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Understanding and definition of scanning and monitoring of the future space in the context of the product engineering process

Albert Albers, Carsten Thümmel ✉, Jessica Schmidt, Stefan Eric Schwarz, Michael Schlegel, Andreas Siebe and Tobias Düser

Karlsruhe Institute of Technology, Germany

✉ carsten.thuemmel@kit.edu

Abstract

Using foresight methods such as scenarios, possible futures can be described and anticipated. Needs and requirements as well as product properties can be derived from that, which is necessary to plan successful products for future customers. Changes that occur in the future development can be identified with monitoring and the expected future can be adjusted. A consistent understanding of the use of monitoring for the product engineering process does not exist and is developed in this paper. Thereby, monitoring is considered in the context of validation and located in iPeM.

Keywords: design process, foresight, monitoring, product development, validation

1. Introduction

The identification of relevant product features and properties starts early in the product engineering process (PEP) and influences the success of later phases (Cooper and Kleinschmidt, 1993). Long development times lead to a considerable time span of up to several years between the start of development activities and the actual launch of the product on the market, which needs to be prognosed (Gausemeier et al., 2019). This leads to high degrees of uncertainty and stakeholder requirements can therefore differ significantly over time from the requirements identified at the beginning of the PEP (Albers et al., 2018a). Consequently, a comparison and observation must take place. In foresight, which is often used in strategic processes to anticipate possible futures, monitoring is an approach for observing change to compare assumptions with actual future developments (Siebe, 2018). But there is no uniform understanding of monitoring in the PEP. It is unclear to what extent there is an overlap with the understanding of validation and to what extent a differentiation can be made. This paper therefore aims to develop an understanding of monitoring of future development in the context and interaction with the PEP and to classify it regarding validation to enable the development of suitable support approaches.

2. State of research

2.1. Monitoring in the strategic foresight

To be successful on the market, products must address the needs and requirements of future customers and must therefore be future-oriented (Cooper and Kleinschmidt, 1993). Besides needs and requirements, especially technologies, boundary conditions and competitor's solutions are not static and can change over time, which leads to changes of the environment which have to be considered for products (Isaksson et al., 2017). The later the intervention into the PEP takes place, the more expensive it will be. Which is why foresight methods are used to anticipate the future environment. Future

management encompasses all systems, methods and processes for the early identification of future developments (Micic, 2007). Fink and Siebe (2016) divide future management into three levels according to increasing time horizon: prognoses, trends and scenarios. Prognoses extrapolate past data for the near future, while trends record current developments into the medium-term future. Scenarios are instruments for long-term foresight and represent alternative, consistent images of the future, which in their entirety span and describe the possible future space and are used to derive strategic directions. (Gausemeier et al., 2016; Fink and Siebe, 2016) Scenarios are systematically created using the scenario technique based on key factors by projecting their characteristics into the future and linking them consistently (Gausemeier et al., 1998). Foresight tools, e.g. scenario updates and monitoring, can be used to take account of changes in future developments (Siebe, 2018).

Monitoring can be described as "watch and check a situation carefully for a period of time in order to discover something about it" (Cambridge Dictionary, 2023). Monitoring is an acknowledged and fundamental activity in companies. In strategic foresight, monitoring is a fundamental part of the strategic planning process. Due to the large number of changes in society and thus the environment, it is necessary to observe these and integrate the resulting consequences into the company's strategy. Monitoring is part of scenario controlling and trend management. In scenario controlling, previously defined and relevant areas of the future space are considered and unexpected changes are retroactively integrated into the scenarios. Trend management deals with uncertain developments, whereby changes within the existing future space are reported and considered. (Fink and Siebe, 2016) Weak signals, which can be signs of change and should be monitored further, play a major role in early detection (Hahn and Taylor, 2006). In the PEP, monitoring can be used to check the current status of research, development or production. (Gruber et al., 2003; Gruber and Venter, 2006)

2.2. Understanding of innovation and product engineering process

The product engineering process (PEP) is part of the product life cycle and includes all steps from the idea and the product planning, via the product development to the production system development and the start of production. The basis for future innovations is forward-looking, system-oriented development. (Albers and Gausemeier, 2012) Innovation is defined as the retrospective successful implementation of a product on the market as a technical invention (Schumpeter, 1939). According to Albers et al. (2018b), the central aspect is the product profile, which is a model of a number of benefits that specifies the solution space for the design of the product and makes the benefits accessible for validation by suppliers, customers, and users. This is in accordance with Patnaik and Becker (1999), who emphasize the importance of firstly focus on the needs instead of specific solutions to keep all possible solutions open. The early phase of product development is very important, because the influence on later development is very high and success depends largely on decisions made here (Cooper and Kleinschmidt, 1993; Verganti, 1997). Products and systems are developed in generations based on references, which is why Albers et al. (2022) have developed a descriptive model with the model of SGE – System Generation Engineering. Products are systems that are perceived as products. Several successive product generations are developed simultaneously, but at different stages. Here, reference system elements are transferred to the new system by carry-over, attribute and principle variation (Albers et al., 2022). Product development can be understood as a continuous interaction of system of objectives, operation system and system of objects (Ropohl, 1975). Based on this system triplet, Albers et al. (2016b) have developed the iPeM – integrated Product engineering Model (see Figure 3), which can be used to describe the PEP through individual sequences based on various basic and core activities. Several generations, the associated production system, strategy and validation system are mapped in layers (Albers et al., 2016b).

2.3. Validation in the product engineering process

Validation is regarded by Albers et al. (2016) as the central, knowledge-generating activity in product development. The knowledge generated during validation is used to specify, expand or reduce the system of objectives within the system triplet. Validation includes the comparison of the system of objects and the system of objectives, considering different stakeholder requirements. According to Albers et al. (2015), see also Figure 1, validation consists of three basic activities: Verification, evaluation and objectification. The aim of verification is to compare the elements of the system of

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objects with elements of the system of objectives, i.e. there is no external comparison. This is the aim of the other two activities. Evaluation aims to examine elements of the system of objects from a stakeholder perspective. During objectification, elements of the system of objectives are examined regarding the expectations of the stakeholders. (Albers et al., 2015, 2016)

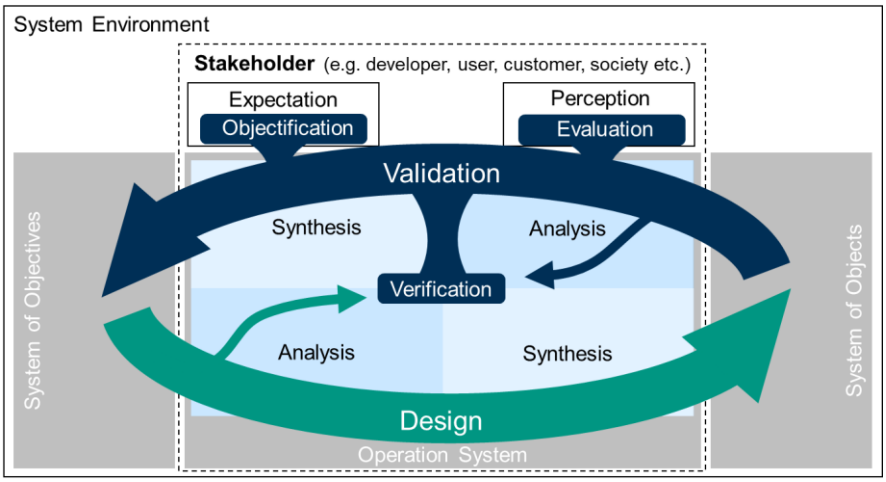

Figure 1. Design and validation in the product engineering process (Albers et al. 2016)

3. Aim of research and methodology

3.1. Research need and research goal

To ensure that the needs of future customers are addressed, it is necessary to regularly review the underlying premises from focused scenarios using foresight methods. There are currently no systematic approaches that support an associated review of future developments in parallel and in conjunction with product development. In order to develop suitable approaches, an understanding of monitoring is necessary. The use of uniformly defined technical terms is essential, particularly for the development of new scientific findings. This makes it necessary to develop a uniform understanding of the terms. Such an understanding of monitoring is not currently known in the context of product development. Also, the connection and coherence to validation is unclear. This work therefore aims to develop an understanding and a definition of monitoring of foresight in the PEP with a classification to validation.

3.2. Research design

The project is structured by the following three research questions.

1. Which understandings and definitions of monitoring in the context of foresight and product creation exist in the literature?
2. How can monitoring be defined in the context of the product engineering process?
3. How can monitoring be distinguished from validation and positioned within the iPeM?

In order to conduct the project and answer the research questions, this work was based on the Design Research Methodology (DRM) by Blessing and Chakrabarti (2009). Preliminary, the research clarification was done in several internal preparatory works and projects. In a first descriptive study, a comprehensive, systematic literature review was conducted to identify existing definitions and understandings of monitoring and validation in the context of strategic foresight and product development. In a prescriptive study, a new, adapted definition for monitoring in the context of the PEP was developed based on the previously identified understandings and definitions. A distinction and classification in relation to validation and positioning into the iPeM was also carried out.

3.3. Preparing and conducting the systematic literature review

The systematic literature review was carried out by creating a thematically appropriate search string. For this purpose, the overarching research topic was divided into its core components in the form of basic

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modules. These modules can be put together and, in their entirety, form the resulting research topic. These are shown in Figure 2 for better understanding. The modules deal with the topics of product development, foresight, product profile and monitoring. The search string was compiled by using AND operators between the modules, OR operator within a module and truncation using the * operator. The search is limited to English and German contributions. Search results in other languages were excluded, as these cannot be evaluated by the authors. In addition, only search results with an abstract were integrated, as nearly all papers and publications include an abstract and therefore enable a systematic selection approach. The international database Scopus was selected as search engine. The search strings lead to 631 results.

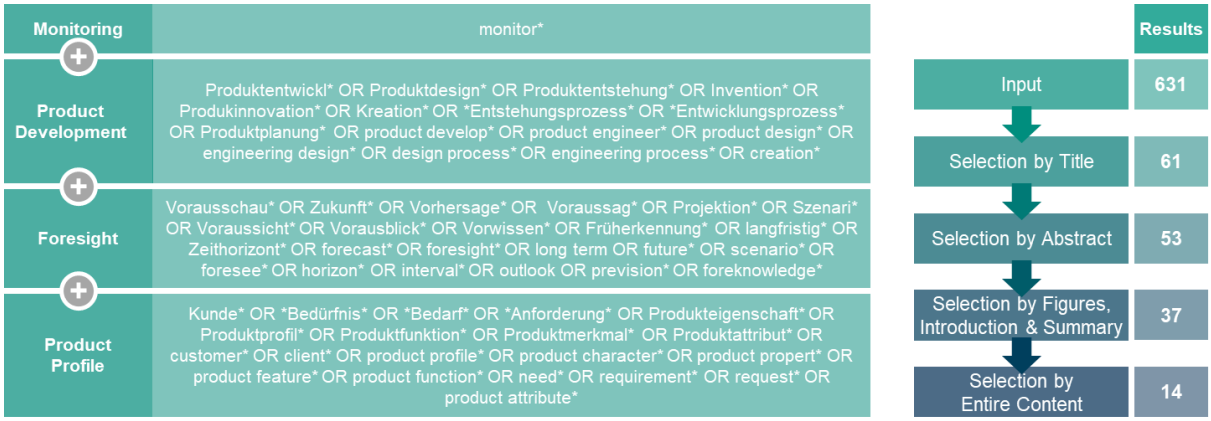

Figure 2. Search string and processing of the results

To select the search results, they were successively classified according to their relevance. Irrelevant results were systematically sorted out. The process is shown in Figure 2. First, the results are analyzed regarding the relevance of the title. Most of the search results were eliminated as they are not thematically related to product development. This is followed by an evaluation based on the abstract without reading the whole publication, because abstracts are normally available within Scopus. Next, the publications were filtered by the introduction and summary, as well as by figures, which often give a good overview of the content and the key findings. Lastly, the the entire content was taken into account to decide, if the paper is relevant. In the final step, suitable, related literature was also searched by using the snowball search method (forward and backward searches).

3.4. Results of the systematic literature review

A total of 14 publications were identified. Of these, nine publications explicitly address monitoring in the intended sense. Although some publications deal with monitoring and mention it as activity, it was found that these often report little about the actual activity itself. The exact meaning, purpose or implementation is rarely described. Nevertheless, some comprehensive understandings of a defining nature are included, which are examined in more detail below to derive a new definition in context of PEP.

4. Definitions of scanning and monitoring in the product engineering process

4.1. Overview of current definitions of monitoring in strategic foresight

The following understandings and definitions were extracted from the literature to describe monitoring in more detail. In addition to monitoring, the term scanning is mentioned in all understandings, which describes a close-by, preceding activity. Understandings and definitions of this were therefore also included. This answers the first research question.

Hahn and Taylor (2006) describe the "weak signal approach", which aims to detect events and information as early as possible to provide indications of a new state of the environment. They distinguish between the two successive basic activities of scanning and monitoring, whereby the transition is fluent. Scanning is described as a search for weak signals by a 360-degree-radar to screen

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the environment of an organization. Additional information is found with Monitoring for the indications of the previously identified weak signals. An in-depth observation takes place to determine if indications are increasing or decreasing. (Hahn and Taylor, 2006)
Lasinger (2011) emphasizes this division into scanning and monitoring: "The separation of scanning and monitoring is necessary, however, as they are characterized by special and very contrasting characteristics" (Lasinger, 2011, p. 129). The main purpose of scanning is to search indications of future changes quickly at any time. This requires an unspecific and wide-ranging search and can take place unconsciously. Monitoring is more formal to perform a targeted in-depth search of the trends already identified in scanning. This means a focused, structured observation for certain goals or ideas about the area. (Lasinger, 2011)
Siebe (2018) also distinguishes between the terms and describes them in a similar way. Scanning is "an undirected, open observation of the environment with the aim of detecting new information" (Siebe, 2018). The large amount of information gathered still needs to be processed. In Monitoring a deeper understanding of the selected information is developed to decide whether the information is interesting and influencing, resulting in business-defining trends or not of strategic importance. (Siebe, 2018)
Despite the different formulations, the understandings and definitions presented here are consistent in terms of content and are taken up in various other studies (Krystek, 2007; Rohrbeck and Gemünden, 2008; Fink and Siebe, 2016). However, they are generally valid and therefore not very specific. All do not explicitly refer to the PEP, but to strategic foresight in context with corporate foresight approaches. There is no direct reference to product development with consideration of established terms and activities. For this reason, a separate understanding will be developed below to create a link to product development.

4.2. Developing a definition of scanning and monitoring in the product engineering process

As it was recognized in the process that monitoring as an activity of strategic foresight is usually listed in literature in connection with scanning, a definition for scanning was developed in addition to a definition for monitoring in the context of the PEP. The definition was developed iteratively in several loops with the involvement of experts in the field of foresight and product development. This involved several scientific discussions in bilateral exchanges and a moderated short workshop with eleven scientific employees in product development.
The aim was to develop a definition that can be understood as directly as possible and without explicit prior knowledge. The definitions should give an idea straight away and be easily accessible. For this reason, some established terms were omitted in favor of better understandability. For example, the term early detection architecture, which is often used in the context of foresight, is not commonly used in product development, which is why reference is only made here to the corresponding methodology. The term 360-degree radar (Hahn & Taylor 2006, Siebe 2018), on the other hand, immediately suggests that it is a tool. Although various tools, for example a trend radar for collecting trends exist, they are operationalizations of the core idea of comprehensive and undirected search. Also there should be no restriction to specific foresight tools in order to keep the solution space open. Therefore, an explicit description of trends for review (Lasinger 2011) is omitted.
The definitions are intended to give a general understanding that explains the central function and core characteristics of both activities in the context of the PEP in just a few sentences. This should make it possible to differentiate between the terms scanning and monitoring. Both terms are to be classified in the understanding of existing approaches, e.g. the system tripel or iPeM, to establish a connection to knowledge already acquired in this context. The second research question is answered with the following two definitions.

4.3. Definition of monitoring in the product engineering process

For the activity monitoring in context of the product engineering process and strategic foresight, the following definition was developed:

> *Monitoring is a validation activity. In the iPeM, validation is understood as a basic activity of product engineering and is the only activity that generates knowledge.*

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> *Monitoring is a targeted search for in-depth information on the development of previously identified indicators for the future environment that are potentially relevant for the company's own process and system development. By systematic and continuous observation of selected indicators during development, monitoring enables the early, cross-generational recognition of changes in future development and thus supports the definition and introduction of suitable actions.*

Currently, monitoring is mainly used to update company strategies. However, it is useful to make it available for the cross-generational product development approach to make the process agile and adaptive. Boundary conditions, objectives and requirements are often uncertain and vague in the early stages. The closer the product comes to market launch, the clearer but also more restrictive these become. Monitoring should be used to identify and take account of changes as early as possible. This should involve a two-way networking of the information flow with feedback between the boundary conditions and premises derived from the foresight and the solutions being developed for the various product generations to check their validity. This requires the definition of indicators that enable targeted and comprehensible monitoring of individual aspects for all generations in different stages of a product. These are defined within the activity scanning and could be, for example, changed trends or adapted laws that significantly influence a specific product characteristic. If a change with an impact on the underlying environment, technology or product scenarios is identified at a certain time, it is necessary to assess whether this has a relevant impact on the properties and design of the product generations currently under development. If this is the case, its extent must be assessed and the various options for action must be weighed up for a decision. A decision could also be to launch the next generation as planned as changes would take too much time to implement but consider the new information to adapt further generations that are already in development.

4.4. Definition of scanning in the product engineering process

For the activity scanning in context of the product engineering process and strategic foresight, the following definition was developed:

> *Scanning is a validation activity. In the iPeM, validation is understood as a basic activity of product engineering and is the only activity that generates knowledge. Scanning is used to detect indicators for the future environment through comprehensive and undirected screening if no or only very vague information regarding changes in future development is available. To gather information, corresponding methodologies (early detection architecture) are used, in which the information gathered through an intuitive and broad approach is assigned to previously defined subject areas.*

To prepare for monitoring, preliminary steps are required, which take place within the scanning process. Suitable indicators from foresight must be defined to check the underlying premises for individual product properties derived from foresight. These can be trends, prognoses or laws, for example, which must be linked to the product properties. Trend radars, the development of certain competitors' products, technological developments and social debates on specific topics are possible points of reference. The initial search is undirected but may be based on the underlying scenarios. In strategic foresight, there exist approaches and methods (early detection architectures) that are designed for updating foresight information. By linking this to product properties, a review of the premises is prepared and can be continuously checked through monitoring. Furthermore, indicators must be defined within product development to actively request the necessary information from foresight in the event of changes in development progress, internal changes in the process, validation activities or certification procedures and to adjust the corresponding parameters for further monitoring.

5. Classification into the iPeM and validation

The focus of both activities is on monitoring future changes in the environment in the context of foresight. Monitoring and scanning generate knowledge about uncertain developments and different expected changes in the environment. Validation is therefore chosen as the frame of reference in which

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scanning and monitoring take place. This assignment is justified because validation is the central knowledge-generating activity within the PEP (Albers, 2010). The assignment to the basic activity of validate and verify in the iPeM also implies that both scanning and monitoring take place within the PEP. However, the two activities could also be used for other basic or core activities of product engineering. An initial classification of the use of foresight in the iPeM has already been made by Meyer-Schwickerath (2014). Based on this, Figure 3 shows an allocation of supported activities through scanning and monitoring in the iPeM.

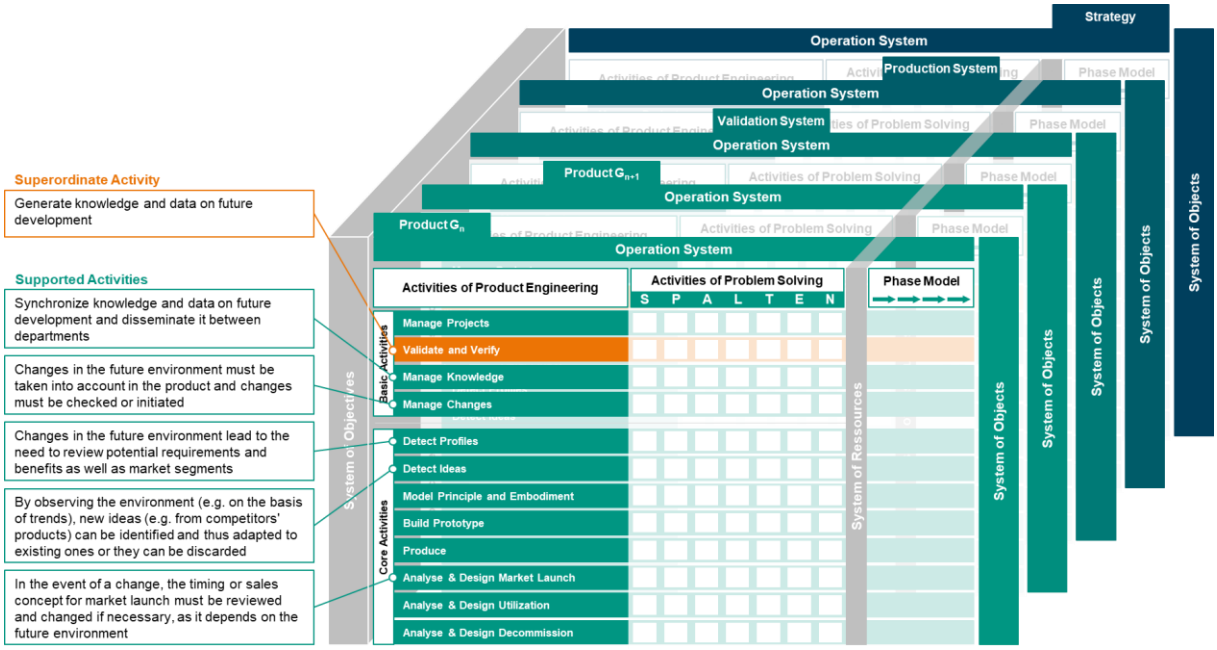

Figure 3. Assignment of monitoring in the iPeM - integrated Product engineering Model

Based on the division of validation into the activities of verification, evaluation and objectification (Albers et al., 2015; Albers et al., 2016), scanning and monitoring would be linked to the objectification activity, as potential expectations of customers can be derived from the foresight. However, these exceed the review of stakeholder expectations, as a comparison with the system environment takes place. Scanning and monitoring could therefore be seen as an additional, separate validation activity. However, a new version of the basic validation activities has been deliberately omitted and scanning and monitoring have been incorporated into the objectification activity, which is thus more broadly understood. This integration into the iPeM and validation answers the third research question.

6. Discussion

According to Albers and Gausemeier (2012), the PEP is defined as a triple of strategic product planning, product development and production system development. In addition, the development of new products proceeds in generations according to the model of SGE – System Generation Engineering by Albers et al. (2022) and several successive generations are developed simultaneously. In accordance with this generational thinking, the PEP is not exited, as the completion of one generation marks the starting point for the development of a new generation and further generations are already in development. For example, in the automotive industry the typical time-in-market is about five years. More than three generations can be already planned and partly developed in different stages. The planning horizon is therefore more than ten years, which results in a high uncertainty and an increased possibility of changed boundary conditions or technologies until market entry which leads to different customer and user requirements. If – in accordance with the strategic approach of the SGE – a certain central property is defined for a product of a given generation G(i=7) well before market entry, the validity of the justification for this property with its underlying boundary conditions and premises must be continuously monitored. The generation moves closer towards market entry over time and changes its

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character in the process (see Figure 4). The closer the market entry is, the clearer but also the more restrictive the boundary conditions and requirements become. During development, there is in principle the potential to implement recognized environmental changes into the product. It is important to check whether changes are still possible and can be implemented technically and economically at the relevant time. The possibility of updates and upgrades to products that are already on the market also means that the knowledge generated can be used for these after the actual development (Kuebler et al., 2023).

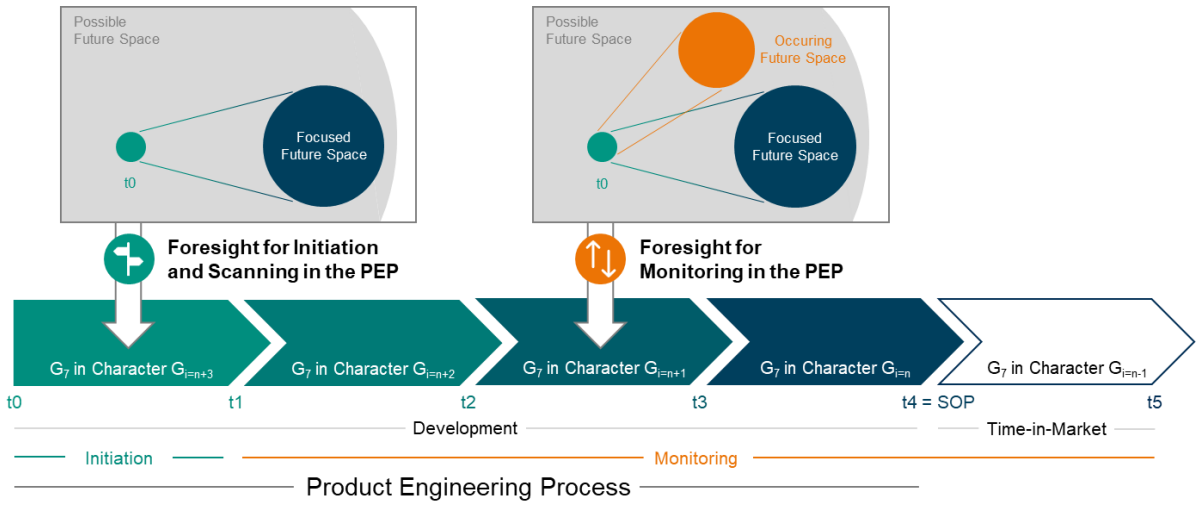

Figure 4. Illustration of a fictional special product generation G(i=7) and its character over time

Appropriate supporting methods need to be developed for scanning and monitoring in the context of PEP. To this end, there are existing research projects that aim to monitor future development using defined criteria from current product development. This enables changes to be identified at an early stage and suitable measures to be derived. The basis for scanning and monitoring in the context of the PEP is the existence of a future space that has been created using alternative, consistent scenarios and needs and product properties that have been comprehensibly derived or assigned from these. Based on these, indicators can be identified by scanning and being monitored afterwards.

In the context of product development, there are various interpretations of the term scenario. In addition to the foresight scenarios addressed here in the sense of descriptions of potential future environments, the terms test scenarios/test cases or development scenarios are also used in the context of validation. However, these refer to cases to be validated in various test environments in the interaction between stakeholders and the system in development and are not the focus of the understanding described here.

7. Summary and outlook

In this paper, a definition of monitoring of foresight in the PEP was developed based on a systematic literature review and consideration of the identified understandings and definitions. In total, 631 search results were obtained and narrowed down to 13 relevant publications through systematic selection. Since the literature research mostly mentioned scanning as a preceding activity in strategic foresight in addition to monitoring, a corresponding definition was also developed for scanning in the context of the PEP. The definitions were created based on the definitions and understandings identified in the literature research in several iterations in exchange with foresight and product development experts. Furthermore, the activities of scanning and monitoring were assigned in the iPeM – integrated Product engineering Model and examined in the context of validation. The definitions provide a basic understanding of scanning and monitoring in the PEP.

Building on this, approaches and methods can be developed to support product developers in adapting products to current developments in the future environment. A corresponding, ongoing research project is concerned with linking foresight with product development to enable targeted monitoring of future developments based on criteria and indicators for individual aspects and properties of a product. This should enable changes to be identified at an early stage and integrated into ongoing product

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developments. Thinking ahead in terms of modular system structures also enables updates and upgrades, for which further research projects exist. To validate future requirements regarding customer expectations, another project is concerned with evaluation based on existing references. Approaches are also being developed to enable future robust product engineering of several products and their interactions across generations in the early phase of the PEP. By implementing future scenarios and products in virtual space, both the environment and the interaction of users or even future users could be tested. Any changes to the focused future could thus be implemented and tested in early and cost-effective tests, similar to early prototyping.

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