The role of quality management in future innovation processes for smart products

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Future products are smart. They are equipped with artificial intelligence and are able to cross-link with other products. In combination with global trends, such as cost pressure from international competition, the development of smart products provides major challenges for future innovation processes. For example, companies need to align modern product features with customer needs by identifying suitable self-optimization or cross-linked application scenarios. Furthermore, there is a high demand for harmonizing collaboration activities of different engineering disciplines involved into development in order to offer viable product solutions to the market on time and on budget. The above-named challenges contain various threats like customer mismatch, the availability of necessary product or production technologies or a delay of the market launch because of necessary iterations for result coordination of the different involved engineering disciplines. The present paper discusses future challenges for innovation processes using the example of smart products. In order to address the challenges, suitable approaches of quality management will be elaborated and discussed. These are concepts such as social media analysis for requirement elicitation or 3D printing technologies for rapid concept validation.

Keywords: innovation management, quality management, agile development

Introduction: future products are smart

Within the past years, digitalization has massively increased in both social as well as in work life. A study of the German university of Regensburg in 2014 showed, that the increasing digitalization has reached all parts of the society and implies a massive influence on work routines. 74 percent of people interviewed within the study think that digitalization has a strong influence on work life in comparison to 61 percent in 2013. On the one hand, there are new business models which bring a whole new flexibility and create new jobs. On the other hand, digitalization also increases the stress level due to the employee’s permanent reachability. Social media is no longer used only to keep up with family and friends but is also entering work life with numerous new applications to optimize human interaction within companies. 26 percent stated that they are already using social media in their job. (Wittmann et al., 2014)

Since the digitalization of the society permanently continues, new products also have to undergo further development. Products have to ‘digitalize’ and have to be able to connect with each other, with people and the environment. These challenges – digitalization and connection – are also two core elements of the German concept ‘Industrie 4.0’. Within the ‘Aachen Approach’, three main areas of research for the field of Industry 4.0 (or digitalization and connection within an industrial environment) are defined (Brecher, 2014):

- Smart services,
- Smart production and
- Smart products.

The present paper brings smart products into focus. These are products which contain information technology (IT). This information technology is revolutionizing products and can be realized by micro-chips, data storage capability, software and/or different sensors. The sensors serve the purpose of gathering data about the environment. This data is processed to useful information with the help of micro-chips and corresponding software. (Rijsdijk and Hultink, 2002; Porter and Heppelmann, 2014)

In order to properly define the term ‘smart product’, Rijsdijk and Hultink describe seven attributes that cannot be found or only to a limited level in non-smart products. These attributes are the following: autonomy, adaptability, reactivity, multi-functionality, ability to cooperate, humanlike interaction, and personality (also see figure 1). Rijsdijk and Hultink characterize the smartness of a product as the “extend to which it possesses these dimensions”. (Rijsdijk and Hultink, 2009)

figure 1: attributes characterizing smart products

The first attribute of *autonomy* describes the ability whether a product operates towards a specified goal and its behavior can be seen as independent without any interference of a user (Rijsdijk and Hultink, 2009; Rijsdijk and Hultink, 2002). Furthermore, smart products *adapt* to consumer needs, the environment and anticipate consumer’s behavior. Adaptability therefore is the second attribute to describe the smartness of a product. Adaptability can be understood as the ability to meet the requirements of the environment due to the products functioning to improve the performance in specific tasks (Nicoll, 1999; Turing, 2010; Rijsdijk and Hultink, 2009). *Reactivity* is the third attribute. It refers to the capability to react, if the considered environment changes. The attribute reactivity extends the concept of adaptability as it also considers changes in the environment the product adapted to in the beginning (Bradshaw, 1997; Rijsdijk and Hultink, 2009; Porter and Heppelmann, 2014). The fourth attribute to describe smart products is *multi-functionality*. As the term already implies, it refers to the characteristic that a product may be able to satisfy multiple requirements by multiple functions. Dhebar points out that due to the increasing use of information technology products in many cases provide a larger set of functionalities (Dhebar, 1995; Rijsdijk and Hultink, 2009; Porter and Heppelmann, 2014). The following attribute is about the *ability of cooperation* with other products and to align the different objectives. Smart products will also have to be aware of their relationships to other products. Prerequisite is the possibility of communication between different products (Nicoll, 1999; Rijsdijk and Hultink, 2009; Porter and Heppelmann, 2014). The sixth attribute is called *humanlike interaction*. It describes the way products are able to communicate with humans in a natural way. Porter and Heppelmann for example mentioned that the interface design of products will be one big challenge for the development of smart products. These products will have to provide for example voice recognition and production or gesture control to communicate with the user (Porter and Heppelmann, 2014). The seventh and final attribute is called *personality*. Bradshaw proposed that for example a software agent should have a personality and emotional states. This would make it easier for humans to communicate and interact with the agent. This concept has to be adapted to smart products. (Bradshaw, 1997)

It has already been mentioned that these seven attributes are indicators for smart products. Of course they cannot be understood as criteria which have to be fulfilled up to a hundred percent. Also products which fulfill only a few of these attributes or even only to a certain degree may be considered as smart products. An example is the ‘Smart Toothbrush’. It extends the simple electrical toothbrush by certain smart functionalities (*multi-functionality*). It is able to connect, communicate and cooperate with a smartphone, by which it also communicates to the user (*ability of cooperation*). It aims at the goal of optimizing the brushing performance and therefore delivers a direct feedback (*autonomy*). It is also able to adapt the special needs of the user’s teeth in coordination with the dentist (*adaptability*). Thus, it fulfills some but not all of the above mentioned attributes for smart products. (Oral-B, 2015)

The role of quality management in future innovation processes

Digitalization, connection and the increasing development and use of smart products also imply new challenges for future innovation processes. In figure 2 four fields of action in innovation-related quality management and development of smart products are shown. First of all, there is the challenge to design suitable application scenarios for smart products. Since product complexity as well as functionality constantly increases, a major challenge will be to correctly understand and interpret customer needs and to derive suitable requirements for the innovation process. The analysis of social media is an approach to get access to valuable customer feedback. Furthermore, the increasing number of sensors and information technology integrated into smart products generates data which can be transferred into useful information by data mining approaches to define suitable application scenarios of how the customer uses the product (see section 1).

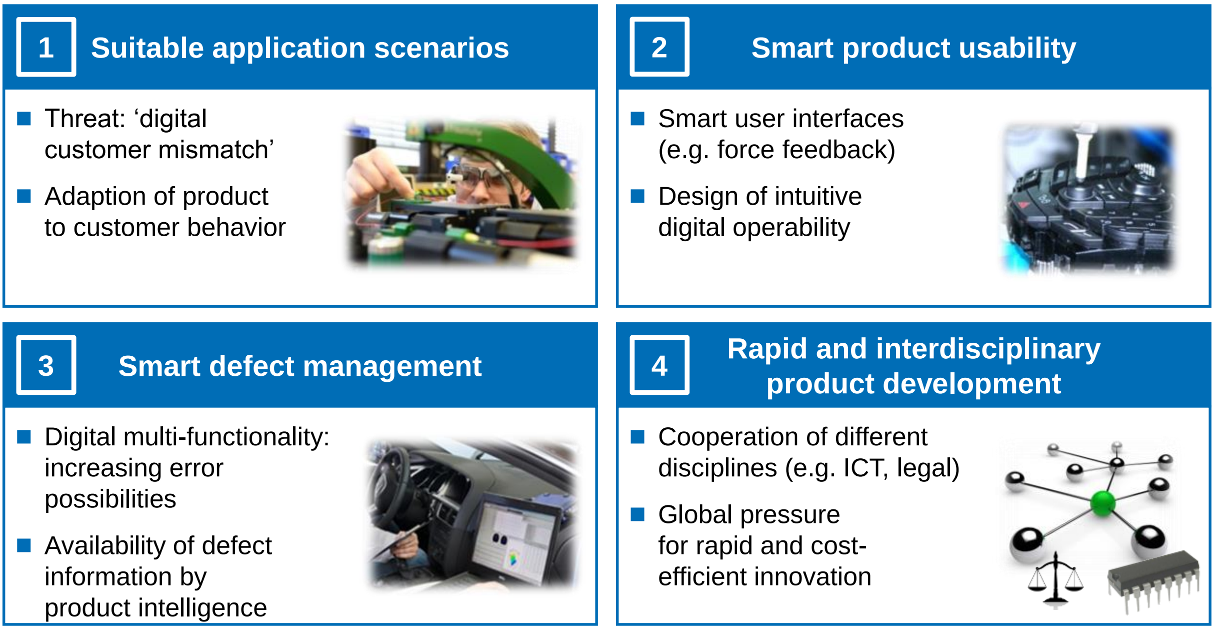

figure 2: fields of action for innovation-related quality management

The increasing level of complexity due to multi-functionality of the product also complicates its operation in daily life. Therefore another challenge is the design of ‘smart user interfaces’. A promising approach is to transfer perceived quality concepts from physical perception (haptic, optic etc. of products) to the digital world and thus to create intuitively functional products (see section 2). Multi-functionality implies ‘multi-malfunctionality’. This means that the more complex products get, the more defects can occur. Thus a ‘smart defect management’ will play an important role by delivering approaches like defect coding and collecting field data to find sources for defects, identify the affected products and faster rectify errors due to data mining (see section 3). These complex products make high demands on the innovation and development process. They require a close cooperation between mechanical and electrical engineers as well as computer scientists. Self-organizing, intelligent, adaptable products with a personality who interact with humans present a whole new set of questions and challenges to the legal department in terms of responsibility and liability. Due to cost pressure development cycles have to be shortened by adapting concepts of agile product development combined with rapid validation to the innovation process of smart products (see section 4).

1. Recording of suitable application scenarios with data mining and social media analysis

Successful product innovation requires a deep understanding of customer demands and needs. In the innovation process of smart products, a mismatch between the characteristic of a product and the customer requirements can always occur. Therefore, the identification of suitable application scenarios is necessary in order to adapt product functionality to the customer behavior. This means within the innovation and development process the customer's specific product requirements has to be decoded and suitable application scenarios has to be designed based on the collected field data. An important field of action refers to social media analysis for measuring customer satisfaction as well as the elicitation of customer requirements. Social media facilitates social interaction and communication in daily life. In the context of innovation processes, it provides authentic field data which is also accessible for third parties. In addition to the internal company database consisting e.g. of sales statistics and complaint rates, companies can access external information by using official statistics and data from social networks (Böhler, 2004). Online customer reviews provide numerous information about the customer's perceived quality and experienced functionality of a product during usage.

The importance of social media is also displayed in investigations of today's customer's purchasing decisions. A ratio of 62 % of all potential customers uses the product review by a third party in order to get basic information before purchasing a product. The competitiveness of a company is directly affected by product reviews. The perception of three negative opinion are sufficient for 37% of all potential customers in order to reject a purchase decision (Heinrichs et al., 2015). Overall, the product review by third parties is decisive for 81 % of all potential customers in regard to their own buying decision (E-Tailing Group Inc., 2007). Virtual communication platforms combined with the in principle unlimited number of recipients stimulate this snowball effect (Mast and Huck-Sandhu, 2013).

A major challenge for analyzing social media content in the context of innovation processes refers to the task of text selection. Collecting only the relevant online customer reviews out of the masses of texts available in social media is a crucial step. Finding those comments displaying the authentic customer opinion and needs is quite difficult, especially with automated processes, because the reliable feedback has to be isolated from fake or ironic reviews. Before this a kind of technical preparation has to be conducted which contains inference of the customer's needs from noisy data, such as typing errors or misspellings. At present, research on social media analysis is based on a restricted data set. The aim is to enlarge research on all legally available data that means all data which can be read without prior registration. Mainly the research is based on formal linguistic pattern analysis to avoid language-given ambiguity, irony etc. These patterns are consecutively transformed into algorithms.

An important enabler for social media analysis is represented by data mining approaches. Due to increasing storage and processing capacity over the decades since the late 1970, it became possible to handle huge amounts of data in short time periods (Chen, Mao and Liu, 2014). Challenging for data handling are the heterogeneous and diverse dimensionalities, because different devices for data collection use different recording schemata or protocols (Xindong Wu et al., 2014). Governmental agencies, the health care industry, biomedical researchers and private businesses spend huge amounts of effort and money in order to collect, aggregate and share large data volumes, because they assume there heavy growth potential. Especially when external large data sets are linked with internal personal information, the privacy and in some cases the personal security is endangered. (Matturdi et al., 2014)

2. Optimizing usability experience by designing 'Perceived Quality'

In Perceived Quality the subjective evaluation of a customer regarding a product is collected (Betzold et al., 2008). That is why it has its biggest impact on the development process in the design phase. The research field of Perceived Quality covers all methods for recording and objectification of requirements for technical specifications. It serves as a multidisciplinary approach to design the product quality. The increasing of customer satisfaction by selective design of product perception is the key to create successful smart products with a high user acceptance.

In order to design smart products, generally the functionality rises by the soaring digitization. This increases the complexity of the product handling and poses major challenges to the design of user interfaces. Smart interfaces offer new possibilities for designing usability. For example smart wearables like smart glasses often have very innovative human-machine-interfaces to make the application in complex scenarios manageable. In the future it is assumed that smart devices support the production staff and simultaneously adopt documentation, information, communication and measurement tasks. The development of smart wearables focusses currently mostly applications in the private field. (Schmitt, 2015) However, according to published studies, the largest economic potential of smart devices is located in the industrial field (McKinsey Global Institute, 2015). Therefore, the perceived quality of smart wearables has to be matched with the requirements of an industrial worker, because the surrounding conditions require a high robustness and reliability.

Such applications demand an interdisciplinary cross-sectoral cooperation that goes far beyond the field of design. The marketing discipline is in charge of determining the willingness of customers to pay for a product and collects all the drivers that affect the product value. The communication science transmits the subjective voice of the customer in quantitative actionable data as objective as possible. Psychologists study the cognitive and emotional contexts of product perception, taking all human senses into account. Furthermore, also the disciplines psychophysics, metrology, virtual reality, product development and quality management are involved. (Schmitt, 2014)

A central challenge is the design of intuitive product operability despite increasing functional complexity. Therefore the integration of different disciplines and harmonization of design and product development are important factors for the success of a smart product. From there the design of user interfaces and product perception by applying the 'Perceived Quality' approach requires high research efforts. In particular correlations of technical product features with the subjective customer perception and evaluation for an optimal product specification are necessary.

3. Smart defect management by defect coding approaches

From the multi-functionality of smart products results an increase of defect possibilities. Besides a comprehensive use of the FMEA it makes an effective defect management much more important. Smart products records comprehensive data about their state and thereby about their defects and provide them linked systems in the network. They often have the ability to realize, when a defect occurs. Smart products are also able to send a report about their own condition during production or customer use to the manufacturer or the customer (Porter and Heppelmann, 2014). This makes a fast defect protection not only possible, but absolutely necessary. Also social media analysis provides information about non-satisfactory products which are caused by failures. That is why companies have to act quickly (Schmitt, Stiller and Falk, 2014).

Handling and consolidation of heterogeneous defect data from different sources (e.g. smart products, manufacturing execution systems) is challenging and quite important for the successful failure elimination. For an efficient handling of incoming complaints the data set has to be structured (Effey and Schmitt, 2012). That is the reason for the high influence of the data organization phase on the whole complaint management process, because in this phase relevant data is collected and consolidates for the following process steps (Linder and Schmitt, 2015). Another challenge is the effort of filtering and analyzing a huge amount of feedback data, especially when a product is produced more than a million times.

Important research fields are the development of defect coding procedures for a consistent defect language to facilitate and accelerate the identification and the handling of failures. For improvement in efficiency data based analysis approaches should be used for intelligent and rapid defect detection. Because smart products collect a lot of data about their status it is necessary to identify the data about defects rapidly and use them effectively for a fast product optimization.

4. Rapid and interdisciplinary product development

The above-named fields of action support the innovation process of companies and organizations in product-related challenges. Recently a profound change for the organization of product innovation processes can be detected. Contemporary product and process development is generally organized according to stage gate models (Cooper, 1990) or closely-related quality gate concepts (Hammers and Schmitt, 2009). Due to increasing product complexity, globally distributed and interdisciplinary teams for product development as well as efforts on reducing development time and cost, the stage gate idea a framework for organizing innovation processes is also challenged.
Beside these process immanent challenges, there is the possibility to realize prototypes significantly faster and in a more cost-effective way. In particular, the plastic-based 3D printing processes have taken a rapid technological development which comes along with a very strong market growth (Wohlers, 2014). These trends in combination require new approaches for product innovation processes.

4.1. Rapid and interdisciplinary product development with an agile approach

Ongoing approaches for project management within physical product development bear resemblance to agile software development applied within the field of information and communication technologies (Schnalzer et al., 2013, Špundak, 2014). Agile techniques, such as SCRUM, pursue the objective of increasing flexibility and reactivity within product development by reducing bureaucracy, deploying small product development teams as well as working in short iteration cycles (Dybå and Dingsøyr, 2008). As a result, customer satisfaction can be increased by flexible reactions on changing requirements during the innovation process.

A central research approach consists of transferring agile development concepts from software development to smart product development, in order to accelerate the innovation processes and makes it more flexible. By transferring agile concepts from software development to innovation management for smart products, novel challenges for innovation-related quality management arise. One major challenge is the measurement and controlling of product maturity enhancement of complex products. Within agile projects, results are based on short iteration cycles performed by small teams. Especially for complex products, component design and development needs to be assigned to numerous development teams. Due to the iterative process character of each team as well as the flexible adjustment of product requirements during the innovation process, product maturity enhancement varies from team to team. Consequently, future quality management for agile innovation processes needs to synchronize maturity enhancement throughout the whole product development scope. Furthermore, the coordination of results from development teams becomes more complex. Only the synchronized development progress leads to a mutual success of the final product. As components and modules need to be integrated to the final product in its entirety, interfaces need to be clearly defined and harmonized continuously throughout the entire innovation process for ensuring a proven product development in due time.

4.2. Rapid validation with rapid prototyping in agile development processes

An important field of action for quality management in smart product development represents the validation of the product design in different stages of the development process, because smart products have often a high degree of complexity making regular consideration of a customer feedback during the development process even more necessary. Referring to this, present development in rapid prototyping technologies combined with agile approaches show great promise for accelerating innovation processes by enabling rapid validation cycles. “The continued use of physical prototyping in engineering design practice is based on its strength in helping teams to make ideas tangible, iterate quickly at a low cost, and develop a shared language (Carleton and Cockayne, 2009)”.

Thus, there are great new potentials for the use of prototypes in product innovation processes. Especially the early stages are predestinated, because a very large percentage of product cost is already fixed in the early stages (Ehrlenspiel et al., 2014). In addition, the so-called "rule of ten" of the failure cost means correspondingly, if failure detection is delayed, the cost for defect elimination increases exponentially from phase to phase (Schmitt and Pfeifer, 2015). Through the target-oriented use of prototypes in the early stages of product development positive effects regarding the failure detection and product validation can be achieved (Elverum and Welo, 2014). In addition, feasibility studies for new product ideas can be carried out with the help of prototypes (Schäppi, 2005) and communicated through physical and tangible models (Carleton and Cockayne, 2009). A major challenge is to find the optimum balance between virtual and physical prototypes, because through a successful integration of both forms, the validation process can be improved (Liu, Campbell and Pei, 2013). Consequently, future research in the field of quality management refers to the question in which case a physical prototype has a detectable additional benefit.

An important research approach is the development of a reference process model for smart products that provides a particular prototype application at selected points e.g. for product validation. Besides this organizational topic there are process-specific subjects, like how can the process be optimized regarding production time, cost and quality. In particular, the surface quality and the mechanical properties have still potential for optimization. Another research topic is the development of test planning based on prototypes for agile or traditional development processes, as this positively affects the duration and the product quality of the production ramp-up process.

Summary

Future products are smart. They are equipped with artificial intelligence and are able to cross-link with other products. Their attributes can be classified into seven characteristics which are autonomy, adaptability, reactivity, multi-functionality, ability to cooperate, humanlike interaction, and personality. These characteristics of smart product affect future innovation processes.

Developing products with these abilities poses major challenges to future innovation processes. An outstanding challenge of prospective product development refers to the coordination of different engineering disciplines. In addition, there are further challenges for future innovation processes, such as to create suitable interfaces, to get access to customer requirements, to properly transform these requirements into product characteristics and also to collect field data and rectify errors within the after sales service. Quality management and product development in general is confronted with several changes and challenges regarding future innovation processes for smart products. Especially at the beginning of the innovation process there is the threat of a mismatch between the characteristic of a product and the customer requirements. Therefore suitable application scenarios have to be identified in order to adapt product functionality to the customer behavior. Social media analysis provides useful data regarding customer satisfaction and facilitates the finding of customer requirements. Efficient activities for social media analysis have to be supported by data mining approaches. The developers have to improve the product features for different application scenarios. Based on a deeper understanding of customer perception, product quality can be designed explicitly by pursuing the perceived quality approach during the design of the usability of smart products. This may lead to increased customer satisfaction by a selective design of product perception. Concepts for defect management show great promise for faster product optimization during field stage. Because of the provided data of smart products and precise defect coding approaches defect knowledge can be assembled and used efficiently for rapid product optimization. Agile concepts from software development may help to improve the traditional development process, because they include a higher degree of dynamics and flexibility. Based on agile approaches in combination with a higher consideration of rapid prototyping technologies, there is a high potential for optimization through a new innovation process approach using 3D-printed prototypes for product validation especially during early stages of the development process. Moreover, quality management needs to support cooperation and coordination between all parties involved into the innovation process.

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