3rd Conference on Production Systems and Logistics

Smart Products For Smart Production – A Use Case Overview

Günther Schuh[1], Max-Ferdinand Stroh[1], Jan Hicking[1], Sebastian Kremer[1]
[1]FIR – Institute forIndustrial Management at RWTH Aachen University, Aachen, Germany

Abstract

Industry 4.0 is driven by Cyber-Physical Systems and Smart Products. Smart Products provide a value to both its users and its manufacturers in terms of a closer connection to the customer and his data as well as the provided smart services. However, many companies, especially SMEs, struggle with the transformation of their existing product portfolio into smart products. In order to facilitate this process, this paper presents a set of smart product use cases from a manufacturer's perspective. These use cases can guide the definition of a smart product and be used during its architecture development and realization. Initially the paper gives an introduction in the field of smart products. After that the research results, based on case-study research, are presented. This includes the methodological approach, the case-study data collection and analysis. Finally, a set of use cases, their definitions and components are presented and highlighted from the perspective of a smart product manufacturer.

Keywords

Industry 4.0; Smart Products; Digitalization; Smart Machines; Product-Service-Systems

1. Introduction

The digitalization found its way into the manufacturing environment. Even traditional industries such as mechanical engineering are affected by this trend [1]. The products of mechanical engineering, tools and machines, which previously contained only mechanical parts are becoming smart and connected. In other words, they are enhanced with electronic and digital components such as sensors and microprocessors [2]. The result are smart products. They are based on cyber-physical systems and consist of both physical and digital components [1]. They form the foundation of industry 4.0 and by that, the establishment of collaborative networks [3,4].

Smart products can be used to generate a competitive advantage by improving the services provided to their users [5]. Smart products are an exceptional opportunity of getting a data based, detailed understanding of a company's customer and how the product is actually used. This allows great insight into what future products might look like and which features need to be updated. Smart services can be tailored and continuously improved to serve a customer's need. [6,2,5]

However, to gain those valuable insights, a well architected digital environment needs to be built around a product, finally making it and its insights smart [2,5]. Many companies, especially SMEs struggle with this challenge, as they are lacking the internal knowledge for developing such complex digital products and architectures and even expect a business loss if they fail to place a smart product on the market [6,7].

In order to facilitate the process of developing a smart product as well as helping the business decisions for smart products, an overview of its possible applications in terms of use cases is needed. In the long run those

DOI: https://doi.org/10.15488/12146 publish-Ing.

use case can serve as a basis for the development of the digital architecture of smart products. This is the goal of the underlying research project BlueSAM, which provides SMEs with blueprints for the development of smart products architectures.

For this reason, this paper presents a set of use cases for smart products from a smart product manufacturer's perspective. First of all, the term smart product is defined in the context of this paper. Subsequently the overarching research project and the envisioned smart product development process for SMEs is described. After that the process of case study research is explained and applied. This leads to an empirically derived set of use cases for smart products, that are validated by industry experts and literature.

2. State of the art

Smart products are in the limelight of Industry 4.0 and one of the main topics among the smart factory, smart logistics and smart development [6]. Smart Products, their definitions and differentiations have been widely covered in scientific literature, such as [8,2] and the authors' previous works [9,1,10]. Based on HICKING'S definition in [1,10] the authors define a smart product as "a product, which consists of both a physical and a digital component. They create value for both, its user (mostly the customer) as well its manufacturer. For users a smart product's main added value is to provide smart services. For the manufacturer it is the opportunity to learn from its newly generated usage data". Smart services are a data based combination of both digital and physical services provided by smart products [11].

In mechanical engineering there are two main fields of application for smart products: the use of smart products in the own production and the sale of smart products as well as accompanying services [12]. This paper will focus on the perspective of a smart product manufacturer. Examples for smart products in manufacturing are smart industrial air compressors, software applications for a mobile steering of machines or connected machines which are capable of gathering and analyzing production data in real-time [13,14].

The applications of smart products are only limited by imagination. However, several publications have offered overviews of existing smart product use cases or described specific use cases. Examples are PORTER & HEPPELMANN [2,5], HERTERICH ET AL. [15,16], ABRAMOVICI [17] or MACHCHHAR ET AL. [8]. As this work employs smart product use cases derived from practical applications by Case Study Research [18], the aforementioned works – among others - are applied in their literature based verification process (see section 4.3). This results in the use case overview presented in this paper.

3. Methodology and focus of this paper

As mentioned before the results of this paper are part of an overall research project assisting SMEs in the development of their smart products' digital architecture and infrastructure. This will be with a use case based, smart product reference architecture with focus on SMEs. From this reference architecture, for every use case, blueprints for a smart product architecture will be derived. The development of the reference architecture is based on the process by KRCMAR ET AL. [19]. This will lead to an overall process for the facilitated development of smart products based on blueprints. The process is drafted in Figure 1. Step one is the selection of smart product use cases in the beginning of the development process. It will give SMEs an inspiration into which applications can be realized with their future smart products. Secondly, architecture blueprints will be selected based on the selected use cases. In the third step, the blueprints will be specified and customized into a company-specific architecture. After that the, the process allows the delegation of development tasks among partner companies and external service providers marking the Co-Development phase. This fourth step considers, that most SMEs do not have all capabilities for smart product development in house and therefore need help in form of a Co-Development guideline for partnering up with and managing external partners.

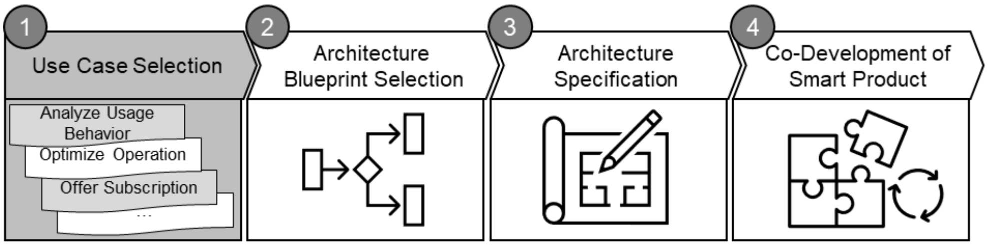

Figure 1: Overall project approach (grey: focus of this paper)

This paper focuses on step one of the envisioned development process, providing a list of smart product use cases based on a smart product manufacturer's perspective. To be up to date, the approach of case study research by EISENHARDT [18,20] was chosen to derive the use cases. It provides use cases derived from empirical evidence, validated with existing literature [18,20,21]. Furthermore, the selected research approach provides valuable insights into the realization of the use cases at the case study partners that could not be achieved by solely focusing on theoretical evidence and existing use case models.

In case study research, theories or hypotheses are evaluated with the help of so called "case studies", that represent empirical data collections from multiple data sources. During the research case studies are collected and then analyzed individually as well as between each other. The identified hypotheses are then developed and enhanced from case to case. After that the derived theories are then verified based on a literature analysis. After 4 to 10 case studies a saturation of the built theory should be reached, meaning, there are no more additions to it [18,20,22,21]. Case study research has become a popular research methodology beyond its origins in social sciences as it delivers an opportunity to analyze theoretical situations where a statistical approach is not feasible or less effective [20,21].

4. Smart Product Use Cases derived from Case Studies

4.1 Selected Case Studies and saturation

In compliance with case study research the set of case studies was very carefully selected in order to lead to valid results. Therefore the selection of use cases was based on theory not on sampling [18,21]. Case study research aims at a replication of results from case to case not on a statistical sampling [18]. Table 1 gives an overview of the case studies selected for this research. The case study companies were selected with the goal to deep dive on use cases analyzing usage data as well as providing smart services to customers. The case studies were selected by company size, measured in number of employees and revenue, the type of their business relationship (business to customer (B2C) or business to business (B2B)), the complexity of their smart product (machine or assembly group), the current lifecycle phase it is in (in use or in development) and their type of company (smart product manufacturer or smart product service provider). The selected set of case studies is both not theoretically identical but also not a random sample of companies. For the company type, next to manufacturers, service providers were chosen on purpose as they offer several smart products or cater to many different customers and thus have a wide knowledge of different applications and use cases for smart products.

Table 1 : Overview of selected case studies

No.	Employees	Revenue	Business type	Product complexity	Lifecycle phase	Company Type
1	> 500	< 100 M. €	B2C, B2B	Machine	Usage	Manufacturer
2	> 1000	< 250 M. €	B2B	Machine	Usage	Manufacturer
3	> 6500	< 1,800 M. €	B2B	Machine	Usage	Manufacturer
4	> 2000	< 450 M. €	B2B	Machine	Usage	Manufacturer
5	> 1500	< 3,000 M. €	B2C, B2B	Machine	Development	Manufacturer
6	> 150	< 50 M. €	B2C, B2B	Machine	Development	Manufacturer
7	> 15	< 0,5 M. €	B2C, B2B	Assembly group	Usage	Service Provider
8	> 6000	< 1,500 M.€	B2B	Machine	Usage	Service Provider
9	> 10	< 3 M. €	B2C, B2B	Assembly group	Development	Service Provider
10	> 10000	< 2,000 M. €	B2B	Assembly group	Usage	Manufacturer

For every case study an individual company was selected. Different data sources such as expert interviews performed by the authors of this paper, publications, presentations or product tests were used in the case studies' analysis. During the data analysis, smart product use cases were derived from the collected case studies and compared to the a-priori use case model. Thusly the smart product use case model evolved during the research. As Figure 2 is showing, after seven case studies, no more new use cases were identified and added to the model. This means saturation is reached.

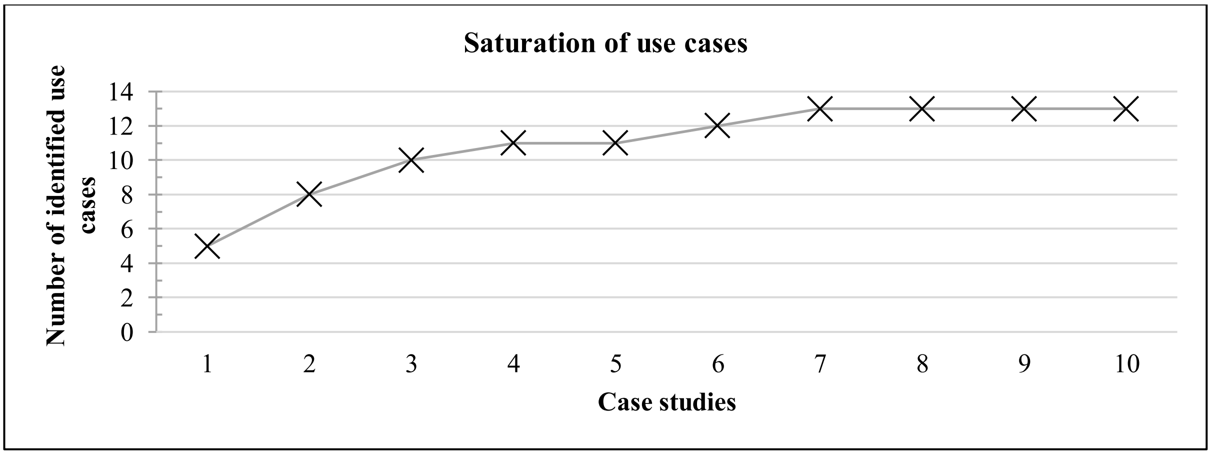

Figure 2: Saturation curve of case study analysis

4.2 Identified Smart Product use cases

In Total 13 use cases were derived which can be distinguished into two main categories. They are shown in Table 2. The first category is focused on use cases focusing on usage and field data. The second category is focused on providing smart services for the smart product's users. The use cases are explained in detail in the following subsections. The descriptions of the use cases represent the aggregated and anonymized findings from the case study analysis. All of the use cases were verified during expert interviews with the user committee of the underlying research project and literature about smart product use cases.

Table 2: Overview of derived smart product use cases

Use Cases with focus on usage data	Use Cases with focus on smart services
Analyze usage behavior	Offer Condition Monitoring
Derive new products or services	Provide Predictive Maintenance

Improve existing products or services	Offer data analytics
Update products or services	Assist operation
Upgrade products or services	Optimize operation
Offer Subscription	Deliver consumables or supplies
	Create digital product image

4.3 Description of the use cases derived from the analyzed case studies

4.3.1 Derive new products or services

The data collected from smart products can be used to identify opportunities for new products and services. This means identifying completely new product ideas, missing product functions in existing smart products or changing the configuration of features in a smart product [23,15,24]. This means omitting unused functions or combining them into new functions. To do so, the existing product configuration is measured against the identified customer needs from the usage behavior analysis as well as the product usage and linked to product functions [25]. From here missing functions can be identified and evaluated for new products [25].

4.3.2 Improve existing products or services

Next to deriving new products and services, existing products or services can be improved with usage data from smart products. Though this use case is very similar to *derive new products or services* it is mentioned separately. The matter of differentiation for the authors is the improvement of existing functions versus the identification of missing ones, which leads to new products or services. In this case the focus of the analysis is set on the existing functions and features and if they can be improved, e.g. for better user experience or performance [26,15,24,2].

4.3.3 Update products or services

The *update products or services* use case means improving or enhancing the existing functions smart product by exchanging physical or digital components [27]. To do so, an update needs to be ready for deployment from the manufacturer. This may be an improvement of software such as a change in the user interface but may also include the exchange of a physical component [24,2]. Before that the update needs to be authorized by the user. If necessary, a downtime is scheduled for the smart product. Depending on service level agreements, an exchange product may be delivered on site during the smart products update time [2,5].

4.3.4 Upgrade products or services

Upgrading a product or a service, in contrast to an update, refers to deploying new digital or physical functions to a smart product, including an entire exchange of the product [28,14,27]. The process of upgrading a smart product is analogous to the update process. Meaning an upgrade is ready for deployment and will be executed similarly to the update (see section 4.3.3). To identify the need for an upgrade the usage of the smart product is monitored against predefined performance KPIs. Once a threshold is exceeded, the current product use is evaluated. This could mean using a smart product at its upper or lower performance limit triggers an exchange against a smaller or bigger product to better fit the customer's usage behavior [14]. The use of upgrades extends the lifecycle of products and the level of customer satisfaction by continuously satisfying the customer needs [28]. Furthermore it also allows a continuous evaluation and change of the smart product based on its usage [28].

4.3.5 Analyze usage behavior

As the use cases are used in the conceptualization phase during the development of a smart product, a detailed yet easy to understand visualization is needed. Therefore, in addition to the use case description every use case is visualized in a UML Use case diagram [29]. It is a type of visualization that is easy to understand, solution agnostic, and yet leaves enough space for interpretation as the design of a smart product is evolving. Nevertheless, it contains the main components that are needed to realize a smart product. The use case diagram for *analyze usage behavior* is shown in Figure 3.

This use case focuses on understanding the user's behavior by analyzing usage data collected by the smart products [30,15,2]. It builds the foundation for better understanding how and why customers are using the smart product and their specific needs [30,15,31,8,2]. It means collecting the usage data such as frequency, duration, and location of usage as well as the used features from the smart product and storing it within the product cloud [30,8,2]. In addition to that, user feedback on the product itself or certain features is added to the analysis [24]. By analyzing the usage behavior over a certain period of time a behavioral profile of the user can be derived [24,2]. The collected data is then matched with customer specific data as well as data about the customer' s segment [30,2]. In addition to that the customer's usage profiles can be compared to one another determining certain usage patterns and customer needs [2,25]. In order to collect usage data, this use case will collect the usage data based on the use case *offer condition monitoring* (section 4.3.7) as well as customer feedback based on *assist operation* (section 4.3.10).

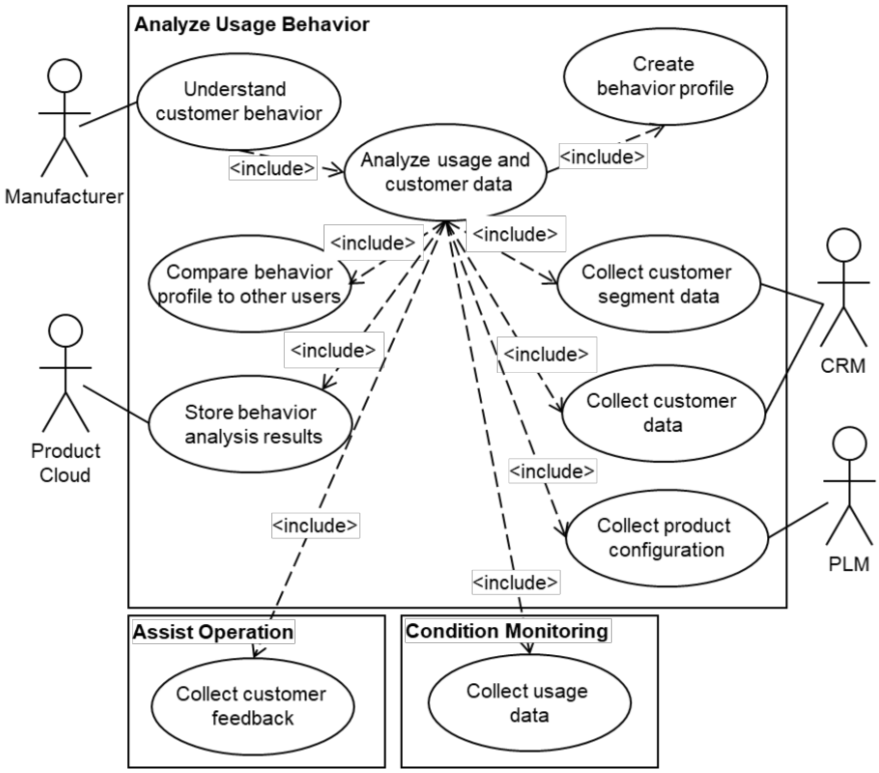

Figure 3: Use Case diagram for *analyze usage behavior*

4.3.6 Offer Subscription

Offering a subscription business model means delivering continuous value improvement for a fixed fee [32,33]. The online streaming service Netflix – with a fixed price rate and ever growing offering – is an example for a subscription based business model from a B2C context [34]. Moving from a transaction based customer interaction to an outcome based customer interaction is becoming increasingly popular in the B2B context and is enabled by smart products [32]. The delivery of value is often measured in product performance [35,15]. The improvement in performance is achieved by analyzing the usage behavior to identify opportunities for process or product improvements for the specific customer use case [35,2].

4.3.7 Offer Condition Monitoring

The use case *offer condition monitoring* consists of visualizing a products condition as well as providing the user with alerts in case predefined thresholds are exceeded or a set of rules triggers it. This means that the user is allowed to define alerts and rules [26,2,5]. To execute the rules the smart product collects data from different sources and aggregates them [15]. The data may be from the product's environment such as brightness, humidity (environmental data), from within the product such as internal sensor values or errors (product data) or regarding the process the product is in (process data) [8]. The later visualized or monitored values may be specific values such as the vibration within a motor or KPIs aggregating different data streams. This could be the asset health or for example the smart product's OEE [26]. The condition monitoring use case serves as a base for many of the identified use cases. This use case can also be applied to the smart product's manufacturer monitoring certain KPIs for the smart product during its usage [26,35].

4.3.8 Provide Predictive Maintenance

Predictive Maintenance aims at providing the user of the smart product with an interruption free usage period. It means identifying the need for maintenance and scheduling it before the smart product breaks down unexpectedly, avoiding unforeseen downtime [36]. In the case of an identified maintenance need a planned maintenance will be scheduled automatically to ensure maximum performance of the smart product [2,14]. To do so the remaining usable life of components or the whole smart product is calculated and monitored. This is done by connecting the as is data from the smart product with historical data and historical maintenance cases [8,5]. Based on the identified issues, maintenance measures are selected and a maintenance is scheduled. Depending on the situation, the maintenance can be executed remotely [26]. As the component to be exchanged is known in advance the maintenance personnel can bring the right equipment and plan the maintenance process accordingly [2,14]. If needed an exchange product can be provided during the maintenance period [37].

4.3.9 Offer data analytics

This use case allows the smart product's user to individually deploy data analytics models on the smart product using its field and product data. This means selecting from a set of predefined analytics models that can be applied to the smart product and its environment [23]. These can be anomaly detection, assistance for teach in of sensor values, vibration and temperature analytics, etc. [5]. It includes external data sources such as business systems as well as storing and exporting the analytics results [2]. Offering such functions may have a positive effect on the perceived value of the smart product.

4.3.10 Assist operation

Assisting the operation refers to helping the smart product's user to operate it. This means the smart product automatically guides its user. It monitors the way it is used and provides helpful information such as manuals, warning about dangerous or unintended maluses of the product and prevents the user from making mistakes [15,16,2]. It will allow remote assistance and remote control as well as collect feedback from the users via its digital interface [35,2].

4.3.11 Optimize operation

Optimize operation refers to helping the smart product's user to operate it at an optimal state. This is done via recommendations for the user to improve the product's performance or lifetime [2,14]. The recommendations can be drawn from a predefined set of recommendations. The recommendations are selected on the base of an optimization model constantly comparing the current operation parameters to an optimal state [26,15,2]. The smart product's data can be enriched with external data sources like the production schedule from an MES or ERP software [2].

4.3.12 Deliver consumables or supplies

In this use case the smart product watches the usage of supplies or consumables during its use. Based on the usage it can estimate the remaining time until new supplies will be needed. Being connected to the stock management system at the company or the supplier it can order material just in time to not run out of stock [38,15,14]. This may also lead to a more detailed usage understanding for the product's manufacturer also offering an additional value stream in case the supplies are directly sold by him.

4.3.13 Create a digital product image

A digital product image gives an overview of historic data from the smart product based on a continuous data flow [39,40]. In the presented set of use cases, the term *digital product image* is used synonymously for *digital shadow* as well as *digital product passport* [39]. It stores all of the historical product data and allows the user to explore it from different views and contexts. Such views may be the manufacturing history or the maintenance history of the smart product. Additionally the data can be exported to other systems or be analyzed in a different context [39,41,40].

5. Summary and outlook

In this paper a set of smart product use cases for developing a smart product are presented. They are described from the perspective of a smart product manufacturer with industrial application. The overarching smart product development process is explained. The use cases are derived with case study research. The methodology as well as the selection and saturation of case studies and use cases is explained. After that, the validated use cases are described in detail and an exemplary use case diagram is shown.

Future research will focus on building blueprints for easily applying the use cases during the smart product development process as well as creating a methodology for a focused co-development of the smart products.

Acknowledgements

The Cornet project 303 EN of the Research Association FIR e. V. at the RWTH Aachen University is funded via the AiF within the framework of the programme for the funding of cooperative industrial research (IGF) by the Federal Ministry for Economic Affairs and Climate Action (BMWK) on the basis of a decision by the German Bundestag.

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Biography

Günther Schuh (*1958) is head of the chair of Production Systems (WZL-PS) at RWTH Aachen University and member of the directorates of the Machine Tool Laboratory (WZL) at the RWTH, Fraunhofer Institute for Production Technology (IPT) and Director of the FIR at RWTH Aachen University.

Max-Ferdinand Stroh (*1991) is a researcher at FIR at RWTH Aachen University since 2017 in the department Information Management. He is head of the department Information Management. His scientific work is focused on the practical application of AI, smart products, and IT-OT-Integration.

Dr.-Ing. Jan Hicking (*1991) has been head of the division Information Management at FIR at RWTH Aachen University since 2020. Starting in 2016, he received his Ph.D. in 2020 in the field of smart products. As deputy head of the division, he is responsible for multifaceted consulting and research projects.

Sebastian Kremer (*1993) Is leader of the group Information Technology Management at FIR at RWTH Aachen University. His work is focused on digital technologies and their applications such as smart products and event-driven architectures.