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Procedia CIRP 50 (2016) 166 – 172

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26th CIRP Design Conference

Using e-mobility as an enabler for a fast and lean product development to optimize the return of engineering with the example of lithium-ion battery

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Abstract

As innovation cycles for new technology products accelerate, markets also demand more complex products with a highly individualized design. Particularly, electric cars represent this case and complexity is not only driven by product variants, but also by an increasing proportion and importance of software applications in value creation. However, the reference processes to develop these automotive products were established two decades ago. The reference process which is used by automotive OEMs is the integrated product and process development which bases on the concept of simultaneous engineering. In contrast to conventional cars with a combustion engine, product architectures for electric vehicles can be planned differently with the lithium-ion battery as the central and most expensive component and can be designed with more degrees of freedom. Such a product architecture can also be simplified that complexity is reduced for both, the product and the development process. Changes in terms of product architecture also imply that there are changes in the technological knowledge of the automotive OEM. It must focus on key technologies. Consequently, suppliers have got the chance to advance from suppliers, who produce products on demand, to technological experts, who provide technology platforms. The development process, moreover, has to evolve from typical stage-gate-concepts to a more agile process tailored to suit continuously changing requirements to fulfil the demand for a fast product qualification for series production. So, even shorter innovation cycles and time-to-market periods can be reached. Certainly, this has an effect on financial aspects with the objective to design the organisational process as lean as possible. Finally, the more agile process design serves an optimised ratio between engineering expenses and customer value – called Return on Engineering. It is the central paradigm to which process design and methods for product development need to adhere.

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Peer-review under responsibility of the organizing committee of the 26th CIRP Design Conference

Keywords: Product and Process Development; Design Methodology; Design Process Management and Organization; E-Mobility; Lithium-Ion Battery

1. Introduction

E-Mobility has gained more and more significance over the recent years. This will rise in the future with emission regulations for automotive companies which can only be adhered to if electric vehicles have a certain share in product portfolios. Electric vehicles contain new components and functions. These components do not only concern the drive train (electric engine, battery pack and power electronics), but also other functional elements like electric parts and software applications. Overall, automotive companies (named OEM hereafter) are challenged to industrialize disruptive technologies and to integrate them into the vehicle with a rising significance of e-mobility. [1]

A shift in the customer's expectation can be observed with the mentioned changes in product functions and components.

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doi:10.1016/j.procir.2016.05.085

Whereas vehicle dynamics and drive train performance have been a major criterion in market differentiation before, nowadays such criteria are range provided by the lithium-ion battery, connected systems and connected services. [2]

Regarding perspectives of future developments for the battery as a key component, automotive companies may need to reorder their key competences. Formerly, those companies had full know-how of performance parts, e.g. combustion engine. Today, performance is mostly defined by the battery and almost every automotive company does not develop and build battery cells by themselves, but buy them from suppliers. And for the future, it is not clear, whether it will stay this way or if know-how of battery cells will be acquired by OEMs.

For these described changes in the electric automotive product and shifting proportions in importance between mechanical and electric parts, it is inevitable to imply adaptions for the development process in the same way.

This paper therefore discusses how the methodic approach of product development can confront the described changes in automotive products and market demand. Upon the background of state-of-the-art product development, three key enablers will be identified to overcome the mentioned challenges.

2. Background

The paper emphasizes three fields of research concerning a fast and lean product development in the context of e-mobility. Firstly, integrated product and process development is examined. This is followed by an encounter of principles of scrum, an agile development method. Additionally, the paradigm of Return on Engineering and its implications are outlined.

2.1. Integrated Product and Process Development

In an effort to fulfill and improve customer satisfaction and meet the competitive global market – the simultaneous product engineering evolved into Integrated Product and Process Development (IPPD). This concept was conceptualized in the 1990s. Since then various industries have had implemented and refined it. Per definition the IPPD is “a management technique that simultaneously integrates all essential acquisition activities through the use of multidisciplinary teams to optimize the design, manufacturing and supportability processes. IPPD facilitates meeting cost and performance objectives from product concept through production” [3].

Within the domain of IPPD, the specialized Integrated Product Team (IPT) is responsible for development and delivery of the product to the market [3]. The time-to-market is very crucial for market domination within the lifecycle of the product. Therefore, the boundaries of design scope are reduced insignificantly at the early stage of product development allowing a significant reduction of the time-to-market. Other than just aiming to capture market domination by achieving reduced time-to-market, IPT has to ensure that the product produced meets the quality standards. For which, the team should be able to develop a sustainable standardized process and product development. This ought to be realized by identifying, quantifying and determining all the relevant restrictions of the product and process [4]. This will lead to the possibilities of process standardizations during the product development process.

One basic concept for process standardization for the IPPD is the Stage Gate Model. Its name derives from the alternation between process phases (stages) and milestones (gates), where deliverables of the previous phase are considered and a decision is made, whether the next stage can begin or work content from the previous stage has to be repeated for better results. The decision is made by a specific committee [5]. The scheme of the Stage-Gate-Process is given in figure 1.

The objective of stage gate model is to eliminate less promising innovations in the development process at an early stage and to minimize financial risk [6].

Today the stage gate model is implemented in various industries involving themselves in product development processes [7]. To fulfil the quality perceptive of product and to eliminate resources being wasted, precise stage wise result oriented definition and monitoring of process specific content is essential. The effectiveness of stage gate model is realized with the aid of various quality decision points, it is determined based on the current status if the process of the project is to be continued, adapted/revised or to be terminated [8]. If the desired quality criteria are not met the development process cannot pass a gate. Quality gates provide a distinct checkpoint where specifically defined requirements are reviewed in a coordinated effort between process customer and process supplier or product customer and product supplier [9].

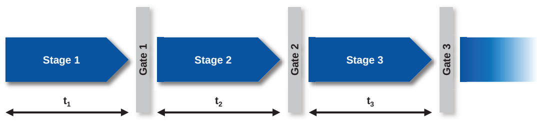

Figure 1 Visualization of a generic Stage-Gate-Process

2.2. Scrum in an Agile Product Development Environment

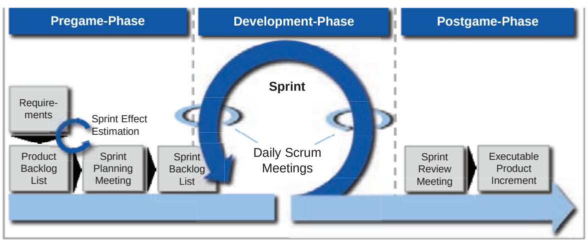

Figure 2 The Scrum Approach [13]

An agile method which is used in industrial planning processes is Scrum [10]. Its basis is the assumption that development processes take place in a volatile environment. This means that the course of the project is not foreseeable with changing variables like availability of qualified personnel or unplanned occurring obstacles. [11] For this, scrum is an empiric approach to handle the complex situation with high flexibility by continuously correcting the course of action with adequate management activities [12].

The scrum approach (see figure 1) consists of three phases. These are the pregame phase, development phase and postgame phase. Product requirements are set in the pregame phase. They are documented in the product backlog list and checked in a sprint planning meeting to determine activities and expenditures for the sprint. The sprint is the nucleus of the development phase and can last for days or weeks depending on the scope of action. Within the sprint, the development takes place and engineering results are generated. In contrast to IPPD, engineers concentrate on one specific task or component of the product, respectively. Here, daily scrum meetings serve to compare results and react to influences in a flexible way. In the postgame phase the scrum is finalised by a sprint review meeting in which the executable product increment – the sprint result – is assessed.

2.3. Return on Engineering

Due to cost pressure for automotive products, it is essential to avoid over-engineering as a kind of idle performance. On the other hand, a high level of cost efficiency can be achieved through an increased customer value for the product [14].

Approaching the combination of an increased customer value – achieved by a differentiation strategy – and an efficient and economic production, target value is the so called Return on Engineering (RoE). It is the ratio of achieved value (for the customer) and engineering costs among overall expenses.

By its approach, the RoE matches the idea of Return on Investment (ROI), which is a performance measure relating gains of an investment with the invested amount to compare investment efficiencies [15].

Other than ROI, the RoE pursues specific targets, which can be described by a formula given below:

$$RoE = \frac{T}{2} + \frac{I}{10} \tag{1}$$

with T = Time-to-Market and I = Invest. A reduction of time-to-market by half and necessary invest by 90% are the target to which product development should adhere in the context of RoE. This means it can be understood as target paradigm to enhance development processes in time and invest costs. Thus, the formula has no units, but summarizes the targets of RoE. Additionally it can be stated that the RoE merges preventing over-engineering with complexity reduction for the product and lean and scalable production systems. Beside product development, particularly the time for ramp-up has the potential to be cut in this case. [16; 17]

The RoE is a valid paradigm for disruptive technologies most of all. However, its basic idea can be taken as a target for well-established product development projects in the automotive industry.

3. Purpose

In general, product development underlies the influences from its environment. These boundary conditions are dynamic and they have to be considered finding the right methodic approach to development processes. In this chapter, three major influences are introduced to outline the challenges for product development now and in the next years. One of them is the advancing software integration into automotive products (see chapter 3.1), followed by perceived quality from the customer's perspective (see chapter 3.2). At last, digitalization and industry 4.0 are dealt with in chapter 3.3.

3.1. Advancing Software Integration in Automotive Products

TICHKIEWITZ and RIEL state that "electronics and software control 70% of modern cars' functionality [and] studies predict 90% and more tomorrow". Furthermore, resulting system complexity of the automotive product increases the difficulties for automotive companies to develop products within their usual cycles. These cycles of several years are still long compared to the electronics industry, where life cycles and development of new products take a year, e.g. smartphones. So, it will be a challenge to "master interdisciplinary, horizontal issues such as quality, reliability, and functional safety". In consequence, the challenges have to overcome in an completely integrated way. [18]

3.2. Prediction of perceived quality is a challenge in disruptive technologies

Consumers decide about a product twice during its consumption. Firstly, the consumer scrutinizes the product which is going to be purchased, "Pre-Purchase Perceptive". During this phase, the consumer can evaluate the product parametrically, i.e. by its features, brand value, design, build quality, Purchase Price and also considers the cost the consumer pays for a new and uncertain technology used in the product. Likewise, the consumer also scrutinizes other similar products in market as the consumer has a choice of alternatives, i.e. "Purchase means choosing" [19]. Finally, after the evaluation of various product parameters, the consumer purchases the product and starts utilizing the product based on individualistic understanding about the product. In this phase the consumer scrutinizes the product more personally and emotionally for the lifespan use of the product, "Post-Purchase Perceptive". The repurchase of a consecutive similar product will be based on the "Post-Purchase" experience of the consumer.

During the utilization phase of the product, the consumer's interaction and understanding of the product evolves. Simultaneously, the quality perceptive of the product to the consumer gradually increases. Capturing these psychological evolutions of the consumer regarding the product is essential and vital for the fulfillment of consumer value perceptive.

Today, automotive manufacturers take advantage over the market by understanding and selectively fulfilling the consumer's pre-perceptive and post-perceptive value addition to the product [20]. The makers of electric cars are challenged by the consumer's perceptive of and interaction with e-mobility. Also, due to the early stage of the product in the market, understanding these interactions, expectations and perceptive about the product is challenging.

3.3. Advanced digitalization within Industry 4.0 and its impact on development processes

Originally, Industry 4.0 is a German term to which an English equivalent can be "Industrial Internet" a term used by General Electrics [21]. Hermann et al. [22] define Industry 4.0 as a superordinate term which aggregates the aspects of Cyber-Physical-Systems, Internet of Things, Internet of Services and Smart Factory. However, this distinction is not emphasized in further passages.

In the context of this paper in particular, technological possibilities concerning communication, virtual reality and connected systems play an important role on enabling a lean accelerated time-to-market. This can be summarized with the term digitalization. In the future, there will be vast possibilities to collaborate in development tasks without being in the same location, but working in interdisciplinary development teams across different continents.

4. Findings

In the first chapter of this paper, it has already been stated that the number of functionalities in automotive products, especially in electric vehicles, will rise in the future and this fact will cause an increased complexity in the product as well as in planning processes and overall supply chain or business relations, respectively. For each of these dimensions, the authors identify key enablers to decrease the complexity and save time in the development process. The enablers are scrutinized in the following passages.

4.1. Enabler Product Architecture

In general, product architecture assigns the functions of a product to its physical structure. Subsequently, it maps functional elements to product components [23]. More precisely, it consists of three key factors. The first one is the arrangement of functional elements, the second one the allocation of functional elements to a physical component. Additionally, specifications of interfaces between interacting components characterize the product architecture.

It can be stated that product architecture is a key driver of the performance of a manufacturing firm, because in the development process technical complexity, i.e. product architecture among others, designates organizational complexity. This is why product architecture is an important element in managerial decision making by choosing the right product structure for a function structure. Concerning the typology of product architectures, modular and integral product structure can be differentiated. A modular structure allocates functional elements one-to-one into physical elements with decoupled interfaces, whereas an integral one has coupled interfaces to combine certain functions in a component [24; 25].

For a complex product like an electric driven vehicle, the enablers in terms of product structure lie in a decrease of complexity regarding full vehicle design (see figure 3).

To achieve higher efficiency, increased value addition and lower cost per output [26] – standardization in form of modular structures, systems or architecture is one possible approach. This approach also aids in higher process transparency. But these implementations and developments require detailed information regarding the processes and also upon successful implementation – standardization will limit the flexibility towards change and innovations.

To allow development and flexibility of modules, information defining the modules and the link between

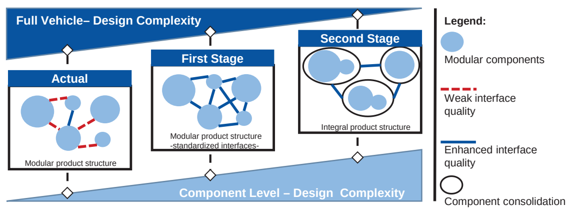

Figure 3 Correlation between planning complexity and the degree of standardization and integration, respectively

integrating modules enable companies to suitably use it to its requirements [27]. Therefore, the modules are often set up in a process library which is a knowledge-management tool and a database of process know-how. This is important for interfaces between mechanical engineering and software development as the advancing software integration implies that more sensors and actors are integrated into the vehicle product.

4.2. Enabler Product Development Process

In chapter 2, Scrum has already been introduced as an agile method to accelerate and enhance the performance of IPPD. In contrast to IPPD, where development contents are structured and planned in advance with the stage gate model, Scrum is more dynamic with work contents only specified for the next Scrum phase. For this and the mentioned advancing digitalization (see chapter 3), three key levers have been identified for the product development process to increase RoE (see figure 5).

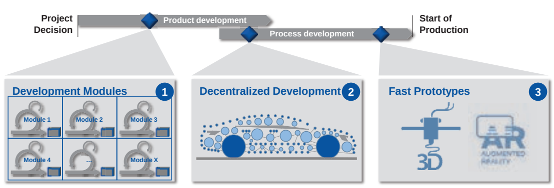

Figure 4 Three major levers in product and process development to increase development performance (milestones only exemplary)

The first lever is a modularization of engineering tasks. Especially, in the Scrum process every single Scrum is planned immediately before its beginning. For different work contents Scrums will have different characteristics. If these characteristics are generically put into categories, Scrum processes can be divided into development modules. For each module requirements, contents of sprint planning meeting and sprint backlog are standardized then (cf. figure 2). The objective here is to cut expenses for sprint planning and other project management tasks to fully concentrate on the sprint execution. A modularization of development content serves the handling of complexity by decoupling development contents, e.g. hardware and software engineering (compare chapter 3.1). An example could be the battery pack with its hardware components and software control systems, such as the battery management system (BMS).

The second lever is a mere decentralized development which derives from possibilities in digitalized networks as mentioned in passage 2.3 and shifting key competences of OEMs. In this case, the product becomes a platform for the OEM and its partners to integrate the technologies from their field of competence. Subsequently, such a platform is useful to validate prototype technologies.

Nevertheless, the perception of prototypes in future development processes has to be recalibrated. This is a third lever concerning product development processes. In a conservative planning of prototypes, they have got three main objectives. Firstly, early prototypes during concept stages serve to evaluate if certain concepts fulfill their desired function in general and to persuade stakeholders of that concept or function. Secondly, prototypes are used to persuade stakeholders in disruptive technologies. A third reason for a functional prototype is testing, risk analyses etc.[28] With a changing customer perception between conventionally driven and electric cars, the architectural product changes have got a direct impact on prototypes in product development. Prototypes will need to be used primarily to test customer acceptance in early stages for a high perceived quality. This means there is a need for prototypes which fulfill a certain function on a technically mature level with little development expense at the same time. And, generally, prototypes need to be put into practice efficiently, adhering to the concept of RoE. This prototype efficiency is most important for a cost-intensive part like the lithium-ion battery.

4.3. Enabler Supply Chain and Business Relations

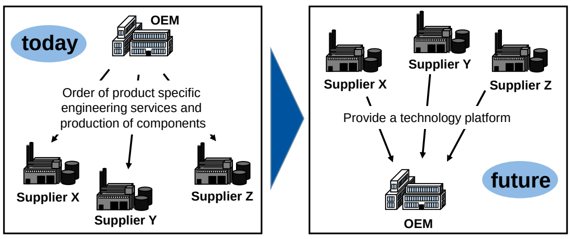

Figure 5 Differing business models between a supplier and technology provider

The third enabler is a change in the business model of automotive OEMs. With an increasing number of integrated functions into electric cars (as well as into industrial products in general) must focus on their key competences. This does not only help to handle advancing software integration, but also bundle competences to target the customer's perceived quality.

This is the chance for suppliers to recalibrate their relation to the supplied OEM. Whereas today supplied components are mostly developed and produced adhering specifications by the OEM, a supplier will engineer and produce technologies in the future. Such a technology platform will be integrated into the OEM's product by adjusting interfaces between product and technology. By this, supplier and OEM are on the same hierarchical level in their business relation then.

An equal business relation has got two imminent advantages for the OEM in terms of costs. On the one hand, a supplier offering a technology platform can offer it to more than one customer for a lower price by allocating engineering expenditures. On the other hand, the product architecture becomes less complex and product development leaner than before.

5. Discussion

In chapter 4, three enablers have been presented which facilitate product development, particularly for electric vehicles in a disruptive development approach. At this point, it will be discussed to which extent the identified enablers can be put into practice. A German manufacturer, which develops and produces electric light-vehicles, serves as a use case. This company uses Scrum as central method in product development. Due to costs and planned start of production, the stage gate logic is set aside completely.

In terms of product architecture (see chapter 4.1), the electric car has got a high level of integration, supporting a less complex development. For example, the drive train including battery system, engine and electronic systems is an integrated part of the product and its development is completely outsourced. Subsequently, the product architecture or components, respectively, remain modular, but from a development perspective it has an integrated structure and mainly interfaces to other product parts have to be considered by the manufacturer.

The above outlined product structure also implies that development is not done by one party – the manufacturer -, but is accomplished in a network. For this network a PLC system serves as central platform to exchange data, e.g. CAD files. Product development itself has got a modular structure. Scrum processes are assigned to lead engineering groups (LEG). One of the LEGs is focused by the Scrum for each week. Furthermore, prototypes are planned in a different way compared to the IPPD. Although, there is a prototype roadmap, this roadmap does not purely derive from engineering to validate product functions. But it is established upon requirements from product management, which resemble market needs. Planning of prototypes is deduced from the requirements. The key of such a prototype strategy is to define the right measurement categories and indicators, which are addressed by prototypes. Here, the main difference in outward appearance of prototypes is that they are not fullyfledged, but they are specifically designed to address a certain measureable indicator. For example, there are battery tests in terms of range to get a correlation between various wheel widths and diameters. For this, it is enough to have a rolling chassis with the lithium-ion battery pack as focus of interest. Further, prototype planning is flexible and dynamic. Whereas normally adjustments will be aggregated in a next prototype phase in IPPD, in this case prototypes are modified within the same prototype phase leading to several prototype "sub-phases".

The depicted manufacturer also resembles the approach described in chapter 4.3 as suppliers establish themselves as technology providers. Taking the example of the drive train including the lithium-ion battery, the supplier develops its cutting edge technology themselves. The product serves as a platform and manufacturer as well as supplier operates on eye level. In the class of light-vehicles, there is room for development in smart battery geometries with an optimized fit into the vehicle's body. The advantages are obvious. The supplier is able to develop and test its technology in practice with a real product periphery. For the vehicle manufacturer, development becomes less complex and the organization can learn from the supplier's know-how regarding battery pack and drive train, respectively. As this has been an exemplary component, the concept is also applicable for other components of the light-vehicle. In consequence, product development becomes lean and adheres to the RoE. On the one hand, the manufacturer's development team can concentrate on key components and therefore save time. On the other hand, the supplier invests into the development, which cuts costs for product development as well.

6. Conclusion

Integrated product and process development in combination with agile methods, such as Scrum, are the State-of-the-Art in automotive product development, especially of electric vehicles.

In this paper, three enablers for an optimized product development process are identified and scrutinized in order to aid an increased development performance and, subsequently, to result in an enhanced RoE. Furthermore, the application in practice is discussed with an exemplary use case at a German manufacturer of electric light-vehicles. As industrialization of the product is still in progress, it will be interesting to see quantified numbers for how long development took place and which expanses will be necessary overall.

Further research is also needed to refine the presented concepts and methods from this paper. In particular, it has to be quantified, which amount in costs is to be saved by implementing the methods like in the use case in chapter 5.

7. Acknowledgement

The presented results have been developed by the Chair of Production Engineering of E-Mobility Components (PEM) at RWTH Aachen within the research project ExLaLiB, funded by the state of North-Rhine Westfalia and the European Union within the program Ziel 2.

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