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Fields of Action in the Continuous and Early Validation of Product Profiles in Product Engineering

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Abstract

Product profiles can be used to model product needs in the early phases of product engineering and describe the product in a way that is open to solutions. Continuous and early validation of these product profiles is crucial in the product engineering process. This allows for the early identification of errors, which can then be addressed through cost-effective changes. While the literature discusses various challenges of early validation related to the characteristics of the early phase of product engineering, there is limited focus on continuous validation. In this publication, challenges for the continuous validation of product profiles were derived from existing literature. In summary, nine challenges were identified and subsequently linked to the characteristics of the early phase, resulting in the identification of four fields of action for continuous and early validation of product profiles.

Keywords
Innovation, Continuous and Early Validation, Needs and Benefits, Product Engineering, Challenges, Field of Actions

1. Motivation
Unique selling propositions and competitive advantages are crucial for the success of companies. Especially in times of change, innovations are necessary to guarantee these competitive advantages and ensure the economic success of companies (Ogrean, 2018). Retrospective analyses of failed products in the market, such as the Amazon Fire Phone or the Microsoft Zune, illustrate this. The failure of the Amazon Fire Phone can be attributed, among other reasons, to its lack of differentiation through its features. While the iPhone convinced users with its revolutionary user experience and extensive app ecosystem, the Fire Phone offered innovative but ultimately unhelpful features such as Dynamic Perspective and Firefly, which did not provide lasting value to users. This lack of differentiation compared to established smartphones meant that the Fire Phone could not make a significant impression in an already saturated market. (Luckerson, 2014) The failure of the Microsoft Zune in comparison to the iPod can be attributed to several factors: late market entry, limited ecosystem, ineffective marketing, inferior design and user experience, and lack of network effects. Specifically, in the areas of design and user experience, the Zune could not compete. While the iPod was distinguished by its elegant design and intuitive user interface, the Zune offered a less appealing design and a less refined user experience. This made the Zune less attractive to users who were already accustomed to the high quality and user-friendliness of the iPod. (Fuss, 2019) These products are therefore inventions that did not become innovations because the requirements or needs were not valid.

2. State of the Art
There are many definitions of innovation in the literature. Hauschildt, Salomo, Kock, and Schultz (2016) categorise various definitions of innovation by individual authors into a total of seven categories. Among other things, innovation

is described as qualitative (1), first-time (2) and perceived (3) novelty, but also as the combination of the need and the means (4) to fulfil this need. In addition, market diffusion is described as important, i.e. a product, system or service becomes established in this market after the brand launch (5). Further categories are the type of innovation (6) and innovation as a process (7). Albers et al. (2018) take up these views of innovation and define innovation as the successful realisation of a novelty, a creative idea or invention on the market with extended customer, user and provider benefits. They introduce three specific elements of innovation: product profile, invention and market diffusion (see Figure 1).

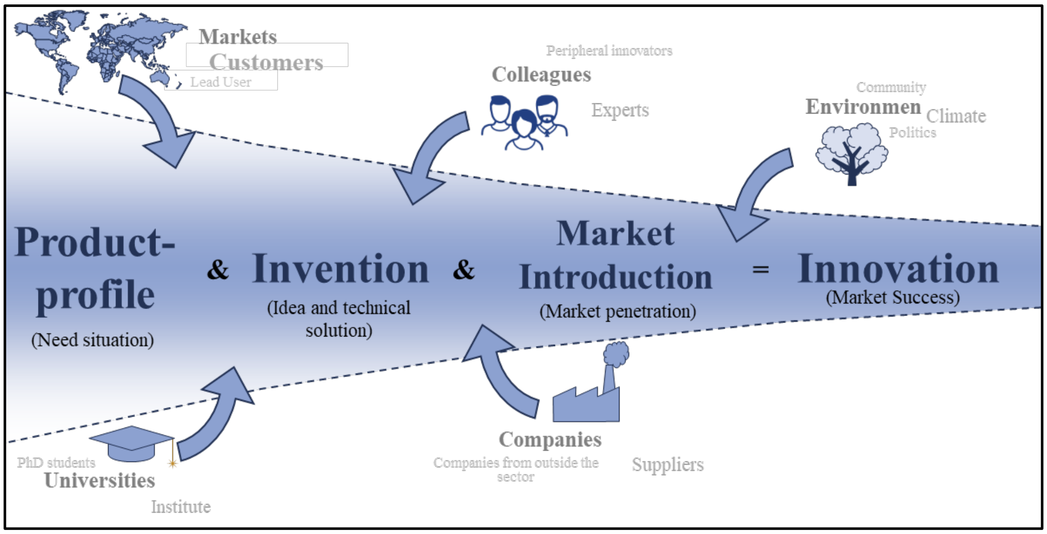

Figure 1. Innovation equation according to Albers et al. (2018): Combination of product profile, invention and market introduction

The invention describes the technical solution for a specific need, whereas the market diffusion describes the presence and implementation on the market. In addition, the product profile is introduced, which describes the need situation. The product profile (see Figure 2) is a model of a bundle of benefits that makes the desired provider, customer and user benefits accessible for validation and explicitly specifies the solution space for the design of a new product, system or service. A bundle of benefits is understood here as an entirety of products and services that is created with the purpose of being sold to a customer and creating extended benefits for them. (Albers et al., 2018)

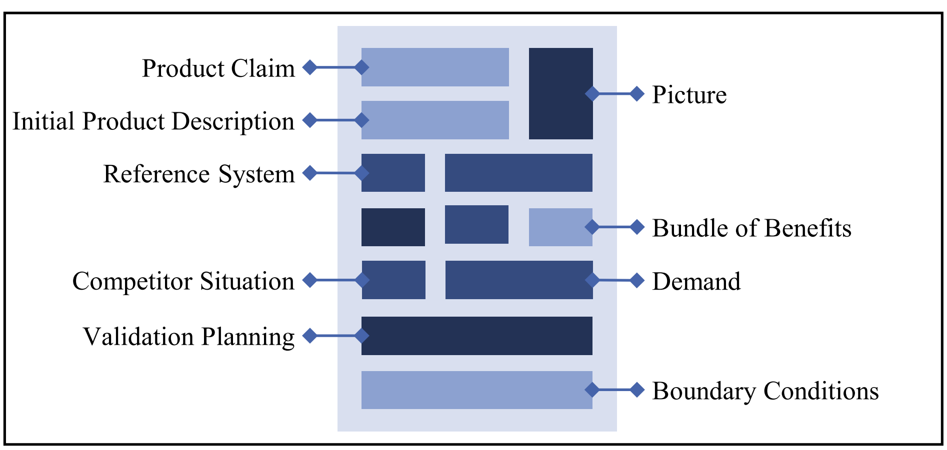

Figure 2. Product Profile with the bundle of benefit (provider, costumer, user) as the central element according to Albers et al. (2018)

One purpose of the product profile is to increase the accessibility of the need and benefit situation for validation (Albers et al., 2018). Albers (2010) describes validation as a central and knowledge-generating activity in the product development process and distinguishes between validation and verification. According to VDI 2206, verification checks the conformity of the realisation of a system or product with the underlying specification, but does not check the relevance of the specification and its benefits for the designated stakeholders (Albers, Behrendt, Klingler, & Matros, 2016; Albers & Düser, 2011; VDI e. V., 2021). In validation, this is carried out, which is why validation is described in VDI 2206 as checking whether the product is suitable for its intended use or achieves the desired value or benefit for the defined stakeholders. So, validation answers the question of whether the right product is being developed, whereas verification answers the question, if the product has been developed correctly. (VDI e. V., 2021) In order to illustrate the connection between validation and verification, Albers et al. (2016) integrate verification as an activity into validation and expand it to include Albers, Matros, Behrendt, and Jetzinger (2015)the activities evaluation and objectification. Evaluation is the examination of increments of the product or the associated development from a stakeholder perspective and is predominantly subjective based on personal perceptions. Objectification describes the extent to which the modelled requirements, objectives and boundary conditions meet the expectations and needs of the stakeholders. (Albers et al., 2015; Albers et al., 2016) Validation must be continuously and early integrated into the development process. highlight the significant potential of early and continuous validation by distinguishing between the pull and push principles of validation.

The push principle describes a validation approach that aligns with traditional phase-oriented process models (Klingler, 2017). In this approach, validation of development results always occurs retrospectively. Validation activities are triggered only by the presence of concrete development artifacts such as prototypes. Primary development activities directly related to the product, such as finding product profiles or modeling principles and designs, are fully completed before secondary activities to prepare and conduct validation, such as developing the validation environment, begin (Albers et al., 2015; Albers et al., 2016; Matros, 2016). In contrast, the pull principle treats validation as a central, process-integrated activity that initiates further development activities, such as the creation of prototypes and simulation models (Albers et al., 2015). The need for validation activities is proactively identified from the start of the development project based on existing technological and market uncertainties, leading to the development of artifacts like product profiles, prototypes, or simulation models necessary to achieve the validation goals and generate the knowledge required for a successful project (Albers et al., 2016). This approach reduces the number of invalid development results that must be discarded and keeps the validation effort manageable (Matros, 2016). The pull principle thus enhances the efficiency of validation activities. For example, the early definition of validation needs ensures that the knowledge gained from validation can be incorporated into the development project at an early stage, ultimately leading to the positive market impact of the developed product (Albers et al., 2015; Albers et al., 2016; Matros, 2016). However, validation activities in the early phase of the product development process pose particular challenges for developers due to the unique characteristics of this phase. Verworn (2005) summarizes typical process characteristics and their manifestations from several authors (see Table 1). This complicates the delineation and prioritization of validation activities in this phase, as validation goals can only be formulated in abstract terms (Klingler, 2017).

Table 1. Challenges defined by the combination of characteristic and manifestation of the Early Phase (Verworn, 2005, S. 31)

Characteristic	***Manifestation***
Degree of documentation	*Low*
Leverage	*High*
Information processes	*Complete*
Communication	*Informal*
Creativity	*High*
Resources	*Low*
Structuring	*Low*
Top management support	*Low*
Uncertainty	*High*
Responsibilities	*Often unclear*

Continuous and early validation of the needs and benefits of a product during its development is crucial to avoid costly changes later on and to obtain accurate information about the product to make informed decisions early. These challenges are closely related to early validation. However, continuous validation also presents its own challenges. These need to be identified and translated into actionable areas. Subsequently, these actionable areas can be integrated into the continuous validation process along with the early phase. This integration enables a discussion of the actionable areas for both continuous and early validation.

3. Research Profile

The goal of this publication is to identify action fields in the continuous and early validation of product profiles (combination of needs and benefits) based on identified challenges on continuous validation and their interaction with characteristics of the early phase. To operationalize this goal, two research questions were derived:

1. What challenges for the continuous validation of product profiles can be derived based on publications from a systematic literature analysis?
2. How can the challenges of continuous validation be connected with the characteristics of the early phase of product engineering based on the influences?
3. What action fields can be derived and described from the interactions between the challenges of continuous validation of product profiles and characteristics of the early phase of product development?

To answer the research questions, the following approach was chosen. For the first research question, a systematic literature review was conducted to identify relevant publications and define challenges to continuous validation of product profiles from these. These challenges were analyzed in terms of challenges in continuous validation. These challenges were evaluated in terms of their interactions with the challenges of the early phase (research question 2) so that action fields can be derived and described based on the defined interactions (research question 3).

4. Challenges of Continuous Validation of Product Profiles in Product Engineering

The following chapter presents the challenges for the continuous validation of product profiles. Firstly, the results of the systematic literature review in the form of relevant publications are presented (see Chapter 4.1), followed by the description of the challenges derived from them individually (see Chapter 4.1).

4.1 Systematic Literature Review for Identifying Challenges

The initial step of the systematic literature review is conducted after a general understanding of the research questions was gained and relevant terms that serve as suitable search criteria were identified Based on the first research question, the basic search terms were chosen to focus on product development, validation, and continuity. The search term "Early Phase" was actively excluded to focus the identified challenges on continuous validation. In addition to these search terms, other keywords were identified to answer the research question: challenges (I), needs (II), benefits (III). These keywords were combined with the basic search string, resulting in three search strings (see Figure 3). The first search string clearly focuses on already identified challenges in continuous validation. The second search string addresses the continuous validation of stakeholder needs, while the third search string examines the validation of benefits for stakeholders. The latter is based on the concept of the product profile.

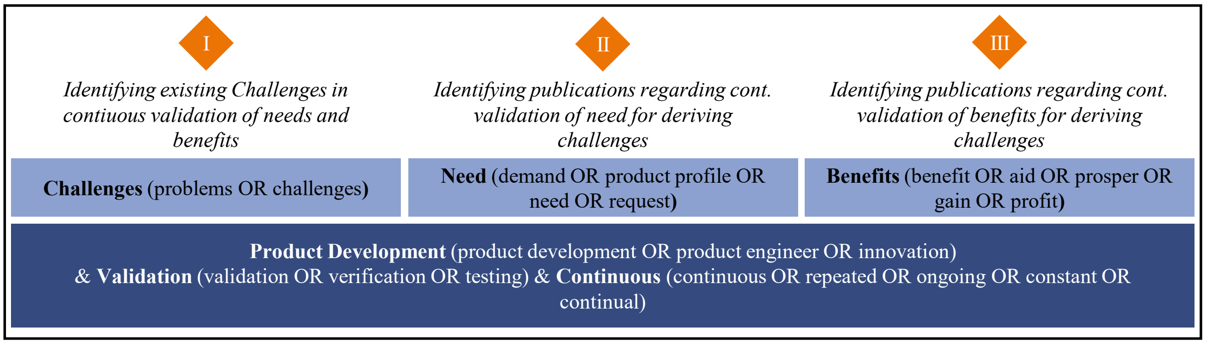

Figure 3. Simplified representation of the created search string with the basic string with the terms Product Development, Validation and Continuous (dark blue) and the additional terms Challenges (I), Needs (II) and Benefits (III)

Scopus is used for conducting the systematic literature review and was chosen to ensure the adequate quality of documents and to counteract publications driven by vested interests by only considering peer-reviewed publications. This approach included a wide range of publications, leaving out only a negligible number of publications that were deemed insignificant for the aim of this paper. (Singh, Singh, Karmakar, Leta, & Mayr, 2021; Stahlschmidt & Stephen, 2020) In addition to individual search strings, further refining search criteria such as type of literature or language can be established to further narrow down the results.

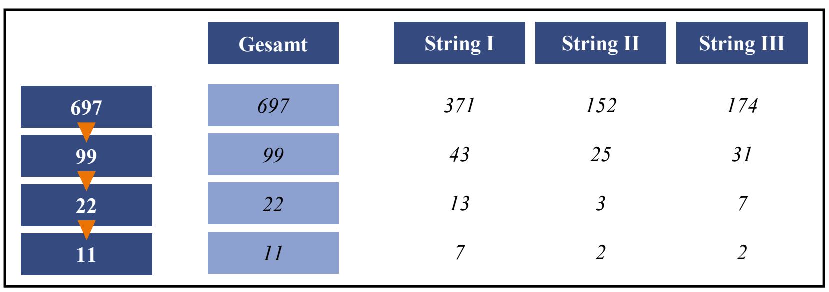

Figure 4. Number of Publications after Each Individual Filtering

Through the systematic literature review using the three search strings, initially, 697 literature results were identified. These were then gradually reduced by first assessing their relevance based on the title. As a result, the number of results was reduced to 99. The remaining publications were then evaluated based on their abstracts, resulting in a further reduction to 23 publications. These publications were then fully examined, and once again, irrelevant results were filtered out. The final number of publications remaining, deemed relevant for deriving challenges, is eleven.

Table 2. Identified and Filtered Publication of the Systematic Literature Review

#	**Publication**	#	**Publication**
1	Duehr, Kopp, Rapp, and Albers (2022)	7	Camburn et al. (2015)
2	Schrock, Junk, and Albers (2022)	8	Nishad, Kandreegula, Jadhav, and H A (2021)
3	Eckertz, Anacker, and Dumitrescu (2022)	9	van der Auweraer, Anthonis, Bruyne, and Leuridan (2012)
4	Kowzan and Pietrzak (2019)	10	Bemmami and David (2021)
5	Raghupatruni, Goeppel, Atak, Bou, and Huber (2019)	11	Promyoo, Alai, and El-Mounayri (2019)
6	Albers, Behrendt, Klingler, Reiß, and Bursac (2017)	12	Eisenmann, Grauberger, Üreten, Krause, and Matthiesen (2021)

The 12 identified publications are focused on challenges in continuous validation of product needs and benefits without focusing on the early phase. Many publications found often focus on the combination of early and continuous validation and were therefore not considered. These publications were analyzed for challenges and subsequently described. In this process, a total of twelve challenges were identified, which will be presented in the following chapter.

4.2 Identified Challenges

Based on the identified publications in Chapter 4.1, a total of nine challenges for the continuous validation of product needs were derived (see Figure 5).

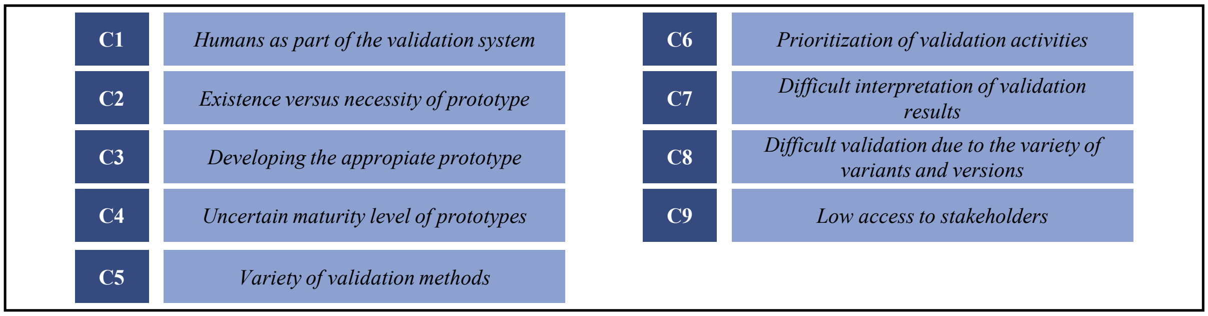

Figure 5. Identified challenges in the continuous validation of product profiles based on the identified publications

<u>C1 – Humans as part of the validation system</u>

Humans are increasingly becoming part of validation activities and environments. This applies to both the acting person for whom the product is developed and the validating person who interprets the results. Specifically, in interactive systems, the networking and interactive socio-technical integration of people in geographically distributed product development processes is steadily increasing and poses one of the greatest challenges (Duehr et al., 2022). In continuous validation, these systems must also be continuously used throughout the entire product development process. The human as a designer and their cognitive and emotional interactions with the development task, as well as their location-based or distributed interaction with team members, still pose challenges (Eisenmann et al., 2021).

<u>C2 – Existence versus necessity of prototype</u>

Challenges regarding continuous validation arise particularly in the early phase of product development due to a high level of uncertainty caused by a lack of resources such as prototypes (Schrock et al., 2022). For successful and, above all, continuous validation, prototypes are required, for which identical production techniques and materials as those used in the series should be used. Physical prototypes or digital simulations used for continuous validation are either too costly/time-consuming or they do not support subjective validation by the customer (Eckertz et al., 2022). However, customer requirements are identified by customers, leading to the need for prototypes to identify these customer requirements (Albers et al., 2017).

<u>C3 – Developing the appropiate prototype</u>

As discussed in C2, prototypes play a crucial role in the continuous validation of product developments. However, there currently exists no widely applied and accepted method to assist designers in making a variety of prototype decisions to create a strategy. The wrong prototype strategy in this context leads to loss of time and resources (Camburn et al., 2015).

<u>C4 – Uncertain maturity level of prototypes</u>

As described in C2 and C3, continuous validation using prototypes presents several challenges. To address these challenges, for example, virtual prototypes are used to obtain results earlier and more affordably than with physical prototypes (Bemmami & David, 2021). This raises the question of when validation can be performed using virtual prototypes in the form of simulations and when more mature or fully matured physical prototypes are needed. Continuous virtual validation must closely mimic the physical behavior of the components, which poses a significant challenge and requires continuous improvement (Nishad et al., 2021).

C5 – Variety of validation methods
Another challenge associated with the increasing complexity of modern systems is the integration of a variety of validation methods. One issue is that there is no "one" uniform simulation method that covers the modeling requirements of all complex systems in today's products. Different product functions that need to be continuously validated may require different models, simulation methods, and tools. Thermal, hydraulic, haptic, and electrical functions may need to be validated with different systems, and the results integrated (van der Auweraer et al., 2012).

C6 – Prioritization of validation activities
In addition to managing a variety of validation methods, another challenge is determining when to perform which validation activity with which method. This can be crucial for the success of a project, as the right activities can save time and resources. Currently, many commercial and open-source modeling solutions are available for systems engineers. Factors that can be used for prioritization include: application domain, industry, and required accuracy of the model for systems engineering activities (Promyoo et al., 2019). Other parameters that could be important for prioritization and assessing the necessity include: modeling costs, available skill level, level of confidence in estimation, and model reusability (Bemmami & David, 2021).

C7 – Difficult interpretation of validation results
Another challenge is the feedback of these validation results, especially with virtual prototypes. For instance, frontloading tests are continuously performed on prototype vehicles or Hardware-in-the-Loop (HiL) and Software-in-the-Loop (SiL) for simulations. The models represented in the simulations must be sufficiently detailed and accurate, considering various scenarios (Raghupatruni et al., 2019). Analyzing the output of simulation models is one way developers can validate early and continuously (Bemmami & David, 2021). However, simulated results always entail uncertainties compared to the real behavior that is being controlled. This necessitates additional evaluation and error checking of the results (Raghupatruni et al., 2019). Additionally, criteria for assessing the accuracy and reliability of the model used in validation are needed to incorporate them into the interpretation of the results (van der Auweraer et al., 2012).

C8 – Difficult validation due to the variety of variants and versions
In addition to the increasing complexity of modern systems, the variety demanded by customers is also steadily increasing. In many industries, the market demands that the same "system" be delivered to different customers in various variants or configurations. Therefore, the same system must function with different variants, generations, components, and system environments (Kowzan & Pietrzak, 2019).

C9 – Low access to stakeholders
As explained in C2, physical prototypes are necessary to conduct validation by the customer. The increasing complexity of products, combined with heightened geographical separation and flexible working hours, hinders the necessary collaboration between developers and customers or stakeholders. Access between developers and stakeholders is thus impeded, which can have serious consequences for continuous validation, as ultimately stakeholders must be satisfied. There are also few suitable methods to integrate the customer early and continuously. (Eckertz et al., 2022)

The described challenges focus on continuous validation of product profiles, the modelling of needs and benefits of products. These challenges can be used to concretize the challenges regarding the continuous validation of product profiles in the Early Phase of product engineering.

5. Field of Actions of Continuous Validation of Product Profiles in the Early Phase
The challenges identified in Chapter 4.2 through literature research pertain to continuous validation. To determine the challenges for continuous validation in the early phase of product development, these challenges are combined with the characteristics of the early phase (see Chapter 5.1), and action fields are described for the continuous validation of product profiles in the early phase (see Chapter 5.2).

5.1 Cross-linking Challenges of Continuous Validation and of Early Phase of Product Engineering
By integrating the challenges of continuous validation with those of the early phase of product development, action fields can be derived. Action fields correspond to clusters of intensified challenges of continuous validation of product profiles. The intensification arises from the challenges of the early phase.

	Humans as part of the validation system	Existence versus necessity of prototype	Developing the appropiate prototype	Uncertain maturity level of prototypes	Variety of validation methods	Prioritization of validation activities	Difficult interpretation of validation results	Difficult validation due to the variety of variants and versions	Low access to stakeholders
Low level of documentation				H			H		
High leverage		H	H	H					L
Complex information processes	H					L	L		H
Informal communication	L						H		L
Low resource utilisation		H	H	H	L	L			
Low structered processes	H				H	H	L	H	H
Low top management support			L				L	L	
High uncertainty			H	H	H			H	
Unclear responsibilities	L			L	H	L		H	H

Figure 6. Defined Cross-Links between Challenges of Continuous Validation and Early Phase of Product Engineering (H of High Influence and L for Low Influence**)**

Figure 6 illustrates the interconnection of challenges, depicting the influence of early phase challenges on those of continuous validation, with influence categorized as high or low. For instance, the challenge 'High leverage' significantly influences challenges C2, C3, and C4, which pertain to prototypes. Developing prototypes becomes more challenging in the early phase, as they have a significant impact. Through these described influences, challenges can subsequently be clustered, and action fields derived.

5.2 Derived Field of Actions of Continuous and Early Validation

Overall, four fields of action for the continuous validation of product profiles in the early phase of product development have been derived. In the following chapter, these will be described in more detail. Firstly, the clusters based on Chapter 5.1 in Figure 7 are presented, followed by explanations of the fields of action.

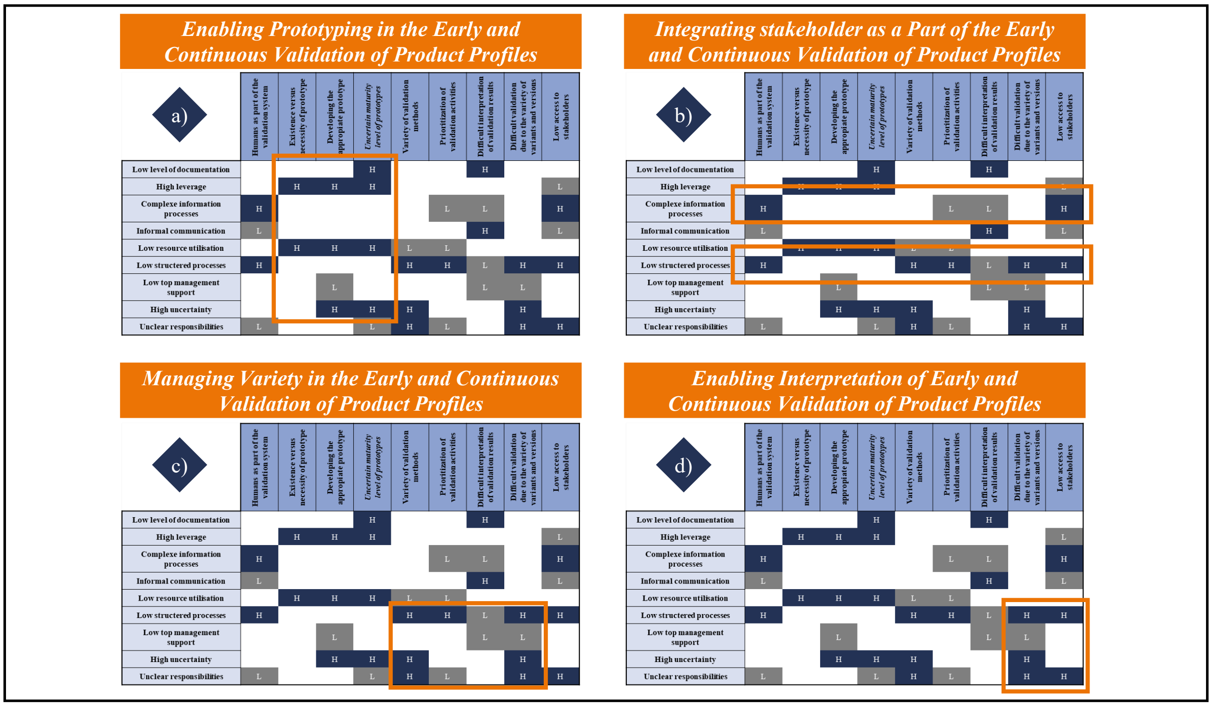

Figure 7. Identified Field of Actions in Continuous Validation of Product Profiles in Early Phase of Product Engineering

The first field of action *Enabling Prototyping in the Early and Continuous Validation of Product Profiles* describes the opportunity using prototypes to assess the validity of product profiles throughout the product engineering process. Especially in the Early Phase, the right assessment of the validity enables the decision making in early project phases and could have a high leverage von the success of the project and the product. But due to low resources utilization it is important to develop an appropriate prototype based on the existing need and situation. Additionally, the high uncertainty and low documentation level prevent the early planning of prototypes, which is why developers must be supported in this process. This field of action therefore calls for support that improves the early planning and development of appropriate prototypes for the validation of product profiles in the Early Phase.

In the second field of action *Integrating stakeholder as a Part of the Early and Continuous Validation of Product Profiles*, the opportunity occurs for supporting the role of stakeholders in the validation of product profiles better by defining the human as a part of the validation system or developing the right prototype for the defined stakeholders. Complex information processes enhance the integration of humans into the validation. For example, it is difficult to find access to stakeholders if the information processes are complex, as it is not defined which stakeholders are relevant, whether they can be integrated at all or whether they can make a valid statement about the existing validation objective regarding the product profile. This field of action therefore requires support for the correct selection, definition and integration of stakeholders in the validation process for product profiles, whereby the correct information is obtained and the stakeholders are integrated into the validation system. Meanwhile in the third field of action *Managing Variety in the Early and Continuous Validation of Product Profiles* a support should be developed that defines what to validate, when to validate and how to validate. What to validate focuses on the variants of the products or systems to be validated. Low structured processes hinder the questions what, when and how to validate by not clearly defining the validation objectives that must be achieved. As a result, it is not clearly structured what is to be achieved with the validation processes. Also, unclear responsibilities hinder the management of variability, as the responsibilities for the individual variants of the methods, systems or products are not defined in this phase. As a result, it is not possible to set up activities with the appropriate personnel. Uncertainty in the early phase also hinders the management of variability in validation, as variants are not yet known in this phase and the necessary information for certain validation methods is not known or does not exist. Support must therefore be provided in this field of action in order to deal with this uncertainty in terms of information, responsibilities and processes. This primarily involves support in the selection and prioritization of validation activities and systems under test. The last and fourth field of action *Enabling Interpretation of Early and Continuous Validation of Product Profiles* Results describes the opportunity for supporting developers with the next steps after the validation by proposing action before and after the validation activities are performed. This is exacerbated in the early phase by unstructured processes, unclear responsibilities, and high uncertainty. Unstructured processes intensify the issue that drawing conclusions for the product based on interpreted validation results is challenging. It is not clearly defined as a process what the results mean for the product. Additionally, uncertainties complicate the traceability, as there can be situations where the validation activities become obsolete because the product has been further developed.

These field of actions can be utilized to develop future methods, processes, and tools for the early and continuous validation of product profiles by defining each field of action as a success factor.

6. Conclusion and Outlook

In summary, the three research questions addressed in this publication have been answered. Regarding the first research question, a total of nine challenges in the continuous validation of product profiles were identified and described. These were utilized to address the second research question by connecting the identified challenges with those of the early phase from the literature. The influences on how the challenges of continuous validation are amplified were described. Based on this connection, four action fields for the continuous and early validation of product profiles were subsequently described. These action fields serve as starting points for the development of new methods, processes, and tools for continuous and early validation of product profiles. By answering the research questions, the research objective of this publication was achieved by deriving action fields for continuous and early validation of product profiles. However, there are further open points that need to be addressed in future research activities. Firstly, the challenges and action fields need to be evaluated and new ones need to be added from an industry perspective to obtain a valid starting point. Surveys and interviews can be conducted for the evaluation of the identified challenges as well as of the action fields and for the addition of new challenges or field of actions. This can help to further specify the descriptions of the action fields. Secondly, based on the action fields, goals, requirements, and constraints for methods, processes, and tools can be derived. Following the DRM - Design Research Methodology by Blessing and Chakrabarti (2009), these can be defined for application, support, and success. Furthermore, these goals, requirements, and constraints can be further specified through a practical view of the action fields.

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Albert Albers has been full professor for product development and head of IPEK - Institute of Product Engineering at the Karlsruhe Institute of Technology (KIT) since 1996. He received his doctorate in 1987 under Prof. Palandan of the University of Hannover. Before his appointment to Karlsruhe, he worked for LuK GmbH & Co. OHG, most recently as head of development and deputy member of the management board. He is a founding and former board member of the scientific society for product development WiGeP, a member of the German Academy of Science and Engineering (acatech) and a member of the Advisory Board of the Design Society. Since 2008, he has been President of the Allgemeiner Fakultätentag (AFT e. V.). In addition, Prof. Albers engages in the VDI and serves of the advisory boards of several companies. In 2016, he and the IPEK team were awarded the Honorary Award of the Schaeffler FAG Foundation for excellent achievements and competencies in science, research and teaching in the technical-scientific field.