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REUSE OF REQUIREMENTS: AN APPROACH WITH A GENERIC REQUIREMENTS POOL

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ABSTRACT
This paper deals with the implementation of a methodology which describes how to reuse given requirements in an industrial company. With an increasing rate of new products projects and an increased number of variants or product family members, the amount of requirements gets unmanageable. Therefore, there is a demand in the industry for an approach for how to get the raising amount of requirements manageable. We focused on a department in the automotive industry which is responsible for the stability of the electrical power system of a vehicle. We observed several challenges of handling the design process of a battery-electrical car. In order to deal with the challenges, we propose a generic requirements list out of which there can be derived specific product specification lists. We depict a process model which addresses the essential activities of the requirements engineering and management. We describe how this process was implemented in the observed department. The proposed approach reduces the time which is needed to achieve a validated specification list and enhances the correctness of the chosen specifications through known description of the planned concept.

Keywords: requirements engineering, requirements management, requirements reuse, traceability, requirements pool

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1 INTRODUCTION

Nowadays, companies face shorter life-cycles and increased complexity of their products. This puts a challenge to strategic planning and designing departments in achieving the proper characteristics in a product within a reasonable amount of time (Hood and Wiebel, 2005). The long duration of the product development is the greatest risk and is a big barrier (Andrew et al., 2008). Especially in the early phase, knowledge about the goal, environmental restrictions and solution spaces are limited. Designers in the early phase often have a marketing or sales background which goes along with deficiency of understanding technical challenges and their solutions. With consideration of change over time, organizations and human resources, generational revisions of a product could be handled by persons who were not involved in previous product projects and therefore have a lack of experience for the task at hand. The importance of knowledge availability and transparency increases with the complexity of products and organization. Among others, one way to document knowledge about a product in a company is to use requirements and specifications as information artifacts. Systematically elicited and applied requirements with comprehensive formal documentation standards are a transparent way of communicating knowledge within a company and along its supply chain (Ponn & Lindemann, 2011). Requirements are used to set and communicate goals for new products. For every new product - revolutionary or incremental change - , there have to be developed requirements which represent both the strategic intentions of the design project and the technical feasibility of a new concept. With an increasing rate of new products projects and an increased number of variants or product family members, the amount of requirements gets unmanageable. New functions need to be implemented, some requirements remain unchanged or are more ambitious and some become obsolete. Hence, the changes also need to be documented in the requirement lists as the goals and impact factors on the product design have changes. This way product and process knowledge can be made available across various design projects.

Individualization trends for products result in an increase in variant numbers in the product portfolios which copes with differentiating customer needs. Therefore, there is a demand in industry for an approach for how to support the management of the increasing amount and complexity of requirements. Despite the increasing complexity of design processes, the implementation of requirements engineering and management is low as the CHAOS report by the Standish Group (2004) shows. Within the company, this puts pressure on the throughput time of product design processes. Beside common procedures derived from product oriented variant management, another promising perspective is linked to the reduction in consumption of time and resources during the design process. The reuse of already developed parts or modules has promise in easing the job of a designer. The reuse of requirements and its describing artifacts is also a potential source for Lean Design activities which are discussed in Rupp and the Sophists (2009), van Lamsweerde (2001) and Lam et al. (1997). Reusability is viewed as a key factor for increasing productivity and quality (Lim, 1994; Sommerville and Sawyer, 1996). Studies have shown that an increase in productivity is possible by up to 200% with a reuse of requirements (Young, 2001). In order to benefit from the reuse of requirements, there are several preconditions to be considered:

- Formal documentation of a requirement itself: In order to use requirements in a complex reuse process, their content schemes need to be standardized with attributes (Orawski et al. 2012)
- Aligned processes for use: Reuse of requirements need to be implemented in the work of project teams
- Knowledge infrastructure which supports design processes: Resources like databases and requirements managers for reuse projects need to be installed and equipped within the organization

This paper deals with an approach for supporting the reuse of requirements. We take account of these three preconditions and provide solutions and examples for each one. The work aims to present a process that handles generic requirements in an information system, a structured database and enables the designer to derive a product-specific requirements list out of the generic one. The generic pool of requirements supports knowledge management and variant management at an early stage of design. The methodology is to be evaluated in an example of a cooperating company.

1.1 Problem outline

Supported by experiences in the cooperating company and examples in literature (Hood and Wiebel, 2005; Wray, 1988; Lam et al., 1997), the following problems need to be addressed in order to achieve a systematical reuse of requirements along design processes:

- Requirements are documented for subsystems and have little relation to customer requirements or the main goal of the product. As a result, designers only focus on their assigned subsystem without considering the overall context of a customer’s benefit
- There is no systematic hierarchy in different abstraction levels documented in requirements, which could provide comprehension about the goal or scenario involved
- Goals and scenarios are not documented, so requirements cannot be referenced to the original intention
- A consistent traceability of requirements along the design process is not guaranteed. Requirements are not combined with their test cases, which makes it difficult to assess accomplishment
- Changes in requirements cannot be tracked. When a requirement is changed during a project, the effect on the overall goal of the product cannot be determined
- Structured reuse of requirements across different projects and products is not guaranteed. By lack of additional documented information, requirements are constantly recreated although usable requirements are already present

These issues have a major impact on design processes. The inability to trace the origin of a requirement can lead to deceleration of the design process or even its failure (Gothel and Finkelstein, 1994). Many of these issues can be solved by methods described in the following State of the Art in Requirements Engineering and Management (RE&M). In the daily use however, there arises the question how they have to be implemented and used during the design process. This paper provides a promising solution to this problem.

2 STATE OF THE ART

Elicitation of requirements and their characteristics results in specified requirements, which are stored in a database. In Carlshamre and Regnell (2000) and Orawski et al. (2012), requirements are defined as a hierarchical structure of attributes. Attributes can be of a simple or complex nature which is formulated according to the necessity of product management in a company or specific department. Attributes can be either mandatory or optional. It may happen that predecessors exist at the beginning of a design process which can facilitate the requirements analysis.

Scenarios illustrate goals by describing interaction effects between the product and external actors (individuals and other systems) that meet or do not meet their intended goal. The definition of scenarios usually leads to a refinement of known goals, a change of known goals and the identification of new goals. The combination of goals and scenarios provides a good basis for the definition and the practical realization of solution-oriented requirements (Pohl, 2008; Rupp and the Sophists, 2009). Scenarios describe the fulfillment or non-fulfillment of goals. Thus, scenarios are more concrete examples to goals. Here, the description is often idealized and episodic. It is recommended to use scenarios as a preliminary step before the actual elicitation of specific requirements. Carrol (1995), Potts (1997) and Haumer et al. (1998) describe that scenarios state an important role as "middle-level mediator". Scenarios are much more specific than goals and more comprehensive than solution-oriented requirements.

Solution-oriented requirements are obtained on the basis of goals and scenarios (van Lamsweerde and Willemet, 1998; Haumer et al., 1998) and define the reference for design (Pohl, 2008). The combination of objectives, scenarios, and solutions-oriented requirements allows for a comprehensive overview from the abstract goal to the specific requirement.

The quality criteria for proper elicitation can be broadly classified into three dimensions:

- Content dimension: checking that all relevant requirements are applicable and are documented in the required granularity
- Documentation dimension: checking whether requirements have been documented according to the documentation and specification rules
- Conformity dimension: checking whether the documented requirements are matched and agreed with the participating stakeholders

An important part of the documentation of requirements is the structural form in which requirements are documented (IEEE 830-98). A fixed prescribed template ensures that all relevant goals are considered and described. The template is described in detail in Davis (1990). While the activities of requirements elicitation and documentation of information is conducted, the use of attributes is essential (Hood and Wiebel, 2005; Ebert, 2010; Orawski et al., 2012) and eases filtering, sorting and shifting of requirements. Wiegers (1999) defines seven different categories of attributes. An example is traceability. Each involved stakeholder is supposed to have the opportunity to know the goal a requirement wants to achieve. It includes maintained traces among the requirements: When a requirement is changed, this may also lead to a change of other requirements, because they are not always independent from each other. The technical implementation of traceability can be done with manually created traceability matrices, hyperlinks or in-/out-links (Rupp and the Sophists, 2009).
Further, handling requirements and lists requires attributes like versioning and conditions. Version and variant management is widespread in industry. The term platform strategy in software engineering runs under the term of product line development. Versions are introduced at different times in the market, while variants are developed for different needs and for different markets (Zamirowski and Otto, 1999). Additionally, baselines play an important role. Baselines serve the purpose of keeping the content and condition of an information consistent for a certain time. It usually represents the binding form of the information at a point of time, this information represents may also be referred to as active information. Through the categorization of requirements artifacts and in combination with traces, it is easier to implement a change management.
Verification checks whether the results meet the specified requirements. It is therefore considered whether the development has created the right product. Verification checks both the final product by means of system tests results and individual work on subsystem components. Thus, the verification runs consistently at all stages in the development specification (Pohl, 2008).
Reusability for example in software design is viewed as a key factor for increasing productivity and quality (Lim, 1994). However, it is an important factor influencing the design decision, as the reuse is always connected with some extra effort in preparing the decision. Nevertheless, in the long run, reuse leads to scale effects as a solution can be checked for reuse in various products. Looking at the life cycle of a product, reuse achieves a fair advantage due to ensuring higher solution quality. Lam et al. (1997) defined ten principles for reuse. In the following, the ten rules are listed:

1. Avoid careless generalization
2. Identify system modules in order to maximize the reuse
3. Rate reusable technology in terms of process change, and not just reuse potential
4. Domain aspects serve as a starting point, which are used for the organization and structure
5. Justified abstraction is an efficient method for generating requirement templates
6. Requirement patterns often occur after the working on a subsystem
7. Explain the context of requirement-use to prevent misuse
8. Parts of the RM process are also reusable
9. Create interfaces for requirements causing variants
10. Anticipate in advance the impact of reuse in the design process

To the above rules may be added, that the reuse candidates should be stored in a reference database or in a reuse pool. For the management of reuse candidates, one person is required to be a reuse manager or a so-called librarian. This person needs to be recruited from the already experienced staff and is equipped with plenty of time for this role (Rupp and the Sophists, 2009).
The process of implementation for archiving reuse benefits is divided into three phases:

- Analysis of existing reuse candidates
- Organization of the reuse candidates
- Synthesis of existing reuse candidates

Basically, the benefits will not show immediately, but it is important for the success that this process is performed continuously. Iterations through accomplished projects produce a more and more complete databases and provide a growing source of reusable requirements. Thus, users can access a larger pool of effective reuse requirements and elicitation of new ones significantly shortens (Rupp and the Sophists, 2009).

3 METHODOLOGY

This chapter develops a methodology for reusability of requirements supported by a generic requirements pool and is enhanced by a process which explains how to implement reusability systematically in a design project. The overall idea is depicted in the following figure.

A comprehensive RM needs to cover all phases of the product design phases and to support involved activities. It also serves as an interface between the development, strategy, production and sales (Gausemeier et al., 2006). The task is to establish an information database which provides easily access for users from various disciplines. One possibility of such information platform would be a RM tool like Doors, as many companies perform their RM already in such a tool. Thus, parts of the required information in requirements are already documented in a tool and only need to be expanded.

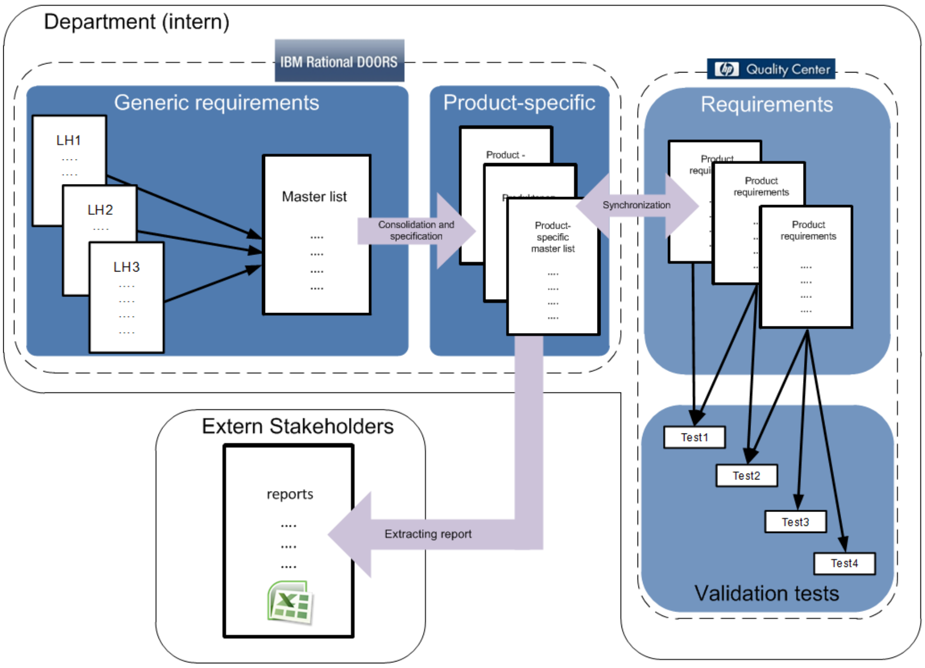

Figure 1. Concept of integrating a generic requirements pool into the requirements environment

3.1 Generation of a systematical collection of generic requirements

The primary demand for developing a faster and more cost-effective RM should be done by a self-consistent and complete requirements collection. This requirement collection is called "generic", because it stores product-neutral requirements. The challenge of choosing the right requirements is discussed in the following bullet points:

- Requirements should be independent of a specific project, product or organizational structure as for a starting point to determine a list of requirements for the initial phase of a design project
- They should be structured in a way that traceability between requirements artifacts is guaranteed
- The allocation of requirement and its verification should be possible
- Deviation of a product-specific requirements list out of the generic requirements pool should be possible. In addition, deviation should support version and variant management
- Implementation of a generic requirements pool should be easy, error-free and consider modular classification of its contents.
- Responsibilities of involved stakeholders need to be communicated and its demands respected

3.1.1 Requirements elicitation

An inclusion of new requirements into the generic list is to be kept in mind during elicitation. This involves products or its variants. It makes sense to distinguish whether the requirement is supposed to specify the whole product portfolio or only some variants. A distinction between fixed characteristics, mandatory alternatives or optional features is of advantage for identifying candidates for the generic requirements pool (Lindemann et al., 2006). In order to attribute a variant-specific requirement, a category and its context should be documented.

3.1.2 Structuring requirements

The foundation for target-oriented requirements elicitation is considering target properties and a direct reference to the final product and its characteristics. Thus, every stakeholder knows the entire product by a clear assignment of goals and scenarios. Further, a hierarchy oriented towards a product portfolio in the documentation structure should be chosen with different levels of abstraction.

3.1.3 Traceability

Structuring of requirements attributes creates a traceability of requirements on different levels of detail. Hence, a traceability matrix should be generated which enables to track the relationships between individual requirements and their influences and can be documented via links in the generic requirements pool.

3.1.4 Assignment of attributes and additional information to requirements and generic requirements pool

Additional information is added to the generic requirements pool and included requirements to meet demands of RM activities. For structuring requirements, it is helpful to assign e.g. goals and scenarios as attributes, which is depicted in Figure 2. Further, attributes are given by Pohl (2008) and can be assigned during the elicitation of requirements or the collection of requirements for the generic requirements pool.

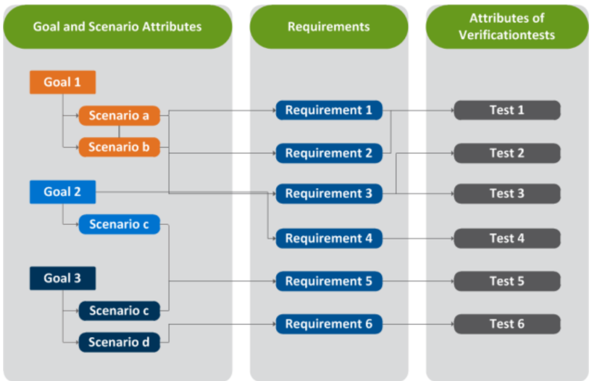

Figure 2. Connection between goal, scenarios, requirements and validation

3.1.5 Reuse aspects:

In order to benefit from reusable requirements, it is important to attach information in which kind of project the requirement can be reused.

3.1.6 Characteristics of a RM tool

As for the elicitation of requirements, there are quality criteria for their management as well. These serve the purpose of minimizing project risks and provide every employee with the necessary information. Rupp and the Sophists (2009) defined the following quality criteria:

- Clear structure
- Meaningful members
- Project-related attributions
- Specific processing
- Restrict access information from a central source
- Ensure data security

The structure and organization of requirement attribution, enables filters and sorting function to support the user. The RM tool itself supports the following activities (Hoffmann et al., 2004):

- Support for the collection, specifying, grouping and attributing of requirements
- Support the derivation of requirements in higher detail levels with a continuous adjustment of attributes
- Provide test specifications with a link
- Support traceability

In addition to requirements handling, a user-friendly RM tool is equipped with multi-user operability, view management and baselines and with further features described in Hoffmann et al. (2004).

3.2 Application process for generic requirement pool

The generation of the generic requirement collection is conducted from all documented requirements which have been prepared for reuse and released by a baseline. By selecting a suitable method of linking or batch processing, requirements can be consolidated into one collection. After the target-oriented filtering and sorting of the requirements with project-specific sorting algorithms, a product-specific diversion can be generated. Filtering and sorting is done according to the relevant attributes, goals or scenarios in the filter function of the RM tool. The resulting product-specific requirements document contains all the information that is stored in the generic requirement collection. However, it needs adaption for further use as some information may vary for each project. This requirement list can now be used for the design of a product and if required supplemented or refined. Following the project initiation, all requirements are analyzed. After consolidation and specification of all requirements, they are examined for consistency. After a positive result, the requirements are included in the project coordination. The process itself was modeled in high detail using event driven process chains. The following figure just depicts the summarized process.

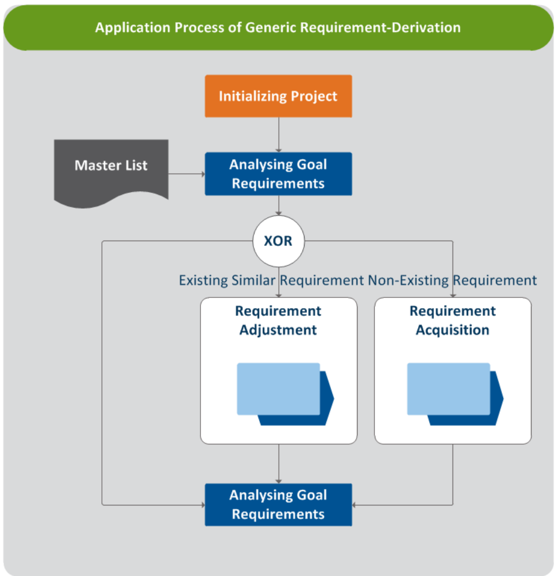

Figure 3. Application of the generic requirements pool

4 RESULTS AND CASE STUDY

The results are shown along the description of a case study, which was conducted in the department of electrical power system within a car manufacturer. This department faces a strong increase in complexity and amount of projects, because of the popularity of new electrically supported functions in modern cars. The provision of stable energy levels is one goal among a lot of others. The implementation of a generic requirement pool in the department-specific form of a "generic master list" was necessary in order to handle future design projects and maintain certain quality standards. This is no longer based on components and subsystems but on its goals and intended functions. Goals, scenarios and properties were identified in the existing requirements and assigned to each requirement. Achieving traceability was achieved through various levels of abstraction. The structured requirements attributes were selected for the needs of project management and the design. These attributes provide an essential overview of instantaneous information. The suggested number of elicited attributes was not reached for cost reasons as the implementation of the generic requirement pool was an experiment which was not conducted with all the functions the department was responsible for. The RM tool allowed the company for large use of the generic requirement pool. However, the interface between the utilized RM tool and the tool which stored verification tests and their descriptions, did not automatically synchronize. This had been done manually. A detailed application process for the generic master list of the department has been defined. From project initiation to the consolidation of the product-specific requirements document, there were necessary steps for handling the amount of requirements. This application process intends to facilitate the initial stages of product design with access to existing requirements and ensure as far as possible the integrity of the product-specific requirements. Since the reference structure is identical for all requirements, all stakeholders involved had access to the same amount of information. This allowed for easier communication and increased the understanding of the implementation process of the generic requirement pool.

Experiences during long-term application

The implementation of the generic master list in the entire process, the acceptance by the employees and the completeness of content are long term processes whose effects were analyzed through the conduction of interviews with the involved employees. These interviews within the department which implemented the proposed approach were held one year after the exemplary implementation.

As already anticipated, the change in the daily work of the employees regarding processes, responsibilities and effort in changing existing requirements into the new structure were considered deprecatorily among the involved persons. Additionally, there must be considered added work flow friction by convincing people to install new concepts which goes with a good deal of communication time. Beside of these general implications with changing work processes which are on a daily basis, it was interesting to receive more positive feedback from persons who were involved in the preliminary elaboration of the needs for the approach presented in this paper.

During the application time, there were discovered problems with the utilized software program to handle different versions. This resulted in the addition of required attributes and the change of handling processes. The interviewed persons regarded the approach as positive once it was installed and disposed from initial errors. This mainly based on the reduced work time in starting a new project for which requirements could be reused and the communication among the engineers on the subject of more consistent requirements as misunderstandings about the contents of a requirement were reduced.

The roll out of the approach into other departments either isolated or connected with the observed department have not happened yet at the moment this paper was written.

5 CONTRIBUTION

While implementing a goal-oriented requirement principle at a department of a car manufacturer, various findings are collected. Strong growth in the size of the department with an organizational and component-based perspective generates various inconveniences in the requirements elicitation and management. The study has shown following points. An immediate change in the existing design process is as impossible as the immediate change in the specification structures. The implementation is facilitated by the use of an existing RM tool. It involves extensive effort to convince various internal and external stakeholders of the project. New responsibilities and new interfaces have to be defined and adopted in different departments units. This is a great challenge for the people involved. Adoption needs strong encouragement and acceptance has to be gained. Training courses could be useful for this purpose. This change in the fields of work and responsibilities requires an acceptance of the employees and a lot of persuasion. This applies as well for the way how people think and understand requirements because it originates in the culture of a company which is even harder to change.

In addition to the usual methods of RE & M from the literature, it is useful to examine reuse concepts to investigate the handling of requirements across multiple product projects and to develop an appropriate methodology for dealing with such requirements. This was done in this paper. The RE&M is made up primarily of two domains: requirements analysis and handling of the requirements. Elicitation of requirements with attached attributes is helpful in understanding a product undergoing a design process. The attribution of requirements can serve the RE&M equally, since the status of the agreement or the validation of the requirement can be documented. In addition to change in management, which is supported by traceability of requirements attributes, the project management, the version and variant management, and verification alike in RM are supported by implementing reuse principles. While examining different areas of the RE & M, the question arose whether the skills required for the use of the RM-tool could be described in an application process. Here, the structure of the existing requirements was adjusted to a goal-oriented form and implemented in the RM-tool. The required goals were achieved largely but interfaces between tools and the representation of a complex network of structural problems could not be solved in the short time of the study. The completeness of the generic requirements set in the given time could not be fully verified. It can be stated that the collection is only possible through a continuous, iterative operation and improvement by experience. A holistic RE&M opens a lot of opportunities. However, the implementation in a routine environment is associated with many challenges.

In sum, reusability by a sophisticated documentation of requirements and a synchronized process supports the comprehension of planning and controlling design projects.

6 INSIGHT DURING APPLICATION

From the application of the newly implemented requirements engineering and management, it can generally be said that the effort to implement a good RE & M is dependent on one major factor: the importance of the RE & M system and its output for the core business of the company. A company which has 100% customer orientation will require an efficient running requirements management to derive system or component functions from customer requirements. These companies will regard a good requirements engineering and management as essential and the management will support responsible persons in conducting their work. To achieve this goal it is mandatory not to change the responsibilities permanently and further to describe the task of the responsible persons in an adequate job description containing the tasks and interfaces. Implementation of newly described tasks and interfaces require a certain amount of time for being mastered as it describes a constant learning process.

To increase the understanding of requirements and their communication, it is further mandatory that requirements are understandably and explicitly described. Otherwise, there is a risk that imprecise requirements will be used in a row and interpreted differently each time or worse interpreted in a wrong way. Therefore it is essential to intense the effort on formulating the requirements with care and structure.

Concerning the tool support for the requirement management, it can be said that the functionality and complexity of the supporting tools are dependent on the skills and experience of the employees. Using a complex and highly functional requirements management tool should always be evaluated with the tool chain of the company. Therefore the tool support and implementation should always take into consideration the development stage of the tool chain and its processes.

7 FURTHER RESEARCH

In future, automatic synchronization of data would ease the work of consolidating the generic requirements pool, improve robustness and reduce the mistake probability. Although a basis for the goal-oriented requirements engineering has been discussed, nevertheless, appropriate methods for implementation need further research as psychological and project management issues have been neglected in this study. Initial projects with the optimized pool structures should be conducted for determining advantages and disadvantages with existent documentation standards. In addition to the implementation process, a long term strategy in the choice of attributes and structure of the generic requirements pool should also be developed, implemented and observed.

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