26th CIRP Design Conference

Agile predevelopment of production technologies for electric energy storage systems– a case study in the automotive industry

Martin J. Hilt*a,b, Daniel Wagner a, Veronika Osterlehner a, Achim Kampker b

*a BMW Group, Ingolstädter Straße 47, 80807 München, Germany
b Chair of Production Engineering of E-Mobility Components, RWTH Aachen University, Steinbachstraße 19, 52074 Aachen, Germany

* Corresponding author. Tel.: +49 151 601 43040. E-mail address: Martin.Hilt@bmw.de

Abstract

Curtailing development periods in the automotive industry require concurrent predevelopment of new products and production technologies. Volatile requirements and complex interdependencies are the main challenges which agile methods originating from software development are designed for. To examine transferability of several agile methods to the predevelopment of hardware, the authors first theoretically analysed existing methods regarding their potential. While adopting the most promising methods, a case study regarding the production technology for electrical energy storage systems was conducted. It showed that many agile aspects and tools are easily adoptable and help developers in the early stage depending on group size and complexity. They contribute by ensuring that complexity remains manageable, encouraging close teamwork, improving information circulation and supporting transparency. Thus agile methods supplement concurrent predevelopment.

Keywords: Agile methods; production technology; predevelopment; hardware Scrum; e-mobility; technology transfer; product generation development

1. Introduction

One crucial factor to success in industries with quickly developing technologies lies in a permanent generation of technology innovations with a rapid transfer to series production. Companies pay attention to effective and efficient predevelopment activities for production technologies affecting both future product design and suitable manufacturing systems. Challenges in the predevelopment derive from high complexity, high level of novelty and variability and relatively low structure [1]. In the field of disruptive technology (such as in the electric car industry) requirements quickly change as products are altered radically during the development process. Thus concurrent predevelopment in the early stages is important for the handling of complexity and an efficient industrialisation of innovations. In earlier studies the authors identified communication barriers regarding requirements, necessary tasks and project’s progress as major obstacles for an efficient predevelopment [2]. Changing requirements lead to problems in deadline compliance for technology transfer.

Agile methods originating from the software industry were designed for similar purposes. They help in managing complexity and can increase the efficiency under open requirements. They been transferred for different non-IT purposes and validated successfully. Based on similar circumstances an application for the predevelopment of production technologies seems feasible.

This paper first presents an overview about agile methods and the state of the art regarding usage of agile methods in non-IT-applications. The focus lies on the adaptation of agile methods including a case study conducted in a predevelopment project regarding production technology for battery module assembly at a German car manufacturer. We validated the method’s usability including expert’s feedback. The article’s purpose is to present the methods and their adaptations, the observations we made in practical use and the expert’s assessment on how much these methods can contribute to a successful industrialization of predeveloped technologies. The major contribution of this article to the current state of research is a validation of agile methods in industry adding the perspective of early development stages.

2212-8271 © 2016 The Authors. Published by Elsevier B.V. This is an open access article under the CC BY-NC-ND license (http://creativecommons.org/licenses/by-nc-nd/4.0/).
Peer-review under responsibility of the organizing committee of the 26th CIRP Design Conference
doi:10.1016/j.procir.2016.04.189
2. Research Question and Methodology

2.1 Research Question

This paper investigates the research questions: “Are agile principles and methods applicable in the predevelopment of production technologies?” and “Are these methods useful to support technology transfer to the series development?”

We accompanied a running project to evaluate the hypothesis: "Using agile methods in predevelopment projects helps transfer barriers such as open and changing requirements, inefficient communication and a lack of transparency with relation to the necessary activities and project progress”.

2.2 Research Methodology

We analysed the main challenges attached to different predevelopment arrangements in literature matching them with our experience in practice. In the next step an analysis of the state of the art describing agile methods (especially Scrum and extreme programming) in non-IT applications was conducted. We identified the most promising approaches for the application in predevelopment that can help to overcome the obstacles described. We adopted them to fit with a running project concerning a new production technology at a car manufacturer. In the role of Scrum masters, we trained the project team and accompanied the project for three months testing. We identified advantage in the predevelopment by participatory observation during project meetings and took interviews with experts after each project iteration. Finally, a feedback meeting with an evaluation of the method’s benefit was carried out. We used a questionnaire asking the project team members about their estimation of the extent to which each agile method can help overcoming the barriers in technology transfer. We asked “Can the method contribute to overcome the obstacles described?” referring to the aspects outlined in the introduction of this paper. We provided an end-named scale reaching from “very low contribution” to “very high contribution” for the evaluation.

3. State of the Art

3.1 Process in predevelopment of production technologies

The main objective of predevelopment activities is the generation of new concepts, including a proof of feasibility i.e. a reduction of risk for series development projects. Predevelopment is commonly arranged in stand-alone projects with separate funding carried out by separate departments. If feasible technologies have to be taken into account by both product development and process planning from series development projects for implementation into new production systems. Generally, there are two major ways of arrangement: Separated from series development or integrated. The separated approach leaves more room for innovation and has the advantage of higher innovation rates but commonly faces the problem of transfer over department interfaces [1]. Integrated predevelopment provides easier prioritization of objectives and tasks and easier transfer. On the other hand, it involves risks of low prioritization of predevelopment in times of capacity shortages and lower chance for “think out of the box”-solutions [3]. For these reasons large companies often have separated organizations [1]. Especially for projects which are driven by technological potential for improvements in production rather than necessity for product realization problems in transfer to series development occur: Lack of flexibility for quick adoption to changes, obstacles in the communication and coordination over department interfaces and disregard of other department’s needs [3, 1].

3.2 Agile Methods

Augustin [4] defines agility as “the ability to deliver customer value while dealing with inherent project unpredictability and dynamism by recognizing and adapting to change”. Highsmith [5] summarizes “agile” by five major objectives: continuous innovation, product adaptability to future requirements, reduced delivery schedules, people and process adaptability and reliable results.

The main principles of agile software development were published in the “agile manifesto” by Beck et al. [6] in 2001. Twelve principles describe the basic rules of agility. Characteristics differing from a traditional approach common to all agile methods include an active user involvement into the project, a self-deciding interdisciplinary team, an iterative procedure with a fixed time scale, development in small incremental releases and a permanent testing of results.

Agile project management provides a large set of specific methods for the implementation of these principles. Many of them are described in the framework Scrum, which is the most commonly used method [7]. Another widely spread similar framework is “extreme programming”. Agile methods have been detailed in the IT-sector and are now spreading over different non-IT areas. The most common methods that were identified in the analysis of literature are illustrated by table 1 [8, 9].

There is no distinct line between “agile” and “non-agile” and many agile aspects can already be found in the predevelopment of production technologies (see table 1). Serrador [10] published a survey showing that 65 % of the identified projects had some agile component. The author found that the greater the agile/iterative way the higher the project success. For this reason, many researchers have worked on approaches for agile transfer into different areas (often called agile tailoring) over the past years. Campanelli [11] recently presented a wide ranging literature review on 56 studies with around two thirds of the papers using empirical research methods.

3.3 Transfer to the predevelopment of non IT-Projects

The only approach for agile predevelopment was published by Gonzales [12]. The author introduced a conceptual model on how agile principles can be applied in the predevelopment stage of innovation. Gonzales proposes an increase in speed and effectiveness as a result. The paper does not present any validation or detailed explanation for specific implementation in practise. Lima et al. [13] developed a model for the co-development of software and hardware based on Scrum on a solely theoretical basis. Hardware development is divided into short phases linked to software design using agile principles. The authors do not show a validation of practical benefit. The project “Wikispeed” developed an entire car prototype using Scrum. It works in self-organizing teams with 44 members using one-week iterations. The team re-evaluates each part of
the car in each iteration deciding on the next highest priority aspects. [14] “Wikispeed” did not focus on production technology though and was not limited by a company’s structure from which difficulties with the use of agile methods can arise. Kampker et al. [15] introduced the new framework “factory planning Scrum” scaling the major Scrum-methods to factory planning activities subdividing the planning process into modules. By that the authors concentrate on a later project phase not directly dealing with hardware development. Schneider et al. [16, 17] adopted Scrum to a detailed method for agile process planning in the automotive industry. The author validated his concept in a planning project for a new engine plant successfully. Agile process planning starts with the target agreement leaving out predevelopment activities. A major difference is the lack of hardware development and lower level of open requirements. Waldmann [18] investigates the early stage focusing on how principles of agile can be applied to requirements engineering by conducting a case study in a large project for the development of platform components for hearing solutions. In the predevelopment of production technologies, a detailed description of requirements is not common though as requirements are often open and volatile.

There are many approaches for agile tailoring (mainly Scrum) in different areas including early stages, hardware design and process planning. None of the methods gives an answer to the question if agile is suitable for predevelopment projects starting with an idea ending with the transfer in the surroundings of production technology. None of the empirical research applied agile in predevelopment projects yet.

The case study that is subject of this paper was conducted in order to proof usability for the early phase in industry, identify advantages and obstacles in practical use and estimate the potential for supporting of technology transfer.

4. Methodological tailoring for production technologies

In order to fit a technology predevelopment project alterations are necessary to some methods described in literature. Agile practices which are concerned with task management can be used without major alterations, as these are independent of the product. Examples are a product- and sprint-backlog, a task board, burndown charts, lessons learned (retrospective) and the definition of done. For the use in technology development a shorter iteration frequency was chosen (two weeks), as tasks derive from experimental results, which are not plannable over 4-6 weeks on a detailed basis (as commonly named by literature). An estimation of the effort for tasks was changed from points to hours (easily manageable) and daily meetings were reduced to two meetings per week, as developers usually work on several projects concurrently.

Significant changes to traditional agile practices are necessary in all methods directly related to the product as the project content differs significantly from software development. This affects the methods incremental development, test-driven development and the function-orientated approach.

The major difference related to increments in technology development projects is that these are not part of the final product (which they are in software development). We defined increments as all information generated by the project, as it adds to the entire set of knowledge enabling the final “product” (i.e. the production system). Increments include descriptions, drawings and CAD-models, evaluation of suppliers, patent research, hardware prototypes, test results etc. Accordingly we understand “tests” in the test-driven development method as all actions used for a validation of increments: Hardware tests on the product such as tensile tests or climate tests, simulations of assembly steps, calculations of process times etc.

For the function-orientated design, defined three categories: process properties (such as force transmission or process time), product properties (such as mass or electric insulation) and others (such as legal aspects). This approach is different to software development where functions are added to the final product and might work independently.

Table 1 shows the methodological set defined for technology predevelopment projects including alterations made to traditional approaches taken from literature.

5. Case Study

5.1 Environment: Predevelopment of production technologies for electric powertrain components at a car manufacturer

The company in which the case study was conducted is a large scale car manufacturer and supplier of mobility services in Germany. The technology predevelopment department for electric powertrain components is separated from series development departments while working closely together with the product development and process planning departments. Objectives are the development of new production concepts for future production systems including a proof of feasibility. Projects aim for an enabling of new product design or an improvement of quality or cost of production.

5.2 Project: Alternative cell bracing for battery module assembly

The project which was subject of this paper deals with a technology for cell bracing in the process of battery module assembly. The project’s objective was to detail a concept for an alternative to the current state of the art being ready for the next evaluation of the planned production system. The aim was a reduction of process time. During the time we accompanied the project, the major task was a testing of feasibility in hardware including material selection by empiric study. This included the altering of an existing prototyping machine and producing dummy modules for product tests.

The running series development project for which the technologies was validated can be seen as the customer of the technology project. It dealt with the development of an entire electric energy storage system. At the time of the case study the project was several years before start of production and around one year before the target agreement (milestone at which product design and belonging production technologies are fixed).

5.3 Project procedure before the case study started

The project team consisted of two developers (one working full-time and one part-time on the project) as well as one sub-project manager responsible for all module manufacturing technologies. He was included every few weeks or on demand of the development team. Direct interfaces existed between the product development and the production planning department who knew the scope of preparing the technology for evaluation.
Information exchange took place on behalf of the sub-project leader in his regular meetings. The team members were working in different buildings, and had a weekly regular meeting. Tasks and relevant information were collected in personal to-do-lists and had been partly discussed in the weekly meetings. Many aspects could be interpreted as agile to some extent, such as the indirect internal customer integration via the sub-project leader and a test driven development based on standard testing of the prototype parts. Table 1 shows a summary of the implementation status of agile in the beginning and at the end of this case study.

5.4 Introduction of agile methods into a running project

For the introduction of the new method we orientated on the key aspects of the framework for agile transition published by Gandomani and Nafchi [19] and Gandomani et al. [20], focusing on a way that is value based, iterative and gradual. Two of the authors took the role of Scrum masters and started with a training of the methods for the project team. We started the case study with an initial set of selected methods introducing iteration (sprints) with sprint planning and retrospective meetings and a backlog list including a definition of done for each task, a digital task board and a burndown chart (based on MS Excel). We added agile components from sprint to sprint and altered them based on our experience and the feedback we obtained from the project team.

When starting to introduce agile methods, we faced some doubts against them. Most aspects concerned additional time effort e.g. for maintaining the backlog lists and for the sprint planning meetings. The doubt was that this effort would not be worth the benefit. Moreover, an increased number of meetings for both the project team and the customer representatives was seen critical as developers had tight schedules and often clashing meetings. Full transparency towards the management created by the task board and the burndown charts were seen critical but were accepted by the project team.

Table 1. Overview on the tested methods with their degree of implementation and adaptations made before and after the case study

<table>
<thead>
<tr>
<th>Agile Method</th>
<th>Prior implementation of the method</th>
<th>Implementation degree before</th>
<th>Manifestation at best project fit for the case study</th>
<th>Implementation degree after</th>
</tr>
</thead>
<tbody>
<tr>
<td>Iteration</td>
<td>Stage-Gate-process with periods of several months</td>
<td>○ sprints with a duration of two weeks</td>
<td>●</td>
<td>●</td>
</tr>
<tr>
<td>Customer integration</td>
<td>every several months and on predefined developer’s demand</td>
<td>customer represented by “Product Owner” with integration on a weekly basis</td>
<td>●</td>
<td>●</td>
</tr>
<tr>
<td>Task prioritizing with product owner</td>
<td>no structured prioritization</td>
<td>sub-project leader ensuring prioritization in customers’ interest</td>
<td>●</td>
<td>●</td>
</tr>
<tr>
<td>Estimation of effort for tasks</td>
<td>meetings on demand (around weekly)</td>
<td>estimation in hours by the team</td>
<td>●</td>
<td>●</td>
</tr>
<tr>
<td>Daily meetings</td>
<td>routine meetings twice a week</td>
<td>○ regular meeting twice a week</td>
<td>●</td>
<td>●</td>
</tr>
</tbody>
</table>

Column 2: ○ not used ● partly used ● fully used

5.5 Observations on the usage

We defined the common roles described by Scrum fitting them to the projects. The “Product owner” was represented by a sub-project leader (responsible for the next larger subassembly - the battery module) and the project team. The “customer” role was occupied by representatives from the process planning and product development departments as the major interfaces. Due to the early phase in the development project, we did not include the customer directly (no need). The “Scrum master” role was taken by two of the authors of this paper. We created a smaller team than the optimal size described by Scrum, where around 5-10 people being optimal (team size is depending on the author) without problems. The function of each team member did not change by the introduction of the roles apart from the higher frequency of the product owner’s inclusion. By the intensive inclusion of the product owner relevant information from the product development and production planning department (e.g. changes in the expected production volume) reached the team much quicker than before.

We added a sprint planning and a retrospective meeting to the prior state of weekly meetings. Additional meetings were used for an exchange of current aspects without rules, as we observed that strict rules on duration and content of information exchange are not necessary in a small team. As a result, we found two meetings per week as the optimal level for this project. In addition, the team communicated via telephone whenever necessary.

We implemented the common documents “product backlog” for the collection of all future tasks, the “sprint backlog” for task of the recent iteration. Moreover, a “task board” as well as a “burn-down chart” for the visualization of project progress were used (all included in one tool based on MS Excel). We observed very well structured meetings with efficient actions in which the team conscientiously worked with the backlogs. The task board as well as the burndown charts were used rarely as the small number of tasks in this small project could be overlooked in the backlogs easily.

Iterations (“sprints”) started with a time-span of one week.
which was increased to two weeks after the second sprint. We found this duration best fitting as it corresponds well with the duration of preparation, execution and validation of material tests which were the main tasks. We noticed recurring effort to reach the self-set objectives in each sprint which raised the effectiveness of actions and increased the speed at which intermediate results were created.

As “increments” deriving from the “definition of done” we mainly obtained material test on product components as preparation for process parameter variation. Finally, the production of prototypes for standardized product tests constituted another increment.

In order to estimate the effort for each task, we started with the method “planning poker” using cards. We switched to a discussion of effort and estimation in hours after the second sprint as the cards could not add any benefit for the project team but meant additional unnecessary time and effort.

We introduced function-orientated development by subdividing the main functions of the prototyping machine. From the subdivision necessary tasks could be derived. The method was dropped after two sprints as experts did not see any benefit in it. Therefore, a further tailoring and detailing of the method for predevelopment of production technologies did not take part in this case.

5.6 Feedback from experts for the evaluation of benefit potential

In each retrospective meeting and in one final meeting we asked for positive and negative feedback for the methods that were tested. We can summarize that in the expert’s view, the most useful methods were the discussion and mutual setting of a “definition of done” for every task. This created a common sense of objectives and helped working more effective. Short iterations in the form of sprints were ranked very useful as the sense of objectives and helped working more effective. Short sprints were ranked very useful.

We can summarize that in the expert’s view, the most useful methods were the discussion and mutual setting of a “definition of done” for every task. This created a common sense of objectives and helped working more effective. Short iterations in the form of sprints were ranked very useful as the sense of objectives and helped working more effective. Short sprints were ranked very useful.

From the expert’s opinion, the methods of function-orientated development was not expedient for the project and daily meetings were too much for the small team. The methods encouraging transparency were seen as less beneficial in the small team but potentially interesting for larger projects with a greater number of developers involved. Table 2 shows a summary of the most significant feedback we obtained including the mean values of the project team’s final evaluation about the contribution to overcome obstacles in technology transfer. The assessment is based on the experiences from five sprints and from several years of technology development.

6. Conclusion

We identified major challenges of predevelopment activities which large companies are facing and matched them with methods described by agile approaches such as Scrum originating from software development. We accompanied a project with a small team developing an alternative production technology for a battery assembly at a car manufacturer. Agile methods were introduced and iteratively adapted based on the authors’ observations and experts’ feedback in order to fit the project best. By that slight changes made to the most common methods described in literature. We did not manage to implement a fully agile project but combined agile aspects with the company’s existing structures and circumstances. Limiting factors mainly derived from people’s time effort they can spend on regular meetings for individual predevelopment projects. The methods were fitted to achieve the best benefit in this specific project.

The results show that agile approaches can be applied separately and can be combined with traditional means in the early development stage without losing their benefit. From the observations we can conclude that many agile methods can be tailored to the predevelopment stage easily and successfully.
combined with the regular integration of the internal customer’s needs as well as a precise definition of interim-objectives showed great benefit according to the expert’s feedback. We assume that further value can be realized in large projects by methods designed to raise transparency of progress.

The team validated that agile methods can contribute to overcoming obstacles in transfer such as communication barriers over department interfaces, inefficient task prioritization and management of changing requirements. We could not actually measure the differences in project success as for example the survey by Serrador [10] did. We based the results on observations during the project and the experts’ opinions. A transfer of the results to any predevelopment activity with small teams and comparable circumstances is possible. Large teams would require additional means as information exchange and coordination becomes more challenging with increasing interdependencies. With the results we substantiate the pro-position of Gonzales [12], that applying agile methods to predevelopment stages causes an increase in effectiveness. For a successful extension of agile methods to any predevelopment project further research is necessary.

7. Outlook

From the results of this case study we can point out further need for research on agile tailoring for predevelopment projects focusing on the technology transfer. Predevelopment projects differ in many criteria such as temporal project phase, number of interfacing departments, technical complexity, degree of novelty etc. This makes a differentiated use of project management means necessary. There is a need for an analysis on criteria affecting the selection of methods in industry in order to guarantee an efficient application. Circumstances affecting project management might change significantly during the development process, so there is need for a validation in different project phases.

This paper did not investigate all agile methods described in literature such as pair programming or continuous integration, leaving room for further work on adaptations. Research also needs to be done on ways of a combination with commonly used methods such as maturity stage control approaches and validation methods in order to build a generic model of innovation management for the early stage. The question if the results of Peterson and Wohlin [21] stating that quality increases with delivery of increments is also true for predevelopment of production technologies can be another base for further research focussing on means to realize virtual prototypes and hardware quickly. Finally there is room for a comparison of concurrent engineering with agile methods quantifying advantages in industry projects.

References


