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ADAPTING A DESIGN PROCESS TO A NEW SET OF STANDARDS – A CASE STUDY FROM THE RAILWAY INDUSTRY

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1. Introduction

Technical products usually have to meet requirements defined by laws and standards, which, on a national as well as on an international level, do not only address technical aspects of the product, but also its development process. These regulations include environmental laws, common quality and safety standards (e.g. EN ISO 9000, CE [The Council of the european communities, 1993]) or application specific safety standards defined by organizations such as the FDA (Food & Drug Administration) or the FAA (Federal Aviation Administration), just to name two examples from the United States.

Following standards is especially important when developing safety critical products, such as railway applications (switches, signals, etc.). A few years ago, there were only a few, quite differing national recommendations and the guidelines of the UIC (Union Internationale des Chemins de Fer) to ensure the safety of these products. Since coming into effect in 1999, EN 50126 ff. [EN 50126, 2000; EN 50128, 2001; EN 50129, 2002] – initiated by CENELEC (Comité Européen de Normalisation Electrotechnique) – define procedures for the management of the reliability, availability, maintainability and safety (RAMS) of such products to ensure their safety over their entire life cycle. The CENELEC-standards are therefore the common European basis for the approval and authorization of railway applications. However, these standards focus on documentation and validation, but do not provide methods on how to actually develop the product.

This study examines the implementation of a new Process Framework for railway applications, based on the CENELEC-regulations, taking a manufacturer of railway applications (Siemens TS) as an example. Due to the new and comprehensive safety standards, the company's development process, documentation process and supporting tools had to be replaced or adapted.
As a result of the newly introduced process, the workflows of the project managers and the development engineers changed in part dramatically.
During the first product development projects that were conducted according to the new Process Framework, difficulties occurred, which lead to exceeding the planned costs. This was the reason for the company to ask the authors of this paper to investigate the problems that occurred. Apart from the degree of implementation within the organisation, this study also looks into the quality and efficiency of the product development processes and points out room for improvement, where appropriate. Special emphasis was put on discrepancies with planning requirements were closely examined for which concrete improvement measures were developed.

2. Research Objects and Methods

The Process Framework, which defines the product development and documentation processes according to the CENELEC-standard, served as the study's starting point. Apart from EN 50126 ff., the process is based on a generic life cycle model (V-Model [Dröschel & Wiemers, 1999; Stevens et al., 1998]), which has its origins in software engineering. It is divided into a specifying, planning branch (top down) and an integrating, validating branch (bottom up). Requirements-, architecture-, design- and implementation phase are located on the descending branch, testing-, integration and validation phase on the ascending branch (Figure 1). These phases are again divided into several process steps that describe the activities and expected results at each step of the process. All phases are concluded with a review. This process model, which can be consistently applied to mechanical and electronic products, is the foundation of a division-wide standardisation of the development process in the company.

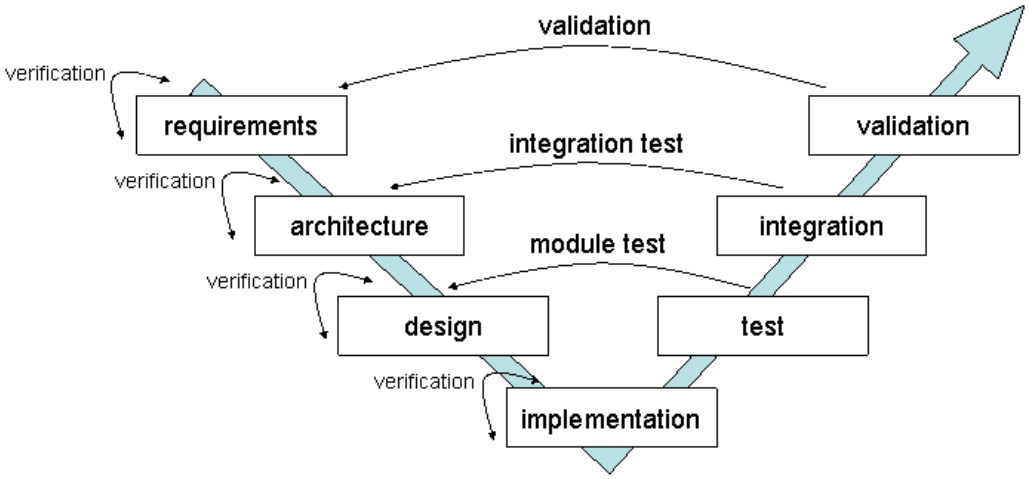

Figure 1. Phase model of the development process [after company documentation]

The Process Framework aims at fully meeting the requirements of the new (i.e. the CENELEC-) standards [EN 50126, 2000; EN 50128, 2001; EN 50129, 2002], and keeping product development traceable by providing for a complete documentation. In order to meet the safety requirements of the referenced standards, it is essential to plan validation tests assigned to the requirements right from the beginning of product development [EN 50126, 2000]. Once the development is complete, the results are examined by an appointed validator or the customer. During the process, the results of each phase are verified by review once complete. An in-house reviewer assures the correctness, traceability and sufficiency of the results based on the initial documents.

The study was divided into three phases (Figure 2). In the first phase, the new Process Framework was analysed based on the previous and new process description as well as on discussions with the main author of the process description, taking into account the appropriate standards. The practical implementation of the previous and the adapted Process Framework was evaluated by analysing two past and two current reference development projects. For that purpose, the project managers were interviewed and available documents analysed. The theoretical examination of the Process Framework was followed by the analysis of past and current projects that were in part carried out according to the new process description. Each time, the project documentation was handed over, discussions took place with the respective project managers, thereby gaining insight to the projects that could not have been retrieved from the documents themselves.

Based on the results of the first phase, assumptions were devised to explain possible reasons for the problems with the new Process Framework. These assumptions were validated by an interview survey amoung 21 employees in the second phase. In the third phase of this study, actions were recommended on how to solve the experienced problems.

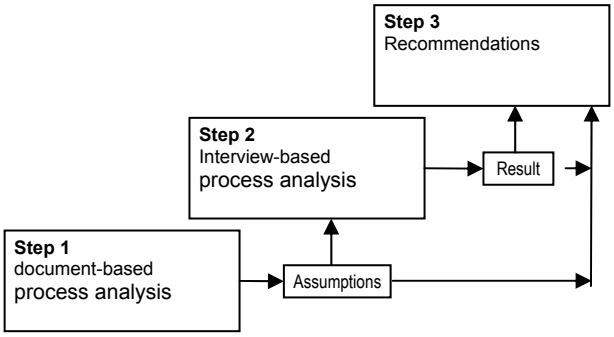

Figure 2. Steps of the study

3. The investigation

3.1 Document-based process analysis

The analysis of the new Process Framework showed that the prescribed steps of documentation and validation are more extensive than the previous Process Framework. The given process steps of the new Process Framework meet the requirements of the CENELEC-standards; the actual product development however, is only rudimentarily integrated into the process. The process steps describe how to prepare documents for safety certifications such as testing specifications and give instructions for verification and validation. Designer tasks such as the detail design of parts or the creation of manufacturing documents are therefore only a small part of the process. The new Process Framework gives no support in terms of development methods to increase the quality and effectiveness of product design.

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Four product development projects were examined: two of the developments were LED railway signals for different applications. One project dealt with the development of a track occupancy indicator. The fourth project was a purely mechanical development: a lever mechanism for a rail switch. It was possible to gain an insight into the practical implementation of the previous and the new Process Framework. Here, for the first time, problems with the application of the process became apparent, causing time losses and therefore increased costs. Although these problems were partly due to a lack of experience with the newly introduced process, certain difficulties resulted from the process being too impractical.

Some other pieces of information that were retrieved in this phase of the study are given in the following:

- The reviews, verifying each phase, lead to a delay in the projects. Although the Process Framework prescribes qualified, competent reviewers with sufficient capacity and time for appropriately conducting a review, the reviewers were not adequately integrated into the projects. Lacking background knowledge belonging to the information contained in the documents that were passed on had to be compensated. As long as a review is pending, the completion of the according phase cannot be confirmed to the management.
- The Process Framework does not mention the possibility of development phases being parallel. When a phase is not wholly complete (confirmed by a review), the following phases are subject to planning uncertainty, which, in turn, can lead to delays or, in the worst case, the standstill of subsequent phases.
- In the reference projects that were examined, existing requirements were often changed or new requirements added by the customer (“feature creep”). Consequently, the requirements phase

was often incomplete even after a considerable period of time since the start of the project and at the beginning of subsequent phases, which lead to parallel project phases. Therefore, in terms of requirements management, product development was reliant on marketing or external groups, whose processes were not optimally harmonised with the processes of product development. Consequently, important information, documents and decisions were always handed on later than necessary and therefore the requirements for athe project could not beon schedule not given anymore.

- The additional documentation required by the new process was felt as a burden by the interviewed project managers. In one project, considerable, unexpected additional effort arose from re-using existing system components. Since these components were developed before the introduction of the new Process Framework, no safety proofs existed that met the requirements of the new Process Framework. These proofs had to be prepared again, which took several man-months.

The above analysis results were used for the upcoming interview survey by devising assumptions for possible reasons for the problems experienced problems. A few examples for devised assumptions are listed in the following table 1.

Table 1. Assumptions (some)

Analysis result	*Assumption*
The Process Framework was not used as a guideline for the whole product development process but rather as a directive for the "additionally" required documentation.	The Process Framework is not complete. It was only created for covering standards, guidelines and regulations.
The experienced difficulties could have their cause in lacking knowledge about the Process Framework and its objectives.	The Process Framework is inappropriately conveyed to the users. Therefore, its use leads to problems.
The reference projects repeatedly suffered from "feature creep".	Uncertainties about customer requirements lead to problems in product development.
The traceability of documents and reviews accompanying the process – both required by the Process Framework – demand a considerable amount of effort from the developers.	Despite the possibility of an adoption to the project complexity, the documentation is too time-consuming, especially for smaller projects. Therefore, too little time is left for core processes.

3.2 Interview-based process analysis

In the following, the structure of the interviews as well as some of the most important results are given.

3.2.1 Interview structure

In order to retrieve the widest spectrum of information possible, structured interviews were conducted [Mehrmann, 1995]. The questions were not read to the interviewed persons in a fixed order, but served as a guideline for the interviewer. Therefore, associative thoughts of the interviewed employees could be recorded as additional information. Apart from direct answers to the questions, numerous question-independent statements could be collected.

In each of the 21 interviews, employees 42 questions were asked, addressing for example personal data, project experience, use of the Process Framework as well as work contingents and -efforts. Due to the problems with requirements management that were identified in the reference projects, 13 questions were dedicated to this topic. The issues of project planning, reviewing, documentation and document management were also dealt with.

Due to the focus of the survey, the interviewees were almost exclusively product developers. with a background in mechanical engineering, electrical engineering, IT or communications engineering.

3.2.2 Process training and access to information on the pescribed process

The interviewees acknowledged training as an appropriate method for introducing new processes. Although a well proven method for introducing employees to the new process, training is not seen as a sufficient preparation for actually working on projects according to the new process. In many cases, it took months before the content of training sessions could be applied practically with much of it already forgotten.

According to the suggestions of the interviewees, the explanation of the development process should be substantiated by examples. For this purpose, a small "showcase project" in which the essential steps of a development project are presented or, better, exercised could be a solution. Also, completed projects that were carried out according to the new process guideline could serve as an example for other employees.

The interviewees preferentially used the intranet to access information on the prescribed process workflow (Figure 3). The printed documentation of the Process Framework was rarely used, since its structure and layout was considered unsuitable to read it from beginning to end. Due to the everyday lack of time, there was the wish for a comprehensible "How-To".

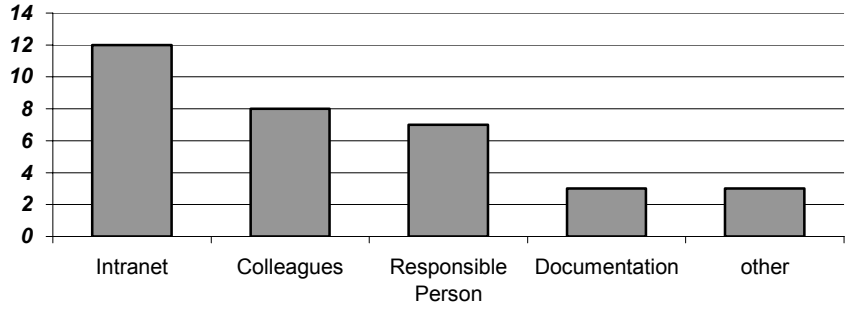

Figure 3. Information sources

3.2.3 Attempting to create a standardised process

The new Process Framework constitutes the company division's attempt to establish a general standard for all product developments. For that reason, this process is supposed to be suitable even for very complex systems. Even though the Process Framework offers the option of adapting the process to the complexity of the product, it is perceived as too extensive by the interviewees, particularly for "small" projects. The interviewed employees were convinced of the usefulness of adapting the process, since this procedure, however, requires substantial process proficiency, it was only partly mastered.

For smaller projects, there was the wish for a "light version" of the process. The interviewees demanded process descriptions that take into account different project conditions in the first place.

3.2.4 Requirements management

According to the interviewees, changed product requirements were the main culprit for an increased project complexity. Hence, these changes were caused by unclear or altered customer demands or – due to the long product life cycles in the railway sector – a result of a changed market, technological innovation or changed standards. However, the change request procedure for more than minor changes of the requirements, as prescribed by the Process Framework, was not consistently followed – the effort connected to the new process discouraged everyone involved. The concern of having to document own mistakes further increased the reluctance to initiate a formal change request. In the past, project managers delayed the initiation of change requests for that reason – until a point was reached, where it was impossible to ignore the problems.

3.2.5 CENELEC-related work efforts

From the employees' perspective, project complexity increased mainly as a result of higher requirements for the documentation of the necessary safety proofs. Averaging the interviewees' work distribution disclosed that only 33% of their working hours are spent on product development (Figure 4).

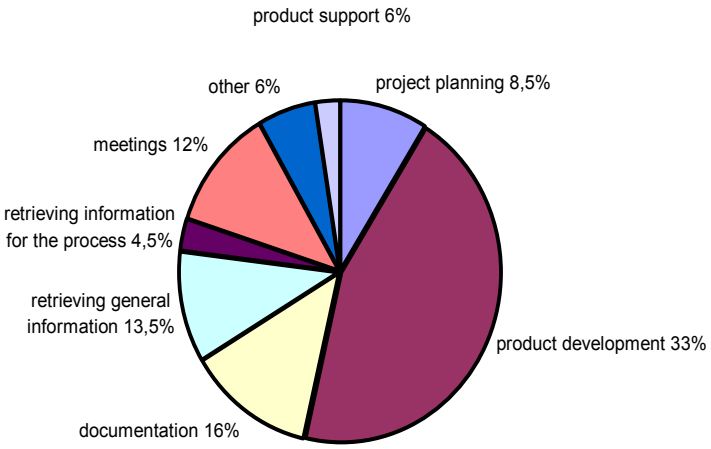

Figure 4. Average distribution of work efforts

According to the interviewees, the increased efforts for RAMS and quality management (QM), which are now required for the safety proofs, were underestimated already at the stage of project planning. The procedures for RAMS management and consequently the involvement of QM, however required by the CENELEC standards, calls for the participation of several departments, which, in the opinion of the employees, leads to a considerable increase of project complexity. The reasons were not only seen in a more time-consuming communication with other departments, but also in project outlays that had to be brought to account by these departments.

3.3 Recommendations

- The comparison with the requirements of the CENELEC standards [EN50126, 2000; EN50128, 2001; EN50129, 2002] shows, that the newly introduced Process Framework meets the requirements of the standards, renders a straight workflow and ensures a consistent and complete documentation. It is therefore suitable as a foundation for a CENELEC-compliant product development process.
- A methodical support of the development process by providing methods and tools is currently not given. It could, however, contribute to a more effective process [Pahl & Beitz, 1996; Ehrlenspiel, 2003]
- The Process Framework does not provide for a smooth development project. The theoretically optimised procedures of the process ensure a certain protection against unexpected mistakes and safety risks during the product life cycle, but can, however, lead to increased project costs. If the verification, which recurs in each phase, is understood as a rigid schema and it becomes necessary to put the completion of a project phase before the beginning of another phase, the phases can only be finished sequentially, which can mean a tremendous loss of time. Having project phases partly parallel should therefore not only be a practice to be tolerated, but integrated into the process by a flexible adoption of phase planning to the project.
- The aforementioned recommendation could to a certain extent be achieved by an proficient project management and experienced project teams. An improved process that eliminates possible mistakes with project management, seems in the long run more promising, however. The approach of Simultaneous Engineering [Ehrlenspiel, 2003; VDI, 1992] could help to

avoid delays in product development projects. Still, in order to achieve an even higher level of process stability, a reference process that serves as a guideline for the entire product development process is expedient [Longmuß, 2003].

- Standardising the product development process in its fundamentals, regardless of the type of product, can increase the project complexity. Therefor, a compromise must be found to optimally adapt the process to the product and minimising project complexity without unnecessarily complicating the process. Tailored sample processes for different product types could exemplify the product development process.
- The development process can only be systematically enhanced, if the employees are sufficiently trained and motivated [Knoche, 1993]. A training schedule that harmonises with the planning of new development projects proved important. The scale of the training should furthermore be expanded: the current one-time training, which takes four hours, proved to be an appropriate introduction to the new process. However, to convey a genuine understanding of the process, more extensive trainings are needed, possibly with integrated workshops. Using small sample projects as example, the Process Framework could be illustrated.
- A coaching of employees by senior experts or "multipliers", would improve the exchange of experience within development processes. Among the interviewees, especially inexperienced project managers hoped to gain more certainty when planning carrying out projects with the help of such coaches. In larger departments, there could be exempt staff members with counselling tasks for projects. Small departments, should at least appoint an employee with process experience, being at any project's disposal.
- According to the results of this study, especially the requirements phase could in most cases not be closed before the beginning of subsequent phases. If requirements could be repeatedly renewed using iteration loops at predefined points within the process, unexpected project complexities caused by changed requirements could be minimised.
- When older product developments shall be used as a component of a new development, they have to be adapted to new standards. The increased project complexity must therefore be anticipated – and budgeted.

4. Conclusion and outlook

This investigation aims at answering the question what mistakes should be avoided when defining and introducing a new Process Framework, especially when such action becomes necessary due to new regulatory demands. While new standards must be fulfilled the process has to remain efficient and effective. Producing the required safety proofs and, connected to that, keeping a traceable documentation result in a more complex product development. Integrating the requirements set by the standards into the Process Framework without an adoption to current development practice and additional auxiliary tools, can result in significantly increased costs for product development. This paper gives the causes for increased complexities in product development and suggests, how those can be reduced.

Currently, sample project plans are worked out for specific product lines of the company, which also incorporates the current results of the investigation. All relevant processes, milestones and documents are centralised in a comprehensive plan that aims at being the basis for the resource planning of future product development. This plan does not constitute a rigid schema that development projects are adapted to, but a guideline that helps less experienced project managers to achieve the stipulated goals of quality, costs and to hold the project on schedule An improvement of the target process and therefore the practised current process still bears considerable potential.

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