, processed and outputted permanently. Thus, knowledge is generated and required to design this process effectively and efficiently, including making the right decisions."

Testing knowledge in particular is defined as: "…knowledge, which is provided for a successful realization of the testing process and knowledge, which is ascertained from the testing", cf. [Karthaus 2013]. According to [North 2011], knowledge cannot be generated without information. Knowledge will be generated, for example, when information is linked with experience or is interpreted in a context. Explicit knowledge can be stored as information, cf. [North 2011]. Information management is a part of knowledge management, e.g. [North 2011], so recirculation of testing knowledge means also recirculation of testing information. The recirculation of information or knowledge from testing in product development has not yet been extensively investigated, see [Wichner 2012]. Even common literature in the field of development methodology (e.g. [Lindemann 2009], [Ehrlenspiel 2013] or [Feldhusen 2013]) makes no statements regarding this context. In single cases, like [Teuchert 2007] or [Albers 2013], for example the methods and tools used for the recirculation are described. These tools are developed for single cases, but it is not shown that there is a general problem.

2. State of the art

The communication of design engineers has been verified as an important factor in many investigations; cf. [Frankenberger 1997]. In this context, Gopsill summarises eight studies performed from 1997 to 2005. The analysis of these studies shows that the consensus is that engineers spend a significant part of their work time for communication, between 25 and 75 %, [Gopsill 2013].

In another study, the communication between the testing department and the product development department has been ascertained in the area of powertrain durability testing in a student research project. The results of this investigation are published in [Akkaya 2012] and [Schenk 2012]. One important factor of this investigation was the documentation of failures during the test. Due to the documentation, there are several failures which could not be assigned clearly. These failures, which represent one fifth of all examined failures, are classified as n.c.d. (= not clearly documented), see Figure 1.

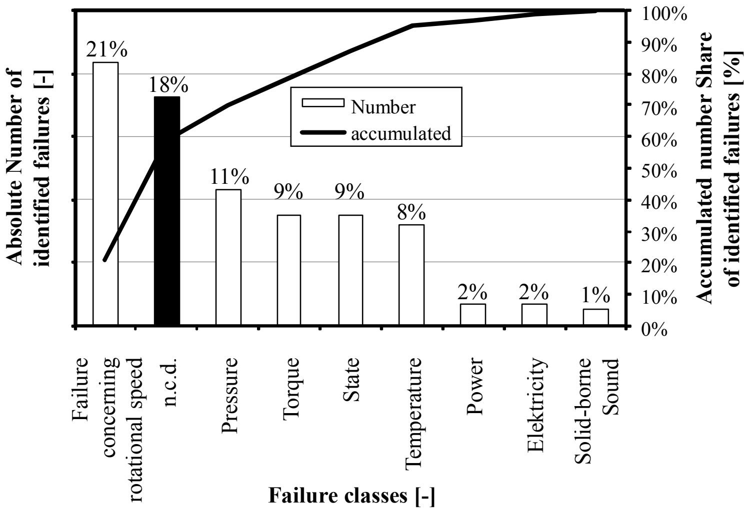

Figure 1. Failure classes and Pareto analysis, see [Schenk 2012]

Although the failures were fixed, the information about them and about the way they are fixed is lost, meaning that following projects cannot benefit from the information. These results show potentials for an effective documentation. These studies only apply to a single company, its structure and the durability testing on test rigs. These results cannot be transferred to other industries, companies or test departments. [Kreimeyer 2006] conducted a similar study concerning the "efficient cooperation between the departments of design and calculation in the product development".
General problems with information flows or with knowledge integration are showed in many references, e.g. [Eckert 2001] or [Kleinsmann 2010], but not for the recirculation of testing knowledge.

3. Motivation and goals

There are many individual studies, see chapter two, but no overview of the recirculation of testing knowledge in the literature, cf. [Wichner 2012]. The motivation for this study is derived from the lack of literature and empirical studies which handle the above-mentioned challenges. Therefore, the state of the art in the mechanical engineering industry on the recirculation of testing knowledge shall be investigated in this empirical study. As a result, the research questions can be stated as follows:

- Main research questions:
  - Will the testing knowledge be used sufficiently?
  - How is the testing knowledge being used in the product development? (knowledge acquisition, knowledge storage and knowledge transfer)
- Sub research questions:
  - Which tools are being utilised to support the recirculation of testing knowledge?
  - What problems occur through the recirculation of testing knowledge?
  - What potential exist in order to improve the efficiency of product development?

From this, the hypothesis is stated as follows: "Knowledge from testing departments and the experience of the testing engineers is not used in product development sufficiently. One reason for this is the inadequate information flow from testing to development. Hence, this information flow has to be supported in a methodical and practical way".

4. Empirical study

There are different methods which can be used to apply an empirical study, see for example [Berekoven 2009]. Due to reasons of the high workload resulting from such an empirical study, only a scientific survey was performed, instead of an observation. Thereby, such surveys can be qualitative or quantitative. The former describes a survey which gives an overview of the elements and the dimensions of the investigation object. The latter represents studies which give a quantitative weighting of statements, characteristics or factors, for example, which could result from a quantitative study. Due to the low number of participants (40) and the limitations on companies acting in field of mechanical engineering, the study is only a qualitative one.

4.1 Method

For this study, all participants were interviewed using the method of a semi-structured interview. The selection process has been performed in accordance with [Berekoven 2009]. The following aspects will support the choice of this method:

- The opportunity to repeat a query.
- The possibility to adapt the interviews for the participant or the company.
- The fact that this is only a pilot study and further quantitative studies may follow. That means this study aims to show the dimensions and elements of the recirculation of testing knowledge.
- The questions of the interview are occasionally very sensitive so that some persons perhaps gave exaggerated answers. That is why in individual cases, the wording and the sequence of the questions had to be changed to get a better answer from the participant.

The major disadvantage of these kinds of studies is their representativeness. This means the statements of the sample group cannot be generalised. Because of the different terms and definitions used in the companies and the ambiguity resulting from this, there is a certain degree of inaccuracy. Thus, the structured interview was preferred in contrast to a questionnaire. The selection of 200 possible participants was conscious and typical, cf. [Berekoven 2009]. Of the approximately 200 invited prospective participants, 40 took part in this study. The interviews were conducted personally. The participants were asked about the suspected influencing factors of the recirculation of testing knowledge, the department, their hierarchical level and the chronological classification of the development process in which they work. Therefore, there was a distinction between predevelopment and development for series production. In addition, the complexity concerning the quantities, the number of parts in the product and the number of persons working in the development were recorded. The distributions of this survey regarding the previously mentioned suspected influencing factors of the recirculation of testing knowledge are as follows, the numbers in brackets correspond to the corresponding number of persons:

- Regarding the corporate departments: design (22), testing (18),
- … the hierarchical levels: consultant (4), team leader (13), head of department (15), division manager (8),
- … the chronological classification of the PDP: predevelopment (11), series development (29),
- … the investigated product groups: See Figure 2. The target was to ask two persons from each company, one from the testing department and one from the design department. In individual cases, this was not possible because the persons were not available.
- … the complexity of the products: See Figure 3. For this, the number of product items, the number of parts and the number of persons in the PDP was recorded. The complexity will be reduced to these three factors to get at least useable values in the interview.
- … the countries in which the participants work: Germany (39), France (1).

The companies as well as the participants were anonymised for reasons of confidentiality of information.

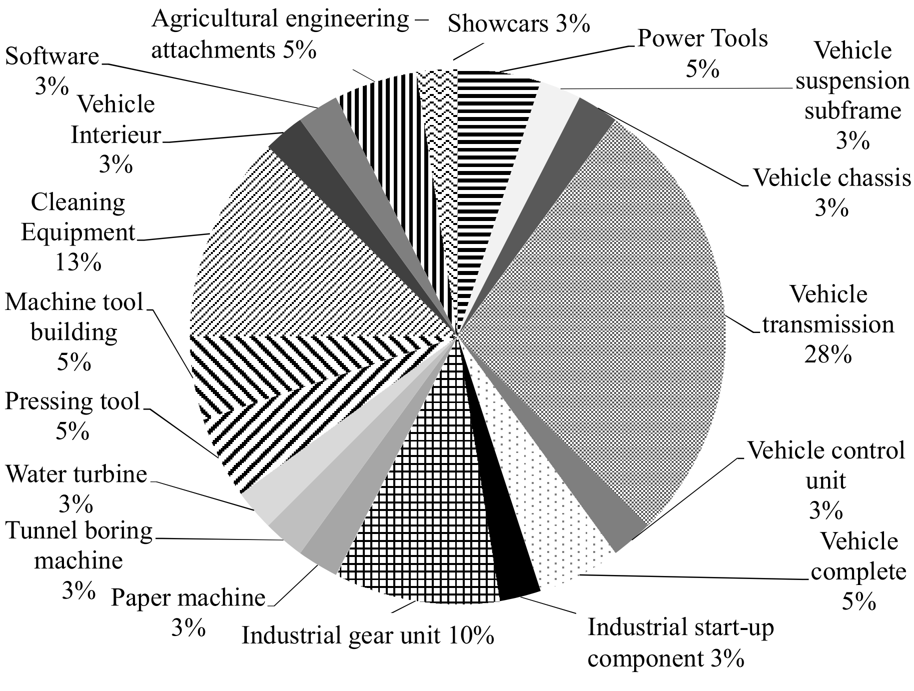

Figure 2. Distribution of the participants into the surveyed product groups

Figure 3 visualises the number of the product items, of the parts and of the persons in the PDP. In order to present the very heterogeneous distribution of product complexity, the number of parts is presented using a logarithmic scale. The number of parts corresponds to the number of different parts of a product. Parts which are installed several times are counted only once. The number of product items complies with both the number of produced products in a year and the planed number of products which shall be produced in one year. Variants of the products are also considered. The area of the circle correlates with the numbers of persons in the PDP. A larger circle represents a larger number of employees. One participant is not visualised in this figure because his product is software, see Figure 2. Software has no physical parts and no items. Since software is not counted as a common part, it is not possible to distinguish between the share of mechanical and software engineering. The complexity of products does not necessarily rise from bottom left to top right. Factors such as the share of software development, the complexity of the working principles, etc., are not considered. However there is a trend of rising complexity from bottom left to top right.

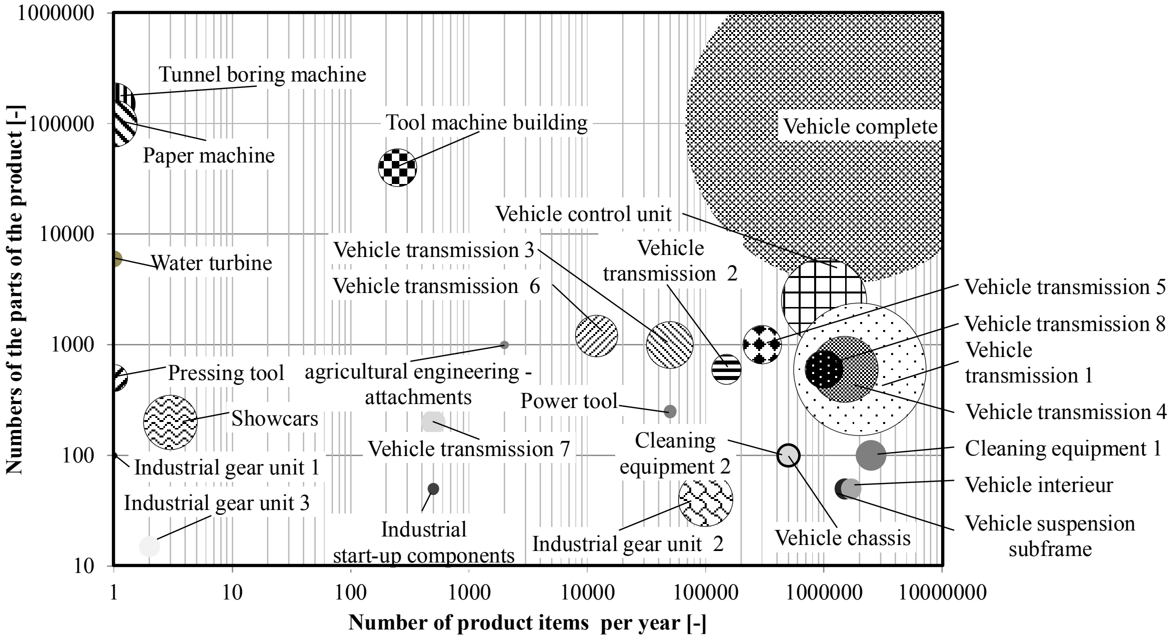

Figure 3. Allocation of the products regarding their product parts, their items per year and number of persons in PDP and resulting from this their complexity

Furthermore, the distribution of product complexity is very heterogeneous. However, the study demonstrates the potential for the recirculation of testing knowledge. The planed duration of each interview was 30 minutes. This moderate time must be maintained in order to be acceptable for the participants. Most of the interviews were performed as individual interviews, only in a single case as a group interview. In accordance with [Berekoven 2009] each interview was recorded and subsequently transliterated. The analysis presented in this contribution is based on transliterated interviews. Due to the confidentiality of the information release, some of the transcriptions had to be released by the companies.

4.2 Aims of the interview

The aim of the interview was to get answers on the research questions from Chapter 3. Therefore, an interview guide was developed to ensure the comparability of the interviews. At this point, the structure of the interview guide has to be mentioned in accordance with [Kreimeyer 2006]. The main questions of the interview guide will be shown next. In certain cases, there are some sub-questions, which are not all presented here:

1. Main question concerning the organisation: “How are the design department and testing department organised in your company?”
2. Main question concerning the process: “Does a standardised process to support the information flow from the testing to the development department exist in your company? Is there any kind of standardized process to ensure the recirculation from testing to development in your company?”
3. Main question concerning the tools: “Which tools do you use for the recirculation of testing knowledge?”

4. Main question concerning the perception of the participant: “In your opinion, does the development department sufficiently use the knowledge generated in the testing department?”
5. Main question concerning the opportunities and improvements: “What do you think are the success factors for an effective collaboration between the design and testing departments?”
   5.1 Sub-question concerning the opportunities and improvements (e.g. there are more sub-questions in each dimension of the problem): “Where do you see potential for a more efficient product development between design and testing?”
6. Main general question: numbers of parts, items, persons in PDP, etc.

In addition, the acquisition, storage and use of testing knowledge and the resulting findings have to be considered. The guideline order on recirculation of testing knowledge is to show the problem and the consequence of insufficient use of testing knowledge, reasons and influencing factors, used tools, potentials for improvement and success factors on recirculation of testing knowledge.

4.3 Results
This chapter details the most important results of this study.

4.3.1 Results and diagnostics
The answers to the main research question, “In your view, is the knowledge generated and used in the testing department sufficiently used in the design/development process?” are shown in Figure 4. Thereby, the participants could choose from the three possible answers given (yes, no and partially). It is important to note that this is a qualitative study. This question was asked to all participants in the same way. The distribution of the test engineers and design engineers is almost identical. There seems to be no dependence on perspective. As Figure 4 shows, most of the participants think that the knowledge is not sufficiently used. Thereby, approximately half of them partially use the knowledge.

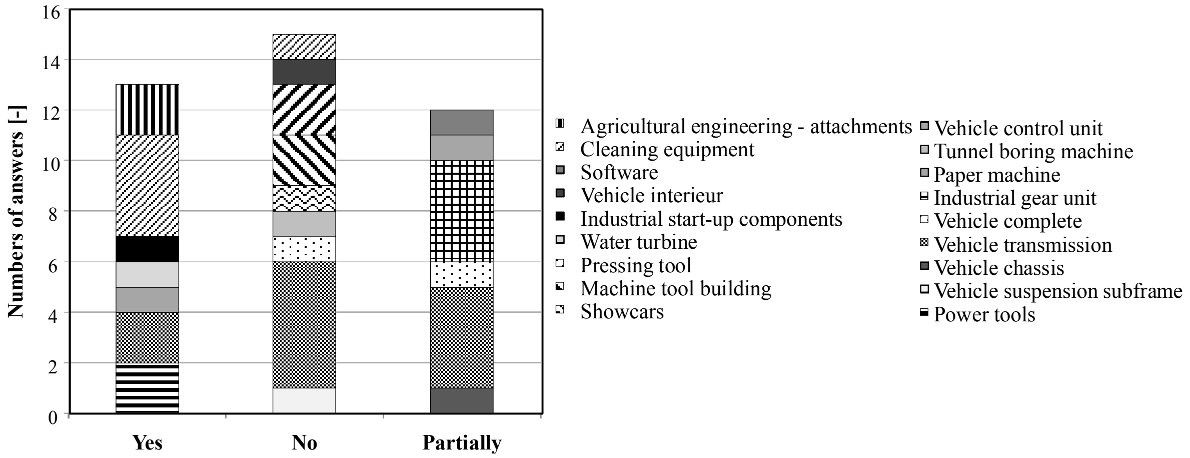

Figure 4. Answers to the main research question

The participants that have answered with yes belong to companies in which the testing technique has grown historically, e.g. water turbines or agricultural engineering attachments. Without testing technology these products would not been developed. Keeping the complexity of the products presented in Figure 3 in mind, there is a tendency for those participants developing products of manageable complexity, for example start-up components, cleaning equipment or power tools, to agree to the research question more often.

Here, many of the persons who answered “partially” distinguished between the recirculation of testing knowledge within one project and the recirculation between different projects. The participants who answered with “no” or “partially” come from companies which develop more complex products, like machine tools or automotive transmission engineering and engineering of industrial gear units.

The answers to the question of whether failures, which already had been identified in a project, are made again will show potential for improvement. 24 of the participants answered with “yes” and five persons with “no”. Failure repetition also is a consequence of insufficient use of testing knowledge. Due to reasons of time, this question could not be asked in each interview.

The further analysis focuses on why knowledge is not or only partially used. The answers here are shown in Figure 5. The most frequently given answers are on the left side. Multiple answers were accepted here. There are several possible reasons why the knowledge is not sufficiently used. The outstanding reasons for the insufficient recirculation are the lack of a suitable documentation of solutions and lack of motivation. The former describe the problem that proven solutions, measures and experiences are not adequately documented for the development department. The latter reason is the lack of motivation of the employees, which includes among others the motivation to communicate or the constraints which result from a spatial segregation of design and testing departments for example.

Next, the information generated in the testing, which is used in the development department, was examined. The information that will be used in development is examined in the next question set.

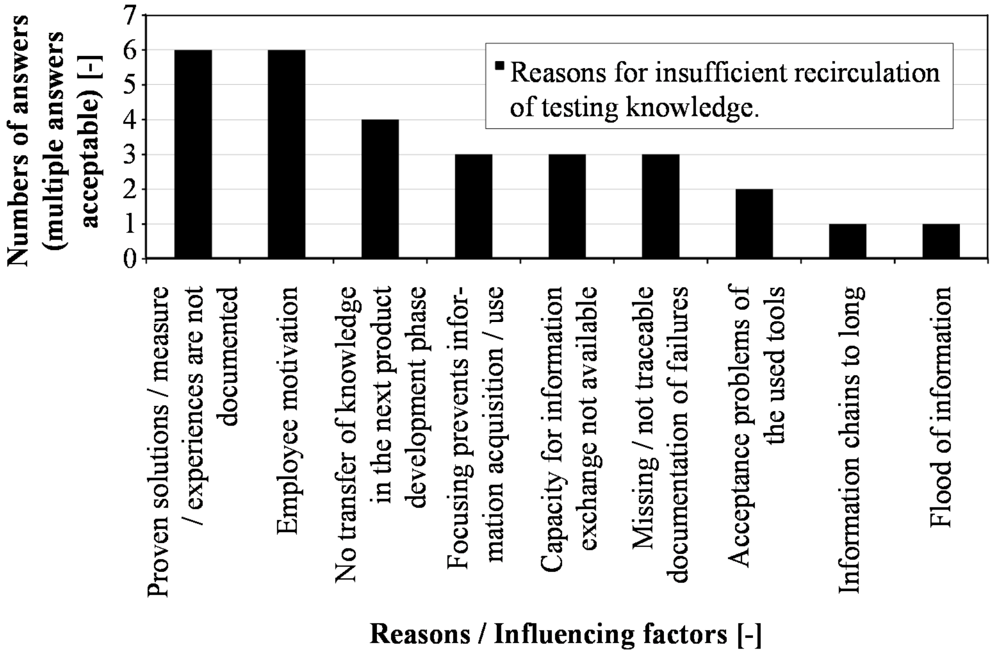

Figure 5. Reasons/influencing factors for an insufficient recirculation of testing knowledge

In the participants’ opinion, the following information from testing is necessary for the product development. Information about:

- degree of maturity trend of the entire product development
- damage/failure situation, e.g. the drive situation of a vehicle in a failure situation
- beginning of damage/cause
- weaknesses and failures of the tested product, the software or the test bench
- physical laws, working principles, influence parameters and their effects
- individual product properties for evaluation of whether requirements are fulfilled
- permitted load collectives and operating conditions of the product
- the quality of computation models in order to verify the models
- potential optimizations/improvements potentials
- optimised geometry of the CAD model, e.g. CAD model of a water turbine.

From the participants’ point of view, the most frequently cited answer was the information about the degree of maturity trend. This was mentioned by four managers. The ranking of the most-needed information depended on the distribution of the sample group. But the absolute ranking of this study is not necessary. What is required to improve the recirculation of testing knowledge is the knowledge of the single piece of information relevant for the recirculation of testing knowledge. Furthermore it is necessary that each person needs additional information in their work, depending on their hierarchical level. The hierarchical level is an influencing factor for the recirculation of testing knowledge.

The **acquisition of knowledge** and its documentation in reports is carried out by testing engineers. In the majority of cases, this process is performed manually. In individual cases, using an automatic process for acquisition and documentation, for example either macros or automatic storage of measurement data are used. The used macros enable an analysis based on the request from the test engineer. The test benches automatically store measurement data at a certain point. Automatically created reports concerning acceptance tests are mentioned by the participants (2). This becomes possible due to the reduced variance of acceptance tests. Nowadays, for the **transfer of knowledge,** classical Office applications (33) like Microsoft Excel, PowerPoint and Word are used. Some companies use self-developed and partially web-based tools (7) to visualise their specific issues. For **storing knowledge,** common reports are used. Therefore, different systems are in use. The participants use (in the study evaluation, the following categories were defined):

- self-developed testing or development databases (24), self-developed "knowledge" databases (2),
- structured storage of reports (9), in particular, the storage of the reports in the "SAP-System" (3),
- storage in PLM-/PDM systems (2),

Key wording and categorisation of test results and reports are used in testing or development databases, in certain cases also with a full-text search. The use of semantic links is not mentioned in this context. In one case, the database had existed for 25 years. These databases are a useful knowledge base for the company today. Self-developed front-ends allow fast access for the engineer to investigate the data of databases. These aspects show that most tools for knowledge storage are self-made, therefore the tools are application-oriented and practice-oriented, as are the methods supported by these tools. This is also logical; in so far the recirculation process of testing knowledge is generic. But the methods and tools have to be adapted for use in each company. That shows there is potential to improve the recirculation of testing knowledge.

The next question was sub-question 5.1 from Chapter 4.2: "Where do you see potential…" The opportunities to improve cooperation and communication between design and testing are shown in Figure 6. The answers were very specific to the single companies and have therefore been clustered in the displayed categories by the authors. For example, one participant saw potential in the standardisation of the damage assessment categories to allow an uniform classification. The most frequently given aspects are in the categories "knowledge management" and "tools".

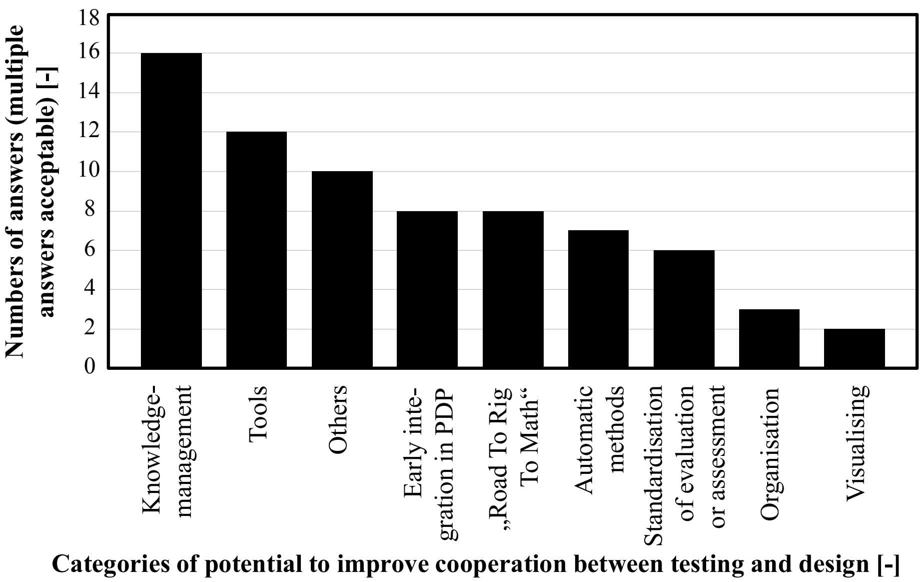

Figure 6. Mentioned potentials to improve the recirculation of testing knowledge

In order to enhance the cooperation between design and testing departments, resulting in an efficient recirculation of knowledge and information, the knowledge about success factors is necessary. The success factors in this context are the aspects seen as relevant by the participants to quickly improve the collaboration between design and testing departments. Here, four possible answers were given (communication, process, data and recirculation of results). The most frequently given answers were communication and recirculation of results. This means that from the participants' point of view, the lack of communication and recirculation of results have to be improved first. One success factor mentioned that concerning class communication is the individual inhibition to get in contact with other employees. Some aspects mentioned by participants as a success factor regarding the recirculation of results are the exact documentation of the situation, the improvement of results documentation and their accessibility.

4.3.2 Conclusion of the study

The study allows some deductions presented in the following:

1. The problem presented in Chapter 2 , that not all failures are sufficiently documented, appears in many industrial sectors of engineering, especially if products with apparently high complexity (high numbers of items and parts) are developed along with complex development processes (high numbers of employees). The product complexity complicates the recirculation of testing knowledge. One challenge is the management of the complexity if faults occur.
2. There are different reasons which complicate the use of testing knowledge. Reasons for this are mostly known and could be confirmed in this study.
3. Some reasons, for example the motivation of employees, cannot or can only be rectified by technical methods with difficulty. However, they can be supported through management methods, like job rotation for example. By using methods of knowledge management, some causes of an ineffective use of testing knowledge could be solved.
4. The question regarding the repetition of failures shows that failures should occur only once. From failures like these, engineers could learn about the product. The rectification of these failures results in an increase of the product's quality. It is not intended that the same failure occur more than once. This opens up potential for further research, including the avoidance of errors and improvement in the recirculation of testing knowledge in the field of knowledge management.
5. It can be stated that the use of databases for knowledge storage is state of the art. The automatic acquisition of information to generate reports for the knowledge transfer from the test bench to the designer is, in standardised cases, used in the late phases of the PDP.
6. There are further research fields concerning the development of application-oriented and practice-oriented methods and tools to enable an efficient recirculation of testing knowledge.
7. Methods from the field of knowledge management can be used to manage the complexity of failure analysis, the result interpretation and the knowledge transfer to the designer, as well as to improve the recirculation of testing knowledge.
8. Companies and their products are individual and the relevant testing information are different, too. So the generic process of recirculation of testing knowledge (acquisition knowledge, transfer of knowledge, storing knowledge and using knowledge) and especially the tools to support this process has to be adapted to each company.
9. The success factors are, among others, the communication between the design and testing department and the recirculation of results. Research in the field of practical methods of results recirculation is necessary.

5. Conclusion and outlook

In the literature, information recirculation is required to increase the efficiency and effectiveness of product development. However, it includes no information on how to ensure this recirculation. The aim of the study was to investigate the state of the art of recirculation of testing knowledge in the industrial practice. A further goal was to show the reasons und influencing factors for the recirculation of the testing knowledge, if this is not used sufficiently. The corresponding hypothesis is shown in Chapter 3. The research questions were developed based on this. In this study, 40 persons were interviewed. The information relevant for the engineers in the design or testing departments was identified. The findings show that this information is not only about product properties. Within the field of participants, it can be stated that the recirculation of testing knowledge in product development should be improved in many cases. The reasons for an insufficient recirculation of testing knowledge were presented. Furthermore, the tools used for knowledge storage and transfer were shown. This study proved the hypothesis. These results must be discussed critically; hence the answers are subjective impressions of the questioned participants. Therefore, the answers are only valid for the sample size. The mentioned evaluation categories are non-exhaustive and can overlap. Further studies can be conducted to prove the results quantitatively. Based on this study, measures for further research should be derived. The knowledge management methods offer the potential to solve the presented problems. However, further research on application-oriented methods and tools for the engineering industry for the recirculation of testing knowledge based on these results are advised.

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