Enabling radical innovation through highly iterative product expedition in ramp up and demonstration factories

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Abstract

Short development times that are characterized by a high return on engineering (RoE) become increasingly important as a critical success factor for the realization of radical innovation. However, the high degree of complexity of modern products results in a long and costly development time when traditional sequential development processes are employed. The paper at hand describes the restraints of typical gate-oriented product development processes and builds up on recent studies recommending highly iterative innovation processes for the fast realization of physical product ideas. The suggested methodology represents an approach based on the Scrum process model from the software industry that includes the continuous integration of customers and production engineers based on the execution of feasibility studies by the early and stepwise development of prototypes. In this context, modern ramp up and demonstration factories possessing a product lifecycle management (PLM) system, an integrated ICT infrastructure, interdisciplinary engineering teams and scalable manufacturing technologies are suggested as key enablers. The authors illustrate that these facilities, together with a sensor-based product expedition are particularly suitable for implementing an adapted Scrum process for the development of physical product ideas. A critical reflection on the basis of the development of an electric car aims to underline the suitability of the presented methodology in enabling radical innovation.

Keywords: Radical innovation; Highly iterative product development; Scrum; Complexity management; Ramp up

1. Introduction

Today’s market environment is characterized by short product life cycles and continually increasing customer requirements. The ability to bring radically innovative and individual hardware products on the market at a high speed is becoming a key success factor for many manufacturing companies [1,2]. Developed at Laboratory for Machine Tools and Production Engineering (WZL) of RWTH Aachen University, the concept of return on engineering (RoE) is regarded as the target figure in this context. The RoE describes the ratio of the benefit obtained to the effort applied for all development activities [3]. Cost- and time-saving product development processes stimulate an innovation-friendly environment and thus the tendency to realize radical innovation [4]. A high RoE is a vital feature of efficient development processes. However, the majority of the established companies show difficulties in the fast and cheap development of physical products [5].

2. State of the art

A lack of systematic processes for designing, developing and introducing new products made a large number of companies in the 80s and 90s adopt the stage-gate process model proposed by Cooper. It provided companies with the necessary structuring of their development processes to increase the success rate of new products [6, 7]. Still today, the vast majority of physical product development projects comply with the sequential stage-gate model, partly modified according to the companies’ environment.
The stage-gate process divides the product development process into phases (stages). At the end of those phases the gates are located. In the phases, value-added activities are carried out in order to achieve the pre-set objectives. The result of the phases are compared with the targets at the gates, so that a decision about the further processes of the project can be taken. Based on the quality of the results, the project is continued, delayed order canceled [6].

The further intensification of the market environment since the introduction of stage-gate process for the physical product development has strongly increased to number of critics of the model. While the traditional process model is still suitable for evolutionary product development, it is considered too slow, linear and little adaptive for radical innovations [8,9]. The principle of an early product definition in the stage-gate process does not take into account the fact that customers usually do not clearly know what they want until they see the products with their own eyes – a characteristic of radical innovations [10]. On the contrary, coming from the software industry, Scrum is an agile and iterative process model in which the benefits of developed solutions are secured through the early involvement of customers and users. The approach requires a minimum of planning and decision-making is shifted to the operative level [11]. In the software industry, Takeuchi and Nonaka’s process model prevailed against other traditional, sequential process models whose bureaucratic and inflexible structure led to an enormous increase in cost in many complex software development projects in the 90s [12,13]. Companies using Scrum report that this method has a clearly positive impact on the efficiency of development processes [14].

So why has the insufficient innovation product development process not been counteracted through the application of Scrum in the hardware industry? There are first publications that discuss this train of thought [14, 15]. On closer examination it becomes clear that the implementation of an agile procedure for the development of a physical product is impeded due to fundamentally different conditions.

Cooper mentions multiple examples where companies have adapted the stage-gate process to their purposes: leaner, faster and partly iterative [14]. However, the holistic adaptation to a Scrum process is particularly difficult because physical products, unlike software, usually cannot be infinitely partitioned into increments. The regular presentation of a functioning, advanced physical product increment for the purpose of user feedback is therefore much more difficult [14]. The engineering challenges posed through the implementation of Scrum deserve special emphasis. The constant consideration of requirement changes from the feedback loops, connected with the avoidance of deterministic planning, lead to high audit costs and availability problems with respect to tools and other production equipment, for instance.

Building on these thoughts, an adapted Scrum process model for the physical product development is introduced in chapter 3. Demonstration and ramp up factories are regarded as a suitable basis for the application of this model.

3. Methodology for highly iterative product development

The Scrum process model is characterized by a clear definition of processes, roles and development objects [16]. The physical realization of a hardware product must be taken into account when designing these three dimensions.

On the basis of demonstration and ramp up factories, the following adaptation of the model is structured along the specific processes of Scrum: Sprint Planning, Sprint and Sprint Review (Fig. 1).

The Sprint Planning is not affected by the adaption from software to hardware products. Also here, the result is a customer-orientated and precise catalog of requirements in the form of a product backlog, just like a specification. From the product backlog, the development team transfers the requirements to the Sprint Backlog and plans their implementation.
3.1. Continuous data consistency through the use of a PLM system

The central step of the iterative implementation of the product idea is the **Sprint** which requires fundamental changes when the model is adapted to hardware products. For these products the physical implementation is an essential part of the development process. The result is Sprint divided into three phases, a

- concept and design phase;
- a work preparation phase and
- a construction phase.

Moreover, radical physical product innovations possess a high degree of complexity which makes the recombinant of different resources and skills indispensable [17]. Hence, the division of labor is essential for the realization of complex products. Parallel Sprints, each focusing on a specific product increment, can potentially accelerate the development.

The Sprint process can be designed adaptively and flexibly along the two dimensions (phase and number of parallel Sprints), following a central demand of Cooper [14]. Depending on the progress in time of a development project and the complexity of the product, the temporal distribution of the phases can vary just as the number of parallel sprints. Moreover, the total duration of a sprint may change [14]. The consideration of the design, work preparation and expedition phase and the parallelization of activities cause a tangible increase of complexity. Connected to the interplay of these phases is the provision of product and process information in form of CAD models, bills of material and production schedules. The diversity of information needed for a successful physical product realization emphasizes the need for an efficient administration of this information.

In the context of work organization as illustrated above, a product lifecycle management (PLM) system, that provides continuously updated and consistent data, can enable an efficient coordination and parallelization of several project teams. In addition, a PLM system provides synchronized data along the different IT systems used in the development phases. Hereby, an efficient process sequence of design, work preparation and expedition phase without interface problems becomes possible. Based on the availability of consistent data, a rapid transition from design to product can be realized.

3.2. Integrated product and process development through interdisciplinary teams and a modern ICT infrastructure

Another challenge regarding the **Sprint** in physical product development projects is due to the aim of an integrated product and process development in which the product design must comply with manufacturing and assembly facilities. Small, interdisciplinary organized development teams consisting of e.g. a design engineer, industrial engineer and production staff form the operational framework in this context. The agreement on a common target gives rise to a sensitization regarding the requirements of all departments involved. All the necessary staff resources should be available and a clear focus on the Scrum project is essential [14]. The open factory layout and short distances in ramp up and demonstrations factories support the coordination processes within the teams in the **Daily Scrums** and between the teams in the **Scrum of Scrums**. Moreover, an organizational separation from the day-to-day business facilitates the autonomous, continuous and smooth work of the development teams [14].

Work planner and production staff should be involved from the design phase of the first Sprint on. Based on a modern ICT infrastructure of demonstration and ramp up factories, information about occurring errors can be traced back very efficiently in the subsequent realization during the work planning and construction phase. Based on continuous data availability, information can be transferred without disruption: parts showing design errors can be identified by RFID technology. Through the use of an appropriate application, mobile devices transfer standardized error documents to an internal data platform which the team has access to. This uncomplicated way of a standardized documentation facilitates the discussion of relevant issues within the **Daily Scrums**.

3.3. High responsiveness through flexible production facilities

The biggest challenges for the production in the Sprint is caused by the implications of the Sprint Planning and the Sprint Review, the avoidance of deterministic planning. Based on the user feedback, Scrum allows for a continuous verification of the current product to ensure the creation of customer value. During the product development requirement changes are the natural consequence of this paradigm. A simple revision of software codes in the software industry corresponds to a change of the CAD model with extensive consequences for production processes in hardware development. The high expenditure of money and time connected to the procurement of new machines or replacement of tools and other equipment can be regarded as problematic.

A flexible and adaptive production infrastructure enables the adaption to different product or production scenarios in a short amount of time. Generative production processes allow not only to produce complete prototypes but also components, tools and jigs. With this ability the production attains new degrees of freedom in terms of velocity and geometry. In addition to the use of flexible joining processes (e.g. laser joining) the application of adaptive jigs permits an accelerated assembly. As a result, the adjustments of jigs are feasible at low cost in the case of geometry changes.

3.4. Obtainment of extensive knowledge through sensor-based testing environments

At the end of an iteration loop, the inspection of the Sprint results is performed at the presence of selected costumers and users in the **Sprint Review**. In this context, an integrated testing environment is particularly suitable for recording feedback. In sentiment analysis, sensors such as camera systems and heartbeat sensors help to assess stress or
excitement, two factors that are normally difficult to measure. Traditional interview techniques and classical specification checks are complemented through this. Thus, extensive insights about the user opinion can be obtained which guarantees the registration of all relevant changes concerning the product requirements.

Generally, the development object as such, which is supposed to be “potentially shippable” in the software specific Scrum process, requires a critical revision when the process is adapted to hardware product development. The increments of a physical product cannot be independently experienced as in the case of a software code [14]. The performance of an electric motor in an electric car can only be assessed in connection with a fully functional chassis, an engine control system, a battery et cetera. The level of product maturity significantly depends on the interaction of the individual product increments. An autonomous assessment is thus extremely limited. Only in some cases, namely when a clear customer focus is set on a particular independent product feature.

The gradual approach to a pre-production prototype based on user feedback is fundamental to the successful realization of a radical physical product idea. By continuously assuring customer benefit, uncertainty is reduced successively. With respect to physical products, requirements may be geometric, haptic, visual or functional in nature [18]. At the beginning of a development process, a product may be defined to less than 50%. On the way to the series product, the definition adapts to new information [14]. Early loops should be carried out quickly. Depending on the product, a prioritization between product features is recommended: For a commercial vehicle, for example, a focus may be placed on the functional properties before optic, geometric or haptic features are considered. In the case of a sports car, the focus can be shifted accordingly. The gradual approach can be realized through the successive realization of a digital mock-up, a rapid prototype and a pre-production prototype.

The early phase of the first prototypes serves as a “proof of concept” of a radical innovation, based on the provision of experienced aspects. The consequence of this experimental, accelerated and focused approach is a reduced need for investment at the beginning of the product development. Development teams are encouraged to experiment. The fact, that the fear of early failure is taken from them, creates an environment that encourages innovation [14].

All enablers mentioned 3.1 – 3.4 are suggested to have a positive impact on the RoE. Their respective capabilities with regards to the reduction of time and cost during product development have been outlined in detail.

4. Critical reflection

The StreetScooter GmbH aims at developing electric vehicles that can be economically produced in small series. As a greenfield project StreetScooter freed itself from traditional restrictions and questioned established structures of the automotive industry right from the beginning. The young company focuses on optimization approaches along the three dimensions of network design, technology platform design and customer value orientation. The maximization of RoE is pursued through the deployment of highly iterative development processes that are reflected in the three dimensions. The methodology for the development of physical products described in chapter 3, supported through the enablers 3.1 – 3.4, finds application in the product development projects at StreetScooter. Thus, a correlation between the applied methodology and the high RoE of StreetScooter (the SOP was carried out 3,5 years after StreetScooter’s foundation) is suggested.

The development approach of StreetScooter provides for a communal development of electric vehicles in a heterarchic network. Due to the technologically sophisticated structure of electric cars concerning product and process, a recombination of distributed knowledge across multiple industries is needed [19]. StreetScooter pursues the development of its vehicles in a network of more than 80 partner companies having equal rights. Eight Lead Engineering Groups (LEGs) serve as separate development departments where specialized partner companies devote themselves to a specific vehicle system (e.g. battery system, body, electronics). The development work of the LEGs occurs independently from each other and simultaneously. Therefore, they follow the paradigm of parallel Sprints to radically shorten the time of development. The Demonstration Factory Aachen (DFA) serves as an adequate infrastructure where a design and a work preparation phase is followed by physical prototyping.

The high coordination costs of the activities in a heterarchic partner network and along the implementation phases are addressed by the means of the integrated product lifecycle management system “Windchill” of the company PTC (Fig. 2). On the one hand, the virtual environment supports the coordination among the LEGs in the design phase through the provision of consistent product and process data. On the other hand, the acceleration of the physical construction along the three phases becomes possible. For instance, motion data are recorded and integrated into the work preparation of following sprints via sensor systems during the production.
StreetScooter’s second cornerstone is its technology platform which aims at an integrated product and process development through modular products and processes. The coordinated product and process architecture acts contrary to the formation of complexity.

The parallel development of product and process modules within the development teams of each LEGs is achieved by the integration of production experts during the design phase. This way, production requirements are considered at an early stage.

In addition to that, the ICT infrastructure of the DFA makes a significant contribution to the removal of remaining product-specific inadequacies that are discovered during the construction phase on the shop floor. Among other things, the body-in-white (LEG body) of StreetScooter was iteratively adjusted in the DFA reaching suitability for series production. Based on an initial design draft, several rear parts of the car body, could be quickly revised and redesigned in the development team by using ICT solutions (Fig. 3).

Due to the utilization of several loops and the continuous integration of recent user feedback into the Product Backlog, the ability of considering changing requirements in the construction phase is vital for the development of StreetScooter vehicles. The highly flexible production resources used for prototyping at the DFA reduce the restrictions of conventional production processes and allow for a fast and cost-efficient adaptation to new product requirements. The prototype construction is enormously accelerated with the help of a 3D printer that allows to produce e.g. complex body parts. In addition to a variety of outer parts, such as front panel, rear panel and door trim, some inner parts, such as the dashboard, can be produced completely independently from jigs. Adaptively designed jig system and the access to a highly automated laser welding system enable a rapid adjustment of joining processes (Fig. 4).

StreetScooter follows a value-oriented approach in its development projects. The company strictly focuses on the maximization of customer value and avoids over-engineering that way. The complete identification of customer requirements and the continuous validation of prototypes form the premise for a value-creating orientation of the development concept. From the beginning, the customized utility vehicle was aligned with the characteristic requirements of the focus group of delivery services, particularly with respect to the feature functionality. Based on a comparable vehicle, the largely undefined functional design of the interior was defined in collaboration with future users in workshops at an early stage of the development process. The resulting concept was directly transferred into a prototype which functioned as a “proof of concept”. The clear focus on the functional characteristics of the interior led to an increasing emphasis on the work of the LEG interior as a product increment (Fig. 5). In the future, more tests based on sensor system will become possible in the integrated test environment of the DFA. The consideration of soft facts shall complete user feedback with implicit information, which is integrated into the Product Backlog. This way, the customer value is steadily increased.
5. Conclusion

The article at hand explores why the dominant approach in physical product development, the sequential stage-gate process model, is overstrained with the realization of radical product innovation. On the contrary, Scrum is characterized by agile and highly iterative processes. The process model has been suggested to enable fast and cost-efficient development projects and to generate an innovation-friendly environment within the software industry. The authors show that an adoption of Scrum to physical development processes can succeed on the basis of demonstration and ramp up factories and their specific characteristics. These enable the implementation of the process model through

- the application of a PLM system ensuring data consistency,
- the work of interdisciplinary development teams with access to a modern ICT infrastructure aiming at the successful implementation of an integrated product and process development,
- the use of flexible production resources which allow a rapid response to product-specific requirement changes and
- the use of a sensor-based testing environment for the complete detection of user feedback.

The successful development of the radically innovative StreetScooter vehicles with the help of the Demonstration Factory Aachen within a few years proves the suitability of this type of infrastructure for highly iterative product development processes. In combination with the application of Scrum ramp up and demonstration factories contribute to the optimization of physical product development processes and master the complex implementation of radically innovative ideas.

The paper presented is of conceptual character and possesses limitations with regards to the validation of the methodology which remains to be investigated in further research. Among these limitations is the absence of an exact quantification RoE and the proof of a correlation to the suggested methodology.

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