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# Solution Approach For Challenges In Product Development In The Context of Emerging Cyber-Physical Systems

Henry Himmelstoß, Andreas Bildstein, Daniel Schel
*Fraunhofer IPA, Stuttgart, Germany*

**Abstract**

The emergence of cyber-physical systems (CPS), cyber-physical production systems and smart products is fundamentally changing the approach to product development. The paper addresses the current challenges in the development and design of product innovations arising from the emergence of cyber-physical systems, cyber-physical production systems and smart products, and the resulting opportunities. To provide a basic overview of the existing challenges, results from studies, scientific publications and experiences from industry are described. These results from industry are obtained from project work with a globally operating German manufacturing company. In the course of these challenges, companies must reorient themselves in terms of their products, services and find their role in changing ecosystems. The aim is to show the extent to these challenges addressed in science and the state of the art. One approach to address these challenges is described in this paper using the technical concept of the asset administration shell (AAS) and the CRISP-DM methodology. The goal is to provide insights in the early stages of product creation to drive incremental innovation or product improvement to facilitate the development of successful CPS and smart products.

**Keywords**

Product Innovation; Product Development; Industrie 4.0; Industry 4.0; Asset Administration Shell; Cyber-Physical System

## 1. Introduction

The digital transformation is permanently changing production environments and thus also production systems. The systems used in production are becoming increasingly intelligent and connected. As a result, in the final vision of Industry 4.0, production systems should be able to control themselves autonomously. To achieve this goal, cyber-physical systems and cyber-physical production systems represent a central enabler technology to enable new use cases. [1].

In turn, the emergence of cyber-physical systems is having a major impact on the way products are developed. Their development is characterized by high demands on interdisciplinarity, resulting in a new complexity in product development that must be mastered for the development of successful products [2].

In this context, cyber-physical products and cyber-physical production systems offer new opportunities. By connecting them to an infrastructure and enabling them to collect data end-to-end, new information can be obtained about their operation, maintenance or manufacturing. This is made possible by the ability of CPS to self-describe. Thus the CPS has knowledge about its own state or about its own capabilities; furthermore, the self-description can also contain information about the periphery or about the system context [3]. These information can in turn be applied in early phases of product development to design cyber-physical products in such a way that they can be sold more successfully on the market or meet the customer requirements in a better way. This requires new methods to select, process and make available this data for product development.

The aim of this paper is to address current challenges in the development of cyber-physical and smart products and to introduce a new approach to meet these challenges. Existing research is described and terminology work on cyber-physical systems and directly related technological concepts is presented in Chapter 2. Chapter 3 covers the current state of science as described by technical interest groups from Germany and in selected literature. In addition, findings from industrial work are considered. Chapter 4 describes an approach for a concept based on the asset administration shell and the Cross Industry Standard Process for Data Mining (CRISP-DM) procedure. Chapter 5 will briefly summarize the paper and conclude with an outlook.

## 2. Current state of research

This chapter explains the terms cyber-physical system and cyber-physical production system as well as the smart product based on them in context of this paper and the presented research approach. The Industry 4.0 component will also be described.

### 2.1 Cyber-physical product, cyber-physical production system and smart product

An early definition for cyber-physical systems dates back to 2006 [4]. Whereby CPS are described as integrations of computations with physical processes. Embedded computers and networks monitor and control physical processes, while physical processes affect computations due to feedback loops and vice versa [4]. The Association of German Engineers (VDI) defines CPS as a "system that links real (physical) objects and processes with information-processing (virtual) objects and processes via open, partly global information networks that are interconnected at all times". It also notes that a CPS can optionally use local or remote services and have a human-machine interface, and that the system can be adapted during its runtime. [5]. A cyber-physical production system (CPPS) is referred to when it is a CPS that is applied in a production-specific context [6].

Smart products are cyber-physical products that are enhanced by external infrastructure (internet) based smart services. A smart service is understood to be a service that is based on product-related data collected from the customer and that can be adapted to customer needs on this basis and can be used in a context-sensitive manner. Basically, it is stated that smart products generally consist of physical components (e.g. mechatronic components), intelligent components (e.g. software) and networking components (e.g. interfaces) [7]. Following this explanation, Figure 1 shows a simplified and generalized structure of the components of a smart product based on [7].

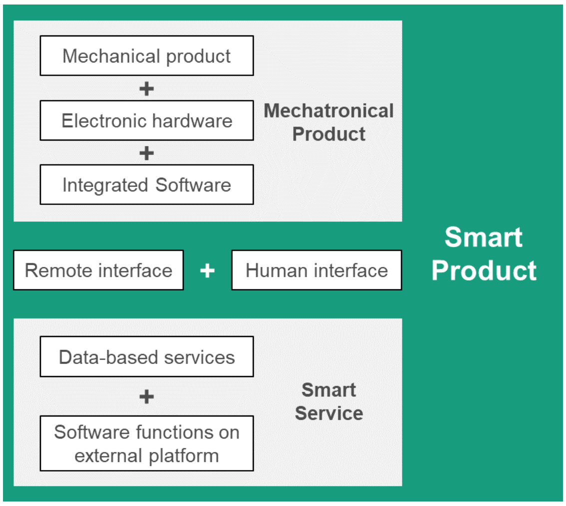


Figure 1: Simplified, generalized representation of the components of a smart product based on [7]

## 2.2 Industrie 4.0 Component

The combination of an asset with the AAS makes the Industrie 4.0 component. Every physical or logical object of value owned by a company or institution can be considered an asset. Capabilities can be attributed to each resource, therefore also to each asset. A capability describes an implementation-independent description of the functionality of a resource that has an effect in the real or virtual world and that serves for the fulfillment of a requirement for the processing a product. This means that the fulfillment of a required capability is checked against the capability of a resource to decide if a capability is the right match for the fulfillment of a desired task. Therefore before the execution of a certain task is initiated, a feasibility check is taking place to assess if a functionality is delivering the desired outcome. Capabilities can be in a hierarchy to each other and be composed of different capabilities [8]. The Industrie 4.0 component can therefore be regarded as the logical next evolutionary stage of a cyber-physical system in an industrial environment.

## 3. Current state in industry and academia

The development of CPS and smart products is complex and requires a high degree of interdisciplinary, since their components described in Chapter 2 require knowledge from different domains. At the same time, however, CPS offer new opportunities since they can allow data from the various phases of the product lifecycle to flow back into the early phases of product development, thus enabling a closed loop - field data from actual product usage can be used to derive new insights. This includes phases such as ideation, the concept phase and development [9].

This is supported by the concept that CPS are aware of their own state parameters as they pass through the different stages of their product lifecycle. Integrated into modern production flows, they can capture and store this data about themselves, as well as communicate and interact with other components in production systems [10]. However, a large part of the CPS currently in use mainly act passively, so that they primarily communicate clearly assignable information about their status in the form of status updates. Some of the CPS can also make or participate in decisions on their own. For example, information can be used to detect indicators of problems or to trigger defined actions [11]. The data generated by these products, for example through maintenance or repair, can be used to derive new products and strengthen customer relationships. This data can also be of great relevance when it comes to developing service-based capabilities for data processing [12]. Furthermore, with the help of CPS, companies can better capture information about actual user behavior, so that new insights will become apparent to companies about which product functionalities are actually used by product users and which receive little attention or are even avoided [13]. This can help companies establish a systematic approach to product improvement [14]. This is particularly important because the integrated development of physical products and digital services requires them to be developed in harmony with each other [15]. New tools are already being used to analyze the behavior of customers and consumers in order to offer products that precisely meet the desired characteristics. The development of products with the help of new technologies that take social and technological megatrends into account is already on the rise [16]. In a survey of experts this is underpinned by the fact that eight out of ten experts are of the opinion that information retrieval through smart products holds great added value for product development in that individual customer needs can be better addressed by new products [11].

Although the description of these possibilities takes place in scientific literature, concrete applications and procedures for the implementation in practice are currently still lacking. In particular, methods for identifying customer requirements are among the most important factors, but at the same time there is a lack of customer integration in the product development and product evaluation process [10]. This also corresponds to the findings of the Platform Industry 4.0 study on the engineering of smart products and services. In this study, research needs in various areas for the development of smart products were identified by analyzing relevant work and conducting interviews with experts. In this context, research needs are expressed several times when it comes to the use of product usage data for product development. For example, in the context of planning approaches, a need for research was mentioned for the provision of knowledge based on feedback information from previous product generations. In the context of requirements specifications and requirements management, for example, a research need was identified for approaches to generate knowledge from product usage data for new requirements specifications. According to the study, there is also a need for new approaches for the processing and for the provision of product utilization knowledge for engineering tasks [17]. It is also predicted that data from the product usage phase will increasingly be passed back into the development process and thus take on a more important role in the future [18].

During an industrial project with a component manufacturer who, like many representatives from the German SME sector, is facing the challenges of digital transformation, it was possible to identify needs similar to those in the study described earlier. Three significant topics that were identified during this work and are relevant for the considerations in this paper are summarized below:

- A concrete need for the collection of product data from the field has been identified. This data is to be utilized in particular with the aid of analytical methods for the improvement of existing products.
- Components that are already in use are able to collect data about themselves. However, there is uncertainty about how this data can be handled and used in the future. This goes hand in hand with the fact that it is currently still uncertain what role the collected data can play in future business models.
- Deriving a scope of services for future products proves to be difficult. Especially in the respect that it is unclear what functionalities will be demanded by customers in the future and expected in products they intend to buy.

From the identified needs of industrial partners, for which concepts are already described in the scientific literature, it is apparent that further solutions for industrial practice are needed.

## 4. Solution proposal

This chapter is describing the asset administration shell, the CRISP-DM and how these two concepts are being used in a new approach.

### 4.1 Asset Administration Shell

The AAS is a standardized representation of an asset and therefore a key factor for the interoperability between applications that are managing, steering and controlling manufacturing systems. The AAS and the asset that's represented by it can be uniquely identified - yet several AAS can be assigned to one asset, e.g. from the manufacturer's and the user's point of view. Submodels of different kind of aspects are contained and technical functionalities are described by the AAS [19]. Thus, by representing the characteristics of an asset through the AAS, it can be linked to the information world. These characteristics can be very wide-ranging and diverse. For example, they can be simple product properties, but also context-specific information about the product or information about its manufacturer. With an AAS containing multiple submodels, all information and functionalities of a given asset that a necessary for the completion of a dedicated use case can be described. Such information can include but are not limited to the features, characteristics, parameters, measurement data, capabilities or properties of the asset [8]. With the help of the AAS, a digital twin, i.e. a sufficient digital representation of an asset that meets the requirements of dedicated use cases, can be implemented [19]. These information can be covered by the AAS over the complete lifecycle of an asset and can therefore access its relevant data in every phase.

### 4.2 CRISP-DM

The CRISP-DM Methodology is described in a 6-step process model. It is a standardized procedure model that finds application in many data mining use cases. General tasks are assigned to each of these six phases, but are not discussed in detail further in this description. The process model consists of the phases business understanding, data understanding, data preparation, modeling, evaluation and deployment. However, the phases are not a rigid sequence, as it is often necessary to go through individual phases several times. In addition, there are other relationships between the phases that are not apparent in the general illustration in Figure 2. Which phase occurs next depends on the results achieved in each phase process model. There is a regular sequence, which also represents the main dependencies of the phases. This is also represented by the arrows between the phases. The large arrows arranged in a circle indicate the cycling nature of data mining, as it is not finished with the deployment, but re-introduces new findings. The CRISP-DM process model is shown in Figure 2 [20].

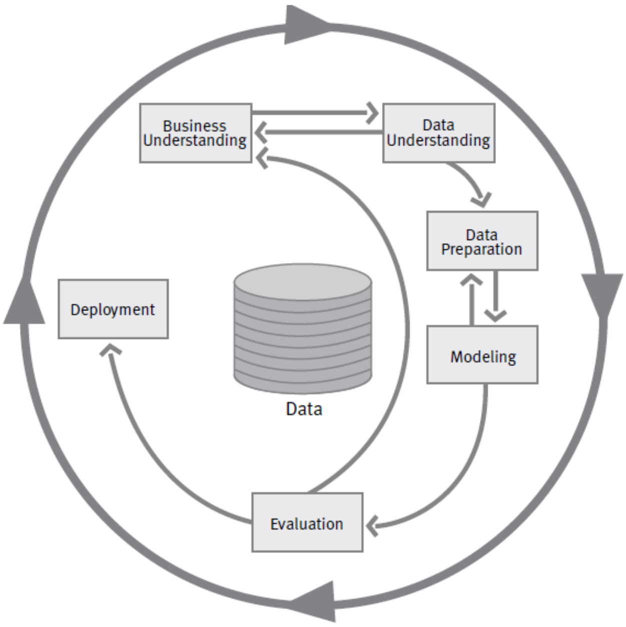


Figure 2: Phases of CRISP-DM [20]

CRISP-DM provides a very suitable framework for the methodological approach, since both aspects for evaluating use cases and technical aspects are given the necessary attention. Therefore, it is suitable for the methodological approach discussed in this paper, in that it also does justice to interdisciplinary problems and can be used in all domains.

### 4.3 Conceptual approach

Although it is described several times in the literature that product usage data can unfold new potentials in development, in practice there is still a lack of available solutions for industrial applications. Products and systems that have all the necessary characteristics of a smart product are increasingly being used in production environments. One approach to successful create new product adaptions and gain additional insights out of the usage of products can be to enrich product creation with additional knowledge from different phases of the product lifecycle. It also supports the product creation to cope with the new complexity in product development and to design products according to actual needs. Due to the given potential of the AAS to capture data of an asset along its product lifecycle, it is a suitable technological concept to realize use cases where data from the different phases of the product lifecycle are to be utilized in the early phases of product development. Figure 3 shows an exemplary product life cycle and the schematic feedback of data from the different phases into product development with the help of the AAS. In this context, assets are already linked to an AAS in their creation and carry information from this phase.

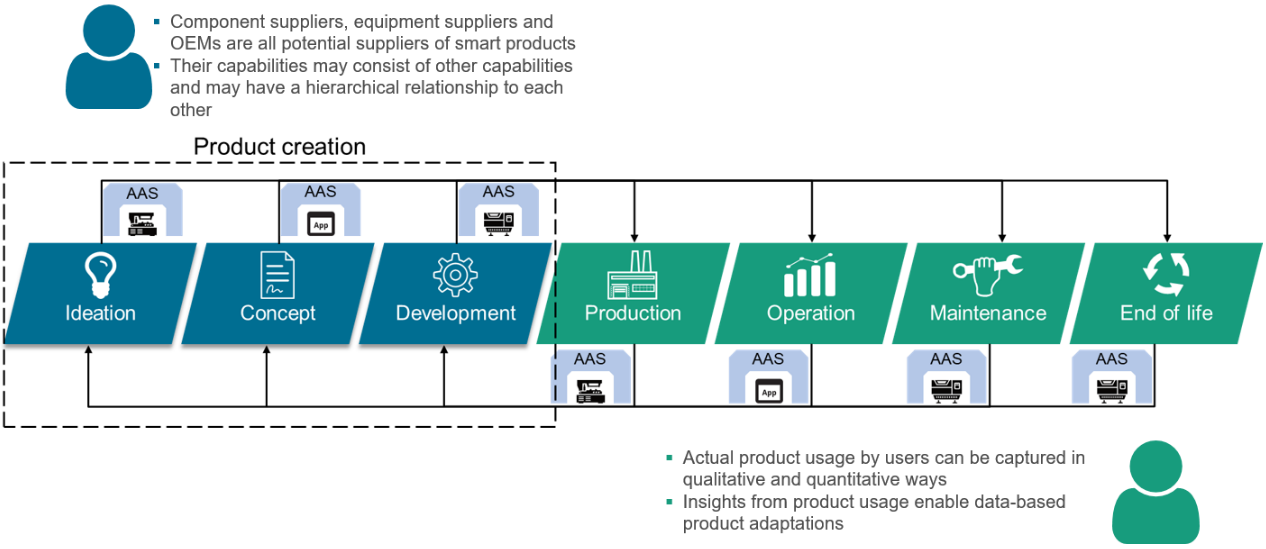


Figure 3: Exemplary product lifecycle with a closed feedback loop

In order to fundamentally assess the extent to which adaptations should be performed on a product, its quality in fulfilling specific tasks can be evaluated. This is to be based on the degree of fulfillment of a technology or a process, which results from the delta of the requirements of a product and the capabilities of a technology or a process. For this purpose, submodels of the AAS must be enriched with properties. These represent defined characteristics that are suitable for describing and differentiating products [19]. The source of this type of data continues to be the asset, with the AAS acting as a vehicle to enable a new type of interoperability and unique identification.

Such products or systems and the AAS create the technological foundation to enable closed feedback loops. To select and analyze the data from the product life cycle and for the early phases of product development, CRISP-DM is a suitable approach [20]. The combination of the AAS and the CRISP-DM procedure represents a novel research approach to systematically enrich product development with available knowledge from the product life cycle. However, since the data continues to come from the asset, it is necessary to consider which of its data is relevant and in what quantity and form it is required for the product adjustments.

| | Business Understanding | | Data Understanding |
|---|---|---|---|
| | Situation Assessment | I4.0 Component | Product Changes |
| Functionality based changes | ▪ Description of requirements and associated formulation of assumptions<br>▪ Description of expected workflows<br>▪ Formulation of hypotheses for potential product improvements | ▪ Definitions of submodels of the AAS with necessary properties<br>▪ Description of the capabilities<br>▪ Description of the hierarchy and composition of capabilities | ▪ Initial Explorative recognition / detection of patterns in procedures<br>▪ Matching of recognized patterns with anticipated workflows and defined capabilities |
| Performance based changes | | | ▪ Initial Collection of performance data according to previously defined capabilities<br>▪ Description of delta between target and actual capabilities |
| Business case based changes | ▪ Description of requirements and associated formulation of assumptions<br>▪ Formulation of hypotheses for potential business case improvements | | ▪ Initial Collection of performance data & detection of patterns in procedures according to previously defined hypothesis<br>▪ Review of the current business model for weaknesses |

Figure 4: AAS specific complementary tasks in the initial phases of the CRISP-DM

Therefore Figure 4 shows for the proposed approach necessary tasks complementary to the CRISP-DM in its early phases to derive product changes with the help of the AAS. A distinction is made between functionality-based, performance-based and business case based changes. While functionality-based product changes are derived from qualitative product usage, for example by not using functions or merging functions, performance-based product changes are derived from quantitative product usage, for example by using a product in a certain performance area in a defined period of time. Smart products also bring new challenges in the design of business models. Be it in the design of new monetization means, the design of value-based revenue models, or the use of product data in accordance with regulations. Therefore it is also important to continuously verify whether a smart product is contributing to the successful implementation and operation of a business model as planned. Therefore, it is necessary to continuously assess whether the currently operated business model meets the defined requirements and thus contributes to the planned business objective. The verification of the requirements and the associated hypotheses can be carried out with both qualitative and quantitative usage data.

For all types of product changes, the product requirements and related assumptions are described in the first phase of CRISP-DM. The assumptions will be used to formulate hypotheses about potential product improvements, which will be confirmed or falsified using real usage data. Massmann et al. propose a hypothesis-based and an explorative approach to data analysis. In the consideration of this thesis hypotheses are used for all types of product changes, however function-based product changes also require an explorative approach [21]. While anticipated usage in the hypotheses is described by workflows in the case of functionality-based product changes, anticipated target performance limits are described in the case of performance-based product changes. For potential adjustments to the business case, assumptions and hypotheses are continuously tested with real usage data to assess whether the intended business objective is being pursued in a target-oriented manner.

For all types of product changes, submodels of the AAS are defined whose properties and thus the collected data are suitable for testing the hypotheses. The capabilities of the Industrie 4.0 components are also described, what other capabilities they may be composed of, and what hierarchical relationship they have to each other.

This is followed by the second phase, Data Understanding. This phase involves an initial review and collection of data, as well as their general and qualitative description. In this phase, it is also necessary to identify which phases of the product life cycle are the source of relevant data and should therefore be the focus of the analysis. The first and second phases are particularly important for developing a concept for using the AAS and CRISP-DM to implement a closed feedback loop. However, the weighing of the need for product adjustments is conducted differently. For functionality-based product changes, patterns in product usage are exploratively sought and compared to anticipated workflows. A deviation of workflows from actual usage, for example, can provide insight into functions that are not necessary and thus can be eliminated if they are not used. However, new functions can also be derived from frequently recurring workflows in actual product usage - in this case, for example, a new, hierarchically superior capability can be derived from multiple lower-level capabilities. In the case of performance-based product change, threshold values formulated in hypotheses are compared with performance metrics from actual usage. This comparison is intended to evaluate the delta between the planned capabilities of a product and their actual manifestation in reality. It must also be taken into account whether the capability under consideration is a composite capability and what its hierarchical relationship is to others. The business case based adjustments can be supported by both the functionality-based and the performance-based usage data. For example, to price the operation of leased machines and systems in the high performance range with higher usage costs or to derive new offers from new functions.

Even if the focus is on these phases for the concept development, the other phases must also be addressed for a holistic assessment of the planned research. Accordingly, the data preparation and modeling phases must also address what data needs to be prepared and how, and what modeling techniques can help achieve the business objectives. In the evaluation phase, it is reviewed whether the results achieved meet the defined requirements or whether further iterations are needed.

## 5. Conclusion and Outlook

The use of CPS and smart products has also increased in industrial environments and the trend points towards increased development of products with intelligent services. Enriching product development with data from the field can be a facilitator in the development of successful products. Even though it is frequently described in the scientific literature that data from the field is fed back into development in a closed feedback loop, it is not often used in industrial applications so far. One of the reasons is that there are still hardly any solutions on the market that solve this problem. At this point, further research needs have been identified. In addition to technical applications, further conceptual work is also needed to systematically address such use cases in the future. In this paper, a new possible approach is presented. It is based on the technical concept of the AAS and the CRISP-DM procedure.

To verify this research approach, further conceptual elaboration is needed. In particular, a methodical approach is needed to make design decisions on the basis of parameters. It is also necessary to discuss the extent to which standardized submodels can be used for data-supported product development in order to proceed as standardized as possible. Also necessary is the application in industrial practice to put the approach to the test. In doing so, it is important to capture and sufficiently consider the needs and requirements of representatives from practice, so that a further step is taken for actual solutions to find their way into industrial practice, to enable closed feedback loops and to return product data from the life cycle to the early phases of product development. In this respect, further potential in product lifecycle management is also anticipated, as further valuable insights can be gained and provided for this through the interoperability of the AAS.

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## References

[1] Bauernhansl, T., Krüger, J., Reinhart, G., Schuh, G. WGP-Standpunkt Industrie 4.0. Wissenschaftliche Gesellschaft für Produktionstechnik WGP e.v. https://wgp.de/wp-content/uploads/WGP-Standpunkt_Industrie_4-0.pdf. Accessed 25 March 2021.

[2] Gausemeier, J., Dumitrescu, R., Steffen, D., Czaja, A., Wiederkehr, O., Tschirner, C., 2013. Systems Engineering in der industriellen Praxis. Heinz Nixdorf Institut, Universität Paderborn, Lehrstuhl für Produktentstehung | Fraunhofer-Institut für Produktionstechnologie IPT – Projektgruppe Entwurfstechnik Mechatronik | UNITY AG. https://www.hni.uni-paderborn.de/fileadmin/Fachgruppen/Seniorprofessur_Gausemeier/systemsengineerings/Studie_Systems-Engineering.pdf. Accessed 6 April 2021.

[3] Bauernhansl, T., Krüger, J., Reinhart, G., Schuh, G., 2016. WGP-Standpunkt Industrie 4.0. Wissenschaftliche Gesellschaft für Produktionstechnik WGP e.v. https://www.ipa.fraunhofer.de/content/dam/ipa/de/documents/Presse/Presseinformationen/2016/Juni/WGP_Standpunkt_Industrie_40.pdf. Accessed 6 April 2021.

[4] Lee, E.A., 2006. Cyber-Physical Systems - Are Computing Foundations Adequate?: Position Paper for NSF Workshop On Cyber-Physical Systems: Research Motivation, Techniques and Roadmap. Berkely EECS. https://ptolemy.berkeley.edu/publications/papers/06/CPSPositionPaper/Lee_CPS_PositionPaper.pdf. Accessed 11 April 2021.

[5] Verein Deutscher Ingenieure, 2020-09-00. Entwicklung cyber-physischer mechatronischer Systeme (CPMS). Beuth Verlag GmbH, Berlin. https://www.perinorm.com/document.aspx?hitnr=0&q=AC:DE45667245. Accessed 11 April 2021.

[6] VDI/VDE-Gesellschaft Mess- und Automatisierungstechnik, 2017. Industrie 4.0 - Begriffe/Terms: VDI-Statusreport. https://www.vdi.de/ueber-uns/presse/publikationen/details/industrie-40-begriffeterms. Accessed 11 April 2021.

[7] Lünnemann, P., Wang, W.M., Lindow, K., 2019. Smart Industrial Products: Smarte Produkte und ihr Einfluss auf Geschäftsmodelle, Zusammenarbeit, Portfolios und Infrastrukturen. Fraunhofer IPA; CONTACT Software GmbH; VDI-Gesellschaft Produkt- und Prozessgestaltung (GPP). https://www.ipk.fraunhofer.de/content/dam/ipk/IPK_Hauptseite/dokumente/marktstudien/vpe-studie-smart-industrial-products.pdf. Accessed 13 April 2021.

[8] Bayha, A., Bock, J., Boss, B., Diedrich, C., Malakuti, S., 2020. Describing Capabilities of Industrie 4.0 Components. Federal Ministry for Economic Affairs and Energy (BMWi). https://www.plattform-i40.de/PI40/Redaktion/DE/Downloads/Publikation/Capabilities_Industrie40_Components.pdf?__blob=publicationFile&v=3. Accessed 25 March 2021.

[9] Rao, P., Palaniappan, K., 2020. Continuous Engineering Through ALM-PLM Integration, in: Product Lifecycle Management Enabling Smart X, Cham. 2020. Springer International Publishing, Cham, pp. 798–811.

[10] Nunes, M.L., Pereira, A.C., Alves, A.C., 2017. Smart products development approaches for Industry 4.0. Procedia Manufacturing 13, 1215–1222.

[11] Wuest, T., Schmidt, T., Wei, N.A., Romero, D., 2018. Towards (pro-)active intelligent products. IJPLM 11 (2), 154–189.

[12] Chowdhury, S., Haftor, D., Pashkevich, N., 2018. Smart Product-Service Systems (Smart PSS) in Industrial Firms: A Literature Review. Procedia CIRP 73, 26–31.

[13] Schuh, G., Zeller, V., Hicking, J., Bernardy, A., 2019. Introducing a methodology for smartification of products in manufacturing industry. Procedia CIRP 81, 228–233.

[14] Meyer, M., Frank, M., Massmann, M., Dumitrescu, R., 2020. Research and Consulting in Data-Driven Strategic Product Planning, In: Journal of Systemics, Cybernetics and Informatics, Vol. 18, Number 2, 2020.

[15] Meinhardt, S., Pflaum, A., 2019. Digitale Geschäftsmodelle - Band 2: Geschäftsmodell-Innovationen, Digitale Transformation, Digitale Plattformen, Internet der Dinge und Industrie 4. 0. Springer Vieweg. in Springer Fachmedien Wiesbaden GmbH, Wiesbaden.

[16] Miranda, J., Ponce, P., Molina, J.M., Molina, A., 2019. Taxonomy of Levels of Sensing, Smart and Sustainable Products to support New Product Development. IFAC-PapersOnLine 52 (13), 2384–2389.

[17] Abramovici, M., Gebus, P., Savarino, P., 2018. Engineering smarter Produkte und Services Plattform Industrie 4.0 Studie. acatech - Deutsche Akademie der Technikwissenschaften. https://www.plattform-i40.de/PI40/Redaktion/DE/Downloads/Publikation/hm-2018-fb-smart.pdf?__blob=publicationFile&v=5. Accessed 25 March 2021.

[18] Abramovici, M., 2017. WiGeP-Positionspapier: „Smart Engineering“: Im Kontext von Industrie 4.0 werden sich Produkte und damit einhergehend auch das Engineering dieser Produkte radikal verändern. Wissenschaftliche Gesellschaft für Produktentwicklung WiGeP. http://www.wigep.de/fileadmin/Positions-_und_Impulspapiere/WiGeP-Positionspapier_Smart_Engineering.pdf. Accessed 25 March 2021.

[19] Sauer, M., Schaber, V., Schel, D., Schell, O., Schier, M., Schleipen, M., Schmitt, M., Schröder, T., Stojanovic, L., Teuscher, A., Uhl, A., Usländer, T., Vialkowitsch, J., Vollmar, F., Walloschke, T., Waser, B., Wende, J., Wiegand, M., Ziesche, C., 2020. Details of the Asset Administration Shell: Part 1 - The exchange of information between partners in the value chain of Industrie 4.0. Specification. Federal Ministry for Economic Affairs and Energy (BMWi). https://www.plattform-i40.de/PI40/Redaktion/DE/Downloads/Publikation/Details_of_the_Asset_Administration_Shell_Part1_V3.pdf?__blob=publicationFile&v=5. Accessed 25 March 2021.

[20] Chapman, P., Clinton, J., Kerber, R., Khabaza, T., Reinartz, T., Shearer, C., Wirth, R., 2000. CRISP-DM 1.0: Step-by-step data mining guide. NCR Systems Engineering Copenhagen, DaimlerChrysler AG, SPSS Inc.,. https://www.the-modeling-agency.com/crisp-dm.pdf. Accessed 15 April 2021.

[21] Massmann, M., Meyer, M., Frank, M., Enzberg, S.v., Kühn, A., Dumitrescu, R., 2020. Framework for Data Analytics in Data-Driven Product Planning. Procedia Manufacturing 52, 350–355.

[22] Issa, A., Schumacher, S., Hatiboglu, B., Groß, E., Bauernhansl, T., 2018. Open Innovation in the Workplace: Future Work Lab as a Living Lab. Procedia CIRP 72, 629–634.

## Biography

**Henry Himmelstoß** (*1991) is researcher at the Fraunhofer Institute for Manufacturing Engineering and Automation IPA since 2019 where he is working in the department competence centre for Digital Tools in Manufacturing. In one of his roles, he is project manager of the innovation lab Future Work Lab.

**Andreas Bildstein, Ph.D.** (*1971) is head of the research group Implementation Methods for Digital Production at the competence center for Digital Tools in Manufacturing at the Fraunhofer-Institute for Manufacturing Engineering and Automation IPA.

**Daniel Schel** (*1986) is researcher at the competence centre for Digital Tools in Manufacturing at the Fraunhofer-Institute for Manufacturing Engineering and Automation IPA since 2011. He has managed and conducted a number of research projects as technical director and software architect, focusing on novel approaches to IT solutions in production.