TASKS AND CHALLENGES IN PROTOTYPE DEVELOPMENT WITH NOVEL TECHNOLOGY – AN EMPIRICAL STUDY

Ravn, Poul Martin; Guðlaugsson, Tómas Vignir; Mortensen, Niels Henrik
Technical University of Denmark, Denmark

Abstract

This paper presents a thematic analysis of 138 monthly reports from a joint industrial and academic project where multiple prototypes were developed based on the same technology. The analysis was based on tasks and challenges described in the reports by project managers over a period of three years. 17 task themes and 9 challenge themes were identified. It was found that test, implementation, and project management were prominent tasks. Familiarization with the technology was found to a very little degree, which was in opposition to literature. The main challenge was found to be system development. It was found that the predominant tasks and challenges are distributed over long periods of time, rather than in chunks linked to a specific development phase.

Keywords: Technology, Early design phases, Project management, Development tasks, Challenges

Contact:
Poul Martin Ravn
Technical University of Denmark
Mechanical Engineering
Denmark
pmrav@mek.dtu.dk

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1 INTRODUCTION

Application of novel technology is regarded as one of the ways that companies can keep ahead of their competitors (Baughn and Osborne, 1989; Iansiti, 1995). Technology developers can benefit from the knowledge of lead companies that implement the technology in pre-development phases, thus increasing the knowledge about the technology in use. In such a case, a multi-prototype development strategy can be chosen, where multiple prototypes are developed sequentially to test the technology in different performance areas.

Early inclusion of companies at an early stage of technology development can be obtained through the use of prototypes. This will allow the benefits and principles of integration into a product system to be investigated and facilitates familiarization with the technology. However, there are great uncertainties at such an early stage, both regarding technology performance and appropriate lead applications (Baughn and Osborne, 1989) as the technology is still under development.

The aim of this paper is to investigate the tasks and challenges in a technology development project, from the point of view of the product developer in a technology transfer setting. The specific setup is where technology developer and product developer work together in the development of a prototype displaying the benefits of the technology in a product from the portfolio of the product developer. In this particular context, the technology was introduced to product developer at a very early stage (TRL 2-3).

As part of a research program this paper seeks to answer the following research questions (RQ):

- RQ1: What are the development tasks and challenges when building prototypes with sub-systems based on novel, advanced technologies, concurrently with the technology being developed?
- RQ2: How does early test of a technology at low technology readiness level affect the tasks and challenges?
- RQ3: How are the tasks and challenges found distributed over time in the projects?

2 METHODOLOGY

The overall methodology used for this paper is illustrated in Figure 1. Previously identified tasks and challenges in two development settings were extracted from literature; product development and development of product prototypes with novel, advanced technology components. Data analysis of 138 monthly reports from an industry project was used to identify the tasks and challenges for four teams working with development of prototypes combining principles of an existing product and a novel technology.

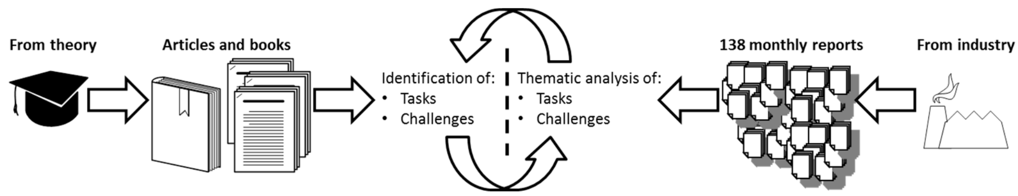

Figure 1. The research approach.

The monthly reports were used as part of the project reporting between the team managers and the overall project manager. The monthly reports covered the project from the time of initiation and three years into the project (august 2011 - October 2014). The reports specifically listed task progression and challenges for the respective months. The reports were analysed using thematic analysis (Braun and Clarke, 2006) with two coding cycles: one for initial summarization of data, and one for thematising. The task and challenge entries, as well as a list of theme definitions were given unique identifiers: PP-#, CH-#, and Co-#, respectively. A data handling record was used to document all steps. To increase reliability of the data coding, team coding was used; a second reviewer was assigned to review the entries in the first coding cycle (Miles et al., 2014). After this, code definitions were compared to create a unified coding scheme. Coding themes originated mainly from literature, but with inclusion of themes emerging from the analysed data as well. To discuss the findings, observations and meeting notes from the project period were used.

3 RELATED WORK

In this paper, two main terms are investigated, tasks and challenges. Tasks are understood as work underdone by engineers in a company, following work processes and procedures. Challenges are understood as areas that are identified to cause an additional effort to solve. This section will focus on tasks and challenges in two contexts; product development, and the development of prototypes with novel, advanced technologies. A distinction is made between regular product development, focused on the optimization of functionality and properties desired by a customer in a smart way (Mortensen, 2012), and early development of devices (prototypes) with novel technological principles applied more focused on exploring the benefits of the novel technology for possible exploitation (Iansiti, 1995; Nobelius, 2002).

3.1 Tasks and challenges in product development

Within the area of product development both tasks and challenges have been subjects of investigation as these are encountered every day in companies A general agreement on six general phases of design can be found: establishing a need, analysis of tasks, conceptual design, embodiment design, detailed design, and implementation (Howard et al., 2008). Each of the phases are often divided into smaller, well-defined tasks to enable concurrent work (Andreasen and Hein, 1987). Other tasks often found are documentation and specification as part of quality measures for the company, as well as what is produced (Pahl and Beitz, 2007).

In general, challenges for product development are represented by performance, schedule and cost (Mankins, 2009). When examining product development literature, subjects such as interfaces (Tomiyama et al., 2007), functions, properties, and structure are prominent (Pahl and Beitz, 2007; Ulrich, 1995). A literature study of previously reported challenges in mechatronic development indicated challenges within product, activity, mind-set, competence, organizational aspects, and other aspects (Morkeberg Torry-Smith, 2013). This indicates that challenges are found in multiple dimensions, and not only specifically target the product, but are also related to process and organization. Therefore, specific challenges will be extracted in the following section.

All together, the list of tasks and challenges in product development is inexhaustible, as each engineering domain will have each its tasks to undergo and challenges to solve. The following section will be used to draw out some of the expectations for what themes will be prominent.

3.2 Applying sub-systems based on novel technology

As complex products are not easy to decompose in order to allow new technology components to fit, a re-design may be needed. One approach is to scale down to prototypes, to a focused level where the combined system can be assessed (Ulrich and Eppinger, 2008). Uncertainty is often mentioned together with technology development (Rogers, 1995; Cooper, 2006; Mankins, 2009). The introduction of the technology element to the product system will result in challenges on more than one level. The general assumption in such a setup is that due to the already existing product design, some things may already be partly pre-defined, such as structure and properties. Therefore, it may be expected that the first general development phases will instead be focused on selecting and defining a match in a proper concept (Iansiti, 1995) as well as familiarization of the technology to break the habits connected with the replaced technology (Katz and Allen, 1985). For familiarization, the transfer of technology prerequisites an interaction between product development and technology development company as "People, not papers, transfer technology" (Foley, 1996). Understanding the technical issues of a technology before transferring it is found to be a challenge (Cohen et al., 1979).In the implementation phase, an emphasis can be expected on testing the prototype as functionality and desired properties need to be verified (Ullman, 2009). As two or more inter- or intra-organizational units are to interact, an agreement on resources, responsibility, differences in aims and ownership have been among the challenges reported by researchers focusing on supporting the process (Nobelius, 2002; Stock and Tatikonda, 2008; Larsson et al., 2006) Thus, project management can be expected to be a prominent factor (Iansiti, 1995).

3.3 Summary

The main tasks and challenges found in literature will serve as a guide for the analysis. Some of the tasks and challenges are expected to be increased when combining existing products and novel

technology in prototypes. Literature indicates that the occurrence of testing tasks should be expected to be high. Also, implementation and project management tasks are expected to be more frequent when integrating novel technology. As a separate task before or during the development process, familiarization should be a substantial part of the work with integrating the technology sub-system.
The technical development of the product is indicated to be a challenge due to the input of a novel technology.

4 INDUSTRIAL CONTEXT

A Danish 10 M€ project investigating, developing, and applying the Electro-Active Polymer (EAP) technology for transducer applications, has been used as a case for this paper. The project was divided into ten work packages (WPs). The WPs focused on the production as well as the product side of the technology (Sarban, 2013). The project was structured as a public-private partnership (PPP) project with multiple partners from industry and academia (I1-4, A1-3) (Hansen, 2013). Focus in this paper is on four WPs (denoted project 1-4) developing prototypes with the technology. For an overview of the projects, see Table 1.

Table 1. Overview of projects

	Project 1	Project 2	Project 3	Project 4
Application	Incremental motor principle	Energy harvesting device	Heating control valve	Loudspeaker
EAP tranducers used	3	1-4	1	2-4
Project partners	I1, A1	I1, I2, A2, A3	I1, I3, A1	I1, I4, A1, A3
Prototype iterations	2	3	3	3

In each of the projects, three sequential prototypes were planned. The data analysed were from the two first prototype iterations. The main difference between the projects was that in project 1, a principle, rather than a specific product was investigated. This meant that the prototype less comprehensive, compared to the other three projects. Project 1 was also initiated later than the other projects.
The project setups, following the PPP structure, had a virtual organization structure, here denoted the PPP shared setup.

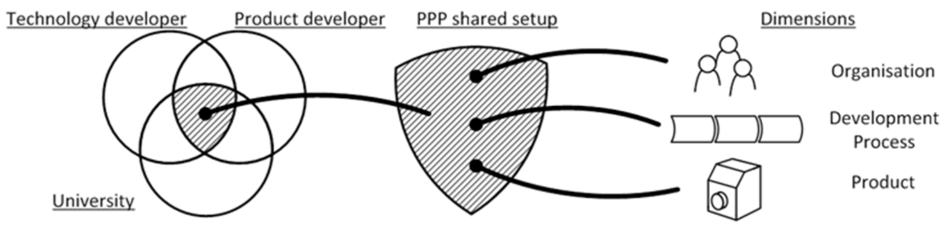

Figure 2. Project setup

The shared setup resources from each of the organizations were shared in a process to produce prototypes for demonstration and evaluation purposes, as illustrated in Figure 2.

5 FINDINGS

A total of 766 entries, from the 138 monthly reports were distributed as presented in Table 2.

Table 2. Overview of reports and distribution of entries in the four projects

Project	Project 1	Project 2	Project 3	Project 4	Total
# of monthly reports	30	39	31	38	138
# of task entries	68	257	117	98	540
# of challenge entries	30	100	58	38	226
Sum of entries	98	357	175	136	766

The entries were distributed with respect to tasks and challenges. The graphs are displayed with respect to the projects and the dimensions illustrated in Figure 2.

5.1 Tasks

All of the 540 task entries (100%) were used in the thematic analysis. As some entries represented multiple tasks a total of 683 task entries were identified. An abstraction adjustment of these, together with classification and collection resulted in 17 main themes. The themes were presented in Table 3 along with percent of total themes and theme description. The descriptions give an insight to the lower level themes found in coding cycle 1.

Table 3. Themes, percent and theme description for tasks.

Themes (Abbreviation)	%	Theme description
Test (TEST)	14,1	Test of systems or sub-systems developed within the projects.
Detailed design (DET-DES)	13,5	Detailed design activities.
Implementation (IMPL)	13,0	Constructing and installing the system or sub-systems
Project Management (PROJ-MAN)	11,4	Project definition, scoping, agreements, planning, and resource allocation activities,
Analysis (ANA)	8,3	Simulations, calculations and other tasks involving an analysis of system or sub-system performance
Conceptual design (CON-DES)	8,2	Concept design, brainstorms.
Problem (PROB)	7,5	Problems, failures, and repair activities
Documentation (DOC)	5,7	Documentation of system, test, or project progress.
Academic work (ACA-WOR)	4,0	Entries directly related to academic work, such as publishing and conferences, as well as preparations for these.
Specification (SPEC)	3,1	Specification of systems or sub-systems, current or future
Collaboration (COL)	2,9	Entries explicitly communicating sharing of knowledge and / or resources across project organisations
Procurement (PROC)	2,3	Finding, ordering, and purchasing parts or components from third parties.
Delay (DEL)	2,2	Delays in project due to various causes.
Review (REV)	2,0	Review of system or development activities.
Embodiment design (EMB-DES)	0,9	Embodiment design activities.
Limited Resources (LIM-RES)	0,7	Explicit entries on limited resources or limited progress due to limited resources
Familiarization (FAM)	0,1	Explicit familiarisation of project members with the technology and / or project.

According to Table 2, which lists the themes along with their proportional occurrence (across the four projects in total), themes relating to the building and testing of the prototypes are prominent for the projects It is also seen that many of the identified tasks from literature are represented.
Figure 3 shows the distribution of themes for each individual project to enable an analysis of common factors.
It was expected that TEST should be high, as well as PROJ-MAN. Common for the four projects was that they all had a representation of TEST as a prominent task e.g. among the top four for each project.
It can also be seen that tasks related to constructing and installing (IMPL) is prominent in all four projects. This is an indication of the technology input to be affecting the development process.
In that relation the familiarization task (FAM) was also expected to be high. However, it occurs only once in a single project.

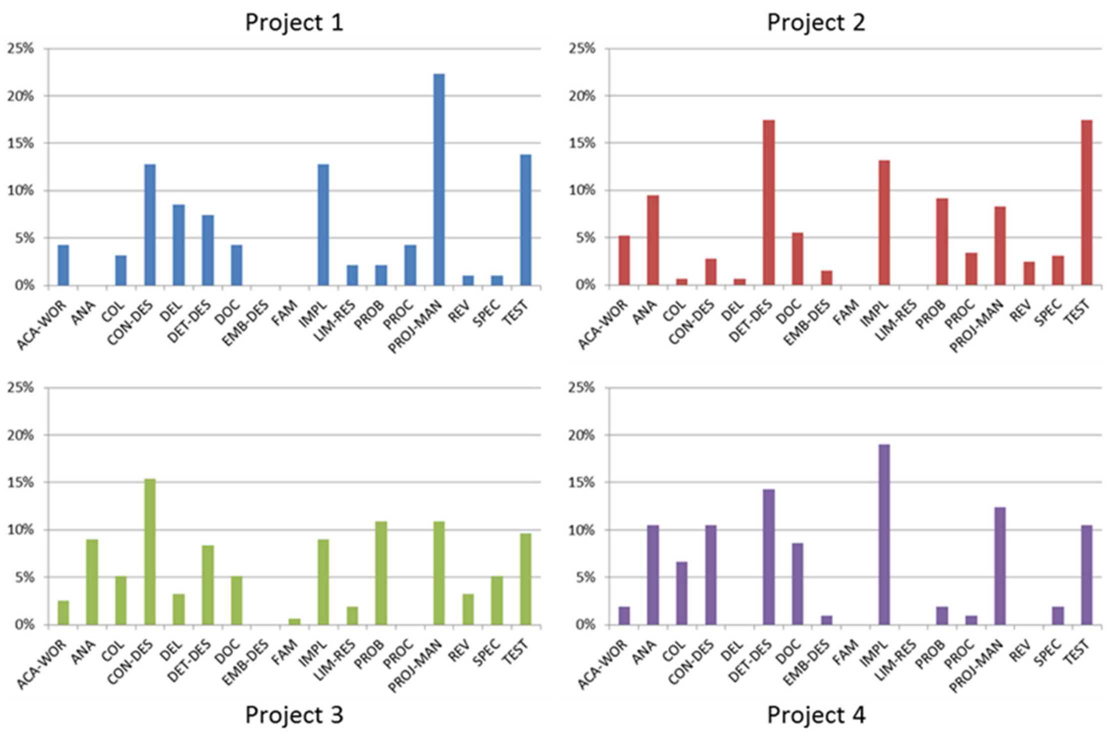

Figure 3. Tasks distributed on projects in percent

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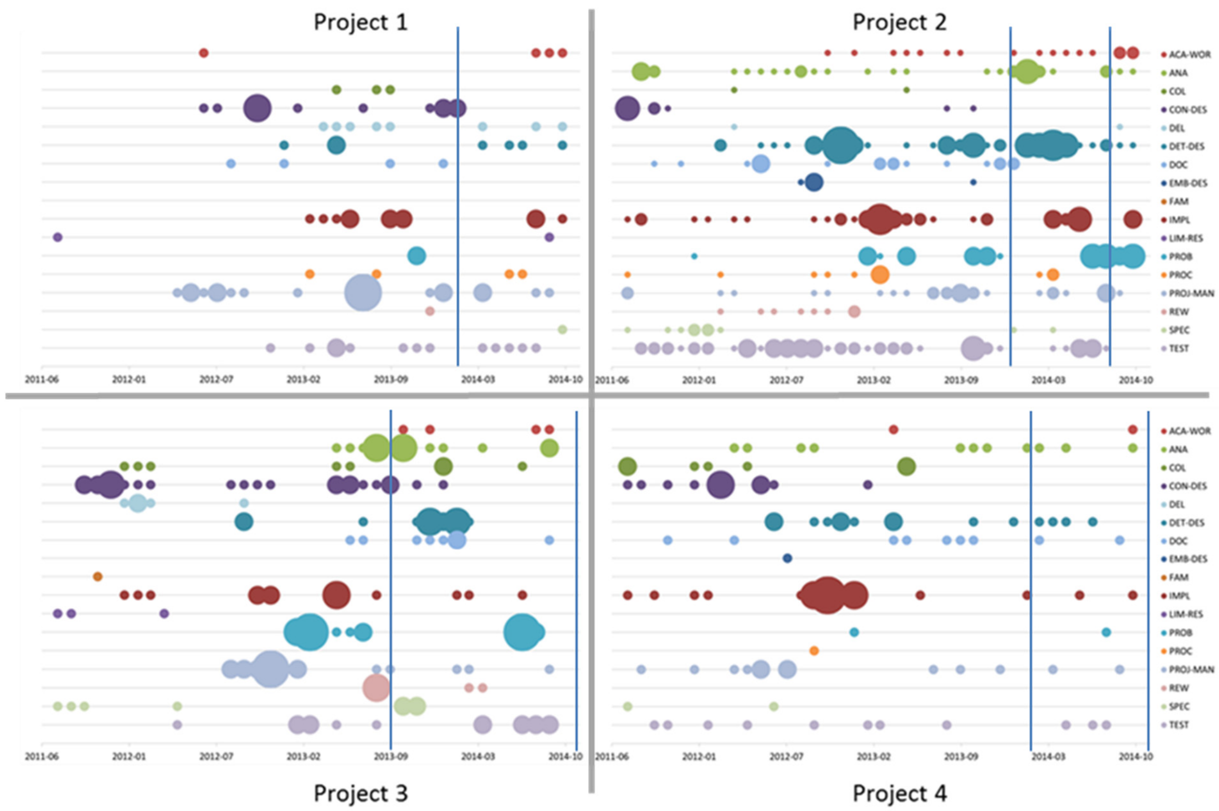

Figure 4. Task entries in the projects over time. Dot size indicates relative number of entries for each theme. Vertical lines indicate prototype completion milestones.

Figure 4 illustrates how the task entries were distributed over time in each project. Here, the number of entries related to a specific theme is correlated to the size of the dots. The larger the dot size, the more entries within the theme in that particular month. Project 1 was initiated later than the other projects, which can be seen from the lack of entries in the beginning of the figure.

As seen in Figure 4, most activities are distributed throughout the period in a greater extent than would be expected in product development projects with more mature technologies. Conceptual design (CON-DES) does occur most frequently at the early stages, but still occurs in all projects after detailed design (DET-DES) activities have been performed. Test (TEST) and implementation (IMPL) entries are seen regularly in most of the projects (see Figure 4), but Project 2 stands out with a high number of entries from an early stage. Problem (PROB) entries seem to occur close to test and implementation activities, which would also be expected in mature product development.

5.2 Challenges

Out of the 226 challenge entries, 202 (89.4%) of these indicated challenges in the four projects. Some of these entries represented multiple challenges, resulting in 251 challenges entries identified in total. Following the same procedure as with the tasks, nine main coding themes were identified. These are presented in Table 4.

Table 4. Themes, percent and theme description for challenges.

Code (abbreviation)	%	Code description
System development (SYS-DEV)	31,9	Challenges related to system development, including analysis, procurement, requirements, construction and testing the systems and sub-systems.
Limited resources (LIM-RES)	20,7	Limitations in personnel, equipment, financial or production capabilities, as well as time for activities.
Project planning (PRO-PLA)	14,7	Challenges related to planning of activities to ensure timely completion of project.
Resource allocation (RES-ALL)	11,6	Allocation of human, physical, or financial resources, including new positions within the project.
Robustness (ROB)	9,6	Issues with robustness of system or sub-systems, e.g. stability, failures, lifetime, and repairs.
Technology component production (TEC-PRO)	7,6	Production quality and production capability challenges.
Organizational support (ORG-SUP)	1,6	Limited support for the project within an organisation.
Technology development (TEC-DEV)	1,2	Challenges due to technology performance, e.g. core material composition and component performance.
Technology familiarization (TEC-FAM)	1,2	Resource use for familiarization with the technology.

Cost is not directly represented in Table 4 but can be seen through the theme LIM-RES. Again, these numbers are for the projects combined, and not for the individual projects. Figure 5 shows the proportional distribution of challenges for each of the four projects. The challenges identified can be organized after focus: Organisation, System and Technology. The organisational challenges cannot be said to be directly linked to development with novel technology. They may be a result of the collaborative setup presented in Figure 2. Therefore, a delimitation is made here; focus will be on system and technology, i.e. the five challenges indicated in Figure 5: ROB, SYS-DEV, TEC-DEV, TEC-FAM, and TEC-PRO. It can be seen that the projects 2-4 have a high occurrence of SYS-DEV. Project 1 on the other hand does not have any entries in the SYS-DEV theme.

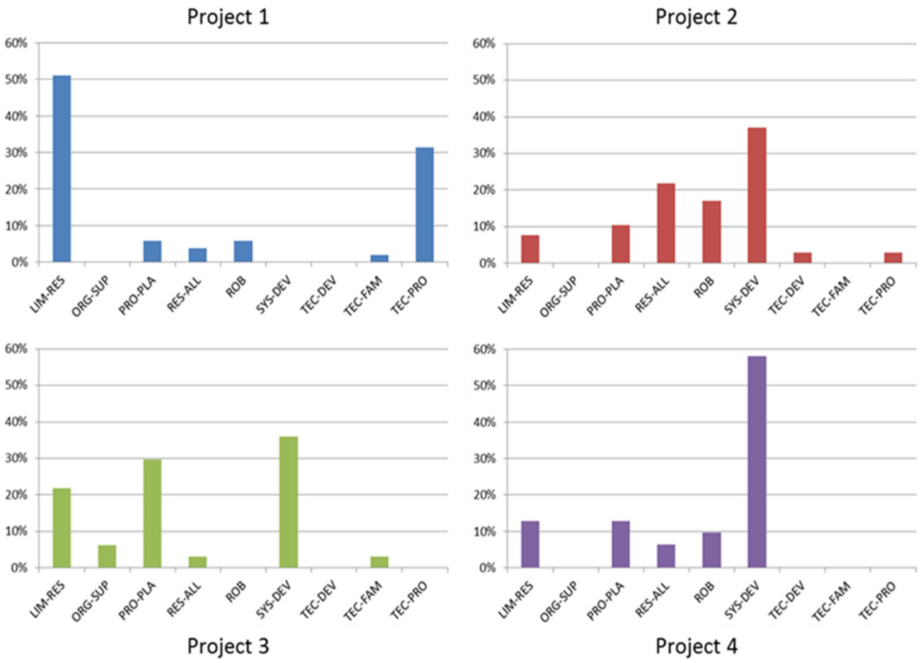

Figure 5. Challenges divided on projects in percent

Figure 6. Challenges in the projects over time. Size of dots indicates relative number of entries within each theme. Vertical lines indicate prototype completion milestones.

While challenges are distributed throughout the period for all projects, as seen in Figure 6, there is little that obviously distinguishes the challenge distribution in the case projects from that which could be expected in more mature development projects. System development (SYS-DEV) challenges are present throughout almost the whole period for projects 2-4, but system development challenges can also be expected to occur, at least in some form, over most of the project period in mature product development. Technology component production (TEC-PRO) challenges are seen for a considerable amount of time in project 1, but production challenges can also hinder more mature product development.

6 DISCUSSION

Two main points will be discussed: the findings and study limitations.

6.1 The findings

The analysis revealed 17 task themes and 9 challenges themes. While a few prominent observations could be done regarding test, implementation, project management, and familiarization for the task themes, for challenge themes, only the system development challenge theme showed a clear similarity between the four projects. The rest of the identified themes either do not showing a tendency or as in the case with the challenges, cannot be directly linked to the development with novel technology.

That familiarization, expected to occur frequently in this setting, has not been found as a task theme reported on may be an indicator that it was either not done, or that it was not reported as a specific task.

It was expected that the SYS-DEV challenge would be high for the projects, but the big difference between projects 2-4 and project 1 was not expected. The main difference in the projects, as presented in the Industrial context section, was the application area, which may be the cause. Projects 2-4 were directly linked to industrial companies, whereas project 1 was used to explore an incremental motor principle - a considerably simpler system than those in the other projects.

To further investigate the correlation between the tasks noted by the project managers in the monthly reports and the time spent on the tasks a comparison with Gantt charts could be used. Looking at the distribution of entries shown in Figure 4 is can be seen that multiple entries can be made for a single month and it could also be seen that most of the themes were distributed over a longer period of time, compared to regular product development. Figure 6 however, revealed little to distinguish between the challenges in this context and a more mature product development.

In the industrial project, a prototyping with technology of low maturity level was tested. A comparison with a more mature technology would be interesting to map the differences between low maturity level and high maturity level, to find clear indications of the effect on the different themes.

6.2 Study limitations

Team coding (Miles et al., 2014), i.e. an additional researcher was used to analyse the data. This was done in order to strengthen the reliability of the analysis. In order to have better inter-coder reliability, the code definitions were discussed and decided upon for the second coding cycle. On the matter of intra-coder reliability the data has been aimed to be coded in focused, single sessions. A re-coding might have given higher intra-coder reliability (Miles et al., 2014). However, the data has not been re-coded for this paper.

Only one source of data has been analysed in this paper. In general, it may be discussed whether the data is a one-to-one representation of the tasks and challenges in the projects as only the comprehension of the team managers is represented through the monthly reports. The tasks and challenges noted in the monthly reports were filtered by the team managers' perspectives. Therefore, the dataset analysed is a representation of what the team managers normally report in their own organisation, and what they put emphasis on in that particular situation. Additionally, some tasks and challenges may have been met within the projects without being included. This means for the results, that they should be regarded as preliminary. For an extended study, additional sources of data should be combined for triangulation of findings. This would strengthen the validity of the findings.

7 CONCLUSION AND FURTHER WORK

In this paper empirical data of the tasks and challenges connected to development projects implementing novel technology has been extracted from 138 monthly reports from an industrial project over a three year timespan. A thematic analysis was performed to identify themes within the dataset.

Through the analysis of the data 17 task themes and 9 challenge themes were identified. When analysing the themes for each of the projects a number of similarities were seen. It was found the task themes test, implementation, and project management tasks had a high occurrence, which was expected. Based on literature it was expected to find technology familiarization tasks, however, only a single entry was found for the theme. For the challenges, a high occurrence of system development

challenge was found which could indicate an effect from testing novel technology with low maturity level in product context at an early stage.
It was found that the predominant tasks and challenges are distributed over long periods of time, rather than in chunks linked to a specific development phase.
Further research could include utilization of additional sources of information. This would strengthen the analysis of a project of this type. Also, a more detailed analysis of the entries could provide valuable insight into the tasks and challenges encountered.

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