Analysis of the Integration of Monitoring Approaches Using Strategic Foresight in the Product Engineering Process

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Abstract

It is essential to develop products that are successful in future markets. However, product engineering often takes several years or even longer, and anticipating the needs and requirements for products is necessary. Strategic foresight provides a solution for identifying future product needs and requirements as well as product properties. Given the constantly changing environment, it is necessary to continually adapt the results of strategic foresight. Changes can be identified through shifting forecasts and trends. To ensure the success of the product in development, changes in the environment must be continuously integrated into the product engineering process (PEP). Thus, the relationship between monitoring changes in the future through foresight approaches and in the product during the PEP is important. This paper aims to analyze the integration of monitoring into the product engineering process based on elements of strategic foresight. The main objective was to identify whether existing approaches support this integration, by conducting a systematic literature review analyzing 1,664 research results. Here, no suitable approaches were identified in the literature. Therefore, to enable the integration of such approaches into the PEP, existing foresight approaches were examined to determine the extent to which monitoring approaches can be linked to them. During the examination of existing foresight approaches, especially scenario methods, commonalities were identified. Although these run individually, they generate the same results, such as influencing and key factors. These commonalities can be used as starting points for monitoring. To define these starting points, general monitoring approaches were examined to compare their structure and process. Here, different processes and structures of the approaches were identified, making it challenging to derive uniform elements for linking to foresight approaches in PEP. The central finding of this research work is that a design support must be defined to enable linkage and integration into the PEP. Initial preliminary work is suitable, in which product properties are derived from the scenarios themselves, as well as key factors. A link between product properties, scenarios, and key factors exists, which can be used for the operationalization of monitoring but has not yet been defined. In summary, different approaches to monitoring exist, but they have different procedures and structures, making integration into the PEP challenging. However, the uniformity of the scenario processes provides a good starting point for developing support for the monitoring of environments, which can help derive the impact on product properties in the event of changes. This enables the PEP to react to changes in the future and develop products that are robust for the future.

Keywords
Foresight, Monitoring, Product Engineering Process, Scenarios, Validation

1. Introduction

To develop a product that is successful on the market, development must always be future-oriented (Cooper and Kleinschmidt 1993). This is relevant to competition for all companies (Siebe 2018). Only through future-oriented development an advantage can be gained in the future market, leading to a successful product (Lindemann 2016). In future-oriented development, all features of the product are adapted to the future customer. The requirements of future customers can vary greatly from the requirements and features a product must have for today's customer. (Siebe 2018) Since the development of a product always takes time and therefore always addresses the future customer, future-oriented development is essential for a successful company (Fink and Siebe 2016). Especially for products with long development times, foresight is very relevant to be able to plan reliably. (Gausemeier 2019)

Using foresight through scenarios, properties can be determined which are necessary for the future product (Albers et al. 2016). Scenarios can also be used to adapt to the development of the market through monitoring. This is important, because the constantly changing of the environment during the long development period. For example, according to Albers et al. (2022) or Kuebler, Schuster et al. (2023), it is already possible to integrate methods of foresight into the early phase of product planning in the product engineering process (PEP). But so far, the integration of validation and a monitoring of the determined product properties within the PEP is missing, as it is enabled by Marthaler's approach for the initial planning of properties using methods of foresight (Marthaler 2021).

Within the PEP, many iterations take place, so that the product to be developed changes continuously. These changes are caused, among other things, by legal requirements (standards, guidelines, etc.) and technical constraints (ease of production, assembly, etc.). Such changes serve the goal of developing the best possible product and placing it on the market. However, with many change steps, the initial focus, the requirements of the future customer and the required product properties derived from them, can be lost sight (Albers et al. 2016). The required product properties may change due to changing customer requirements for the product (Albers et al. 2018). Mainly because of changing customer needs and requirements, it is necessary to develop a methodical integration of monitoring to validate the properties in relation about future customer requirements using a future-oriented scenario preview. (Meyer-Schwickerath 2015).

1.1 Objectives

This work aims to identify existing methods of strategic foresight for the planning of needs and requirements as well as for their validation and monitoring towards the future development. It will be examined whether the approaches and methods already exist link strategic foresight and, in particular, foresight monitoring with the PEP. In addition, potential starting points for integrating methodical monitoring and validation of strategic foresight into the PEP will be found by analyzing existing approaches. The integration of validation or monitoring methods of strategic foresight into the PEP should help to keep the properties, needs and requirements - that were defined at the beginning of the PEP - permanently in view, to recognize changes in the expected future and to be flexible and quick in using for the organization.

2. Literature Review

2.1 Product Engineering Process – From the Idea to Innovation

The product engineering process (PEP) is an "interplay of different activities" (Albers and Gausemeier 2012). It consists of product development, strategic planning and production. According to product generation engineering (PGE), all technical systems are not completely new, but are developed in generations and always based on references through the three variation types carryover, embodiment and principle variation (Albers et al. 2019). For a developed product to be sold profitably, a need must be met with it. This need is triggered in a customer by a problem that is potentially solved by the product. (Braun 2013) Such a need situation is recorded in the product profile (Albers et al. 2018). In the PEP, "starting from customer requirements, goals are generated and transformed into objects by an action system" (Braun 2013). In the Kano model, the relationships between customer satisfaction and the degree of fulfillment of a specific requirement for a product are illustrated. Here, three different types of requirements are assumed: must-be, one-dimensional and attractive requirements (Kano et al. 1984; Sauerwein, 2000). The problem here is not only that development is carried out for the needs of future customers, but also that the requirements for certain properties change over time. Albers et al. (2015) present this problem in a classic Kano model. Since customer needs can change during a PEP, it is important to perceive these changes in needs and incorporate them into the target system (Meyer-Schwickerath 2014). The activities validation and verification are considered fundamental elements in the PEP (Albers et al. 2016). These two activities are very important from the beginning of the development because the later changes must be made, the more expensive the development becomes and is therefore subject to losses. This is described by the "Rule of Ten" according to Erlenspiel et al. (2020).

2.2 Developing Future Products Using Strategic Foresight in the Product Engineering Process

The main reasons for using strategic foresight are the long development times and the ambition to develop innovative products (Gausemeier 2019). It was often considered as a separate process, but it is more and more included in the PEP (Müller 2008). The term strategic foresight comes from future management. By means of future management, companies want to react adaptively and quickly to changes in the future (Westkämper 2009). Here, a distinction is made between three levels: the operational, tactical and strategic level. Various instruments of foresight can be assigned to these levels according to the addressed, ascending time horizon: prognoses (short-term), trends (medium-

term) and scenarios (long-term). (Siebe 2018) Scenarios are used to highlight possible developments in the future. They are separated from trends by using future-opened and networked thinking. (Fink and Siebe 2011)
The scenario technique according to Gausemeier et al. (1998) consists of five steps. Based on an analysis of the previously defined scenario field, factors are identified that describe the current situation. From these, a manageable number of key factors for the further process is selected by evaluation. For each key factor, alternative projections into the future are made based on two dimensions to be defined in which the factor can develop independently. Scenarios are compiled by plausibly combining one projection of each key factor. These are transferred into a picture of the future and described. Subsequently, measures can be derived in the scenario transfer. (Gausemeier 2019; Gausemeier et al. 1998; Siebe 2018)

In addition to the use of scenarios for the strategic alignment of companies, there are approaches for deriving product properties for implementation in the PEP. According to Thümmel et al. (2022), a distinction can be made here between a future-oriented and future-robust orientation. Albers et al. (2022) have developed an approach for deriving product profiles and properties of future product generations through strategic foresight. Among other things, the properties are evaluated in terms of future relevance using the Kano model. If properties contribute to customer satisfaction when various scenarios occur, they are considered to be future-robust. (Albers et al. 2022) The properties determined are used as the cornerstone for the target system of the PEP (Meyer-Schwickerath 2014). With the approach to determining changing product properties using foresight by Kuebler, Schuster et al. (2023) another approach exists. This addresses the foresight of upgrades and updates (Kuebler, Thümmel, et al. 2023).

2.3 Monitoring in the Product Engineering Process and Strategic Foresight

Monitoring can be understood as "targeted continuous monitoring of specified sections and objects of a system to record information about activities and changes" (Sieg 2007). Monitoring is a recognized and fundamental activity in companies. In PEP, for example, monitoring can be used to check the current status of research, development or production. (Gruber et al. 2003; Gruber and Venter 2006) In strategic foresight, monitoring is an essential part of the process. Due to the high rate of change in society, it is necessary to monitor these changes. Monitoring is part of scenario controlling and trend management and thus has a direct influence on changes in the characteristics of the key factors. Scenario controlling looks at the relevant areas of the future space of the scenarios. If changes in the development are identified that are unforeseen, they are retroactively incorporated into the scenarios. Trend management deals with unforeseen developments in the future. Relevant, known trends are observed, but new unexpected trends are also considered and analyzed. These changes are reported and incorporated into the scenarios as needed. (Fink and Siebe 2016).

2.4 Interim Summary

Products are planned and developed within the product engineering process (PEP). This is based on references and thoughts in generations. To be successful in the market, customer needs must be addressed. However, these are changeable and must be thought ahead for the future. For this purpose, methods of foresight exist. Using scenarios, alternative futures can be described and used to derive measures. Initial approaches link foresight methods with the PEP to be able to directly derive properties for future products. Monitoring methods exist to monitor changes in the future. These are linked to the scenario process. Little is known about the extent to which monitoring methods are linked to the PEP. An approach to consider changes of the future compared to the focused future in product development is currently not known.

3. Methods

3.1 Research Need and Research Goal

Products must meet the current needs of customers. In product development, however, this corresponds to the needs of future customers. Methods of foresight are used to anticipate future needs. Scenarios are an adequate tool for describing alternative, consistent futures. Methods exist for incorporating scenarios into the PEP to derive product properties. So do methods to monitor future development and adjust scenarios. However, it is not known whether approaches exist to link methods of monitoring future developments that are directly linked to the PEP to adjust planning and ultimately implement changes in the product.

Currently, there is a lack of an overview of the different methods and processes for the creation of scenarios in the literature. For this purpose, various existing methods are to be identified and analyzed. From commonalities and differences, starting points for monitoring in connection with the PEP can be identified. Likewise, there is a lack of an overview of which methods exist for monitoring foresight and to what extent they interact with the PEP. Therefore, existing methods will be identified and examined. Derived starting points can be used to develop new approaches and methods.

3.2 Research Design

Based on the research need and the research goal, the following research questions were derived to this research project. Based on the questions, the results will also be analyzed and evaluated.

1. Which methodological approaches of strategic foresight and foresight monitoring exist in the literature?
2. Which starting points can be found in scenario building to include a monitoring method for the PEP?
3. To what extent are foresight monitoring methods incorporated into or addressed by the PEP?

To answer the research questions, the approach will follow the Design Research Methodology (DRM) of Blessing and Chakrabarti (2009). First, the research subject is clarified, and an initial literature review is conducted to gain a first understanding. A descriptive study is then done to conduct a comprehensive systematic literature review to identify existing methods. These are then analyzed and compiled into a review.

3.3 Preparing and Conducting the Systematic Literature Review

For a broad search field and meaningful results, the research was conducted on three search platforms: Scopus, Web of Science, and Research Gate. Google Scholar was initially not included due to technical limitations and the resulting unmanageable number of results without specific exclusion criteria. It will be used in a second step. For the systematic search, it was necessary to establish search strings. These were clustered into three main topics, following the idea of platform building. Strategic foresight and product development are the starting point. Following this, the search is supplemented in each case by one of three additional subtopics: monitoring, validation and product properties. For this purpose, each was extended with an AND operator, so that a total of three different search strings were formed as combinations. These are shown in Figure 1a.

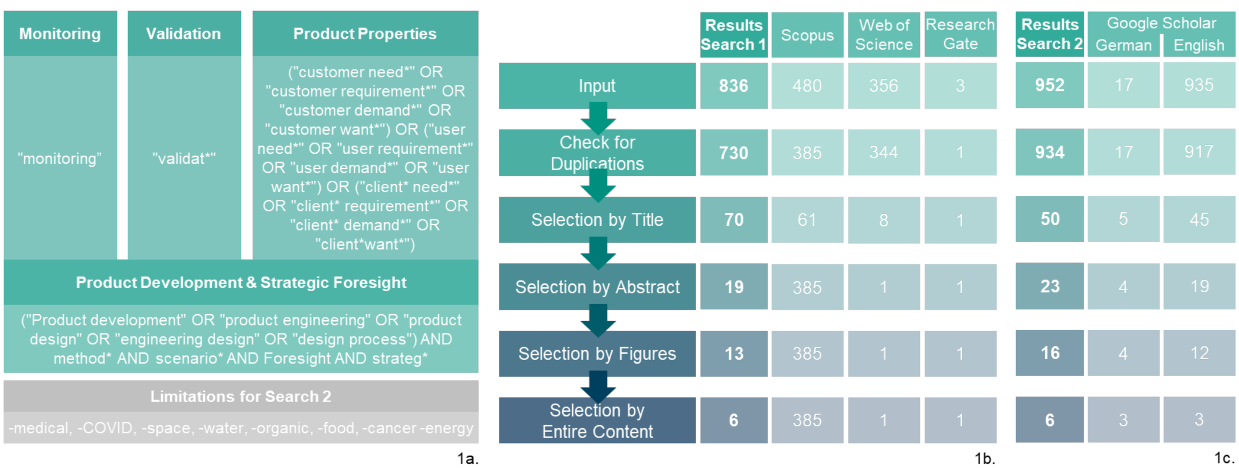


Figure 1a. Search string combinations for searches 1 and 2 and limitations for search 2 / Figure 1b. Selection process of the publications in search 1 / Figure 1c. Selection process of the publications in search 2

The results of the search strings in the respective search engines were exported for further review. The 836 total results were first checked for duplicates. This was followed by sorting by thematic content of titles and abstracts. Since the focus of this investigation is methods, flow charts and figures were a relevant factor by which to sort out. Nevertheless, this criterion was not treated absolutely. If a text was interesting despite the lack of flow charts, it was still considered further. Thus, 6 titles remained for closer examination. The selection process is shown in Figure 1b.

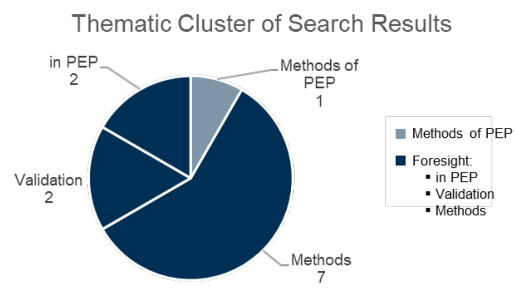
Based on the knowledge gained from the first search run, further exclusion criteria could be defined due to irrelevant hits: -medical, -COVID, -space, -water, -organic, -food, -cancer, and -energy (Figure 1a). This allowed a second search run in Google Scholar to be performed with appropriately adjusted search strings. This resulted in a total of 952 results from the second search. These results were also compared to the original search and examined for duplicates and sorted out. They were also subjected to the same sorting-out process as the initial results, which is shown in Figure 1c. This identified an additional 6 sources of interest.

3.4 Results of the Systematic Literature Review

Throughout the literature review, 1,664 documents were analyzed from two searches with three modularly designed search strings in a total of four search engines, and from these, 12 relevant sources were identified, which are listed in Figure 2a. An overview of addressed topics is shown in Figure 2b.

No.	Source	No.	Source
1	Marthaler 2021	7	Amer et al. 2013
2	Mietzner 2009	8	Schwarz 2008
3	Meyer-Schwickerath 2014	9	Pahl et al. 2007
4	Marthaler et al. 2019	10	Meyer-Schwickerath et al. 2012
5	Müller-Stewens et al. 2012	11	Vishnevskiy et al. 2015
6	Gruber and Venter 2006	12	Daim et al. 2013

2a.



2b.

Figure 2a. Identified search results after selection process / Figure 2b. Thematic cluster of search results

4. Analysis of Approaches for Scenario Building and Possible Starting Points of Monitoring

4.1 Procedure of the Analysis

To get an overview of existing approaches, the identified sources of the systematic literature review were analyzed and the included methods were collected. For each method or approach, a brief summary was prepared in the form of a short profile to provide a general overview. These are listed in Figure 3. Together with the monitoring methods which are listed in Figure 6, these answer the first research question.

1 Heinecke and Schwager 1995	**5 Durance and Godet 2010**
8 steps with rough description Creation of alternative, plausible and consistent images of the future without probability of occurrence. They help to find gaps in the corporate strategy.	*Rough procedure description* Creation of possible, feasible and desirable scenarios to achieve internal flexibility to respond to external uncertainties.
2 Schwartz 1996	**6 Schwarz-Geschka et al. 2012**
8 steps with rough description Illustration of alternative future environments to raise awareness to make the driving forces visible.	*8 steps with detailed description* Scenarios are plausible and justifiable images of the future that can also be understood as a path.
3 Schwab et al. 2003	**7 Gausemeier and Plass 2014**
9 steps with rough description Creation of future environmental situations (scenarios) and the way to get there in order to develop alternative strategies.	*5 steps with substeps* Scenarios forecast complex possible futures, thus they present complex interrelationships in a clear way.
4 O'Brien 2004	**8 Siebe 2018**
8 steps with detailed description A scenario is a description of a possible future in order to be able to capture uncertainties in strategic planning at an early stage.	*4 steps with several substeps* Scenarios are not exact predictions; they are intended to show the possible future space. They present complex interrelationships in summarized form and can thus be an aid to decision-making in strategic planning.

Figure 3. Overview of the analyzed approaches to scenario creation

To find starting points for integration into the PEP within the existing approaches to scenario creation and thus to answer the second research question, it is necessary to look at the similarities and differences of typical steps in the creation of scenarios. Based on the systematic literature review, the approaches were analyzed in more depth. For this purpose, their individual procedures were examined in terms of the methods and used sub-steps.

For the more in-depth analysis, the individual components were identified in the form of methods and sub-steps. These were then presented according to the logical sequence in individual flow charts for a good overview. An example is shown in Figure 4. Based on this, a comparison of the different approaches is possible. For better comparability, the individual flow charts were summarized in a common representation. This is shown in Figure 5.

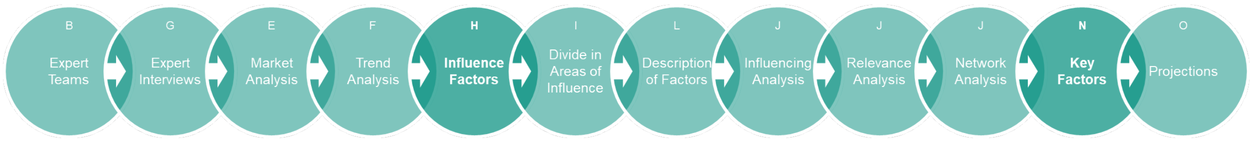


Figure 4. Schematic representation as a flowchart of scenario creation according to Siebe (2018)

4.2 Results of the Analysis

The flow chart in Figure 5 uses paths to show the sequence of the respective sub-steps of the approaches examined. The diagram was divided into the two areas of analysis and factor selection, and the methods and sub-steps used were sorted thematically. For better comparability, individual steps of some methods and sub-steps were summarized for standardization. This makes it possible to present the various approaches in one diagram and to compare them directly with one another in terms of their logical and thematic sequence and to identify both similarities and differences.

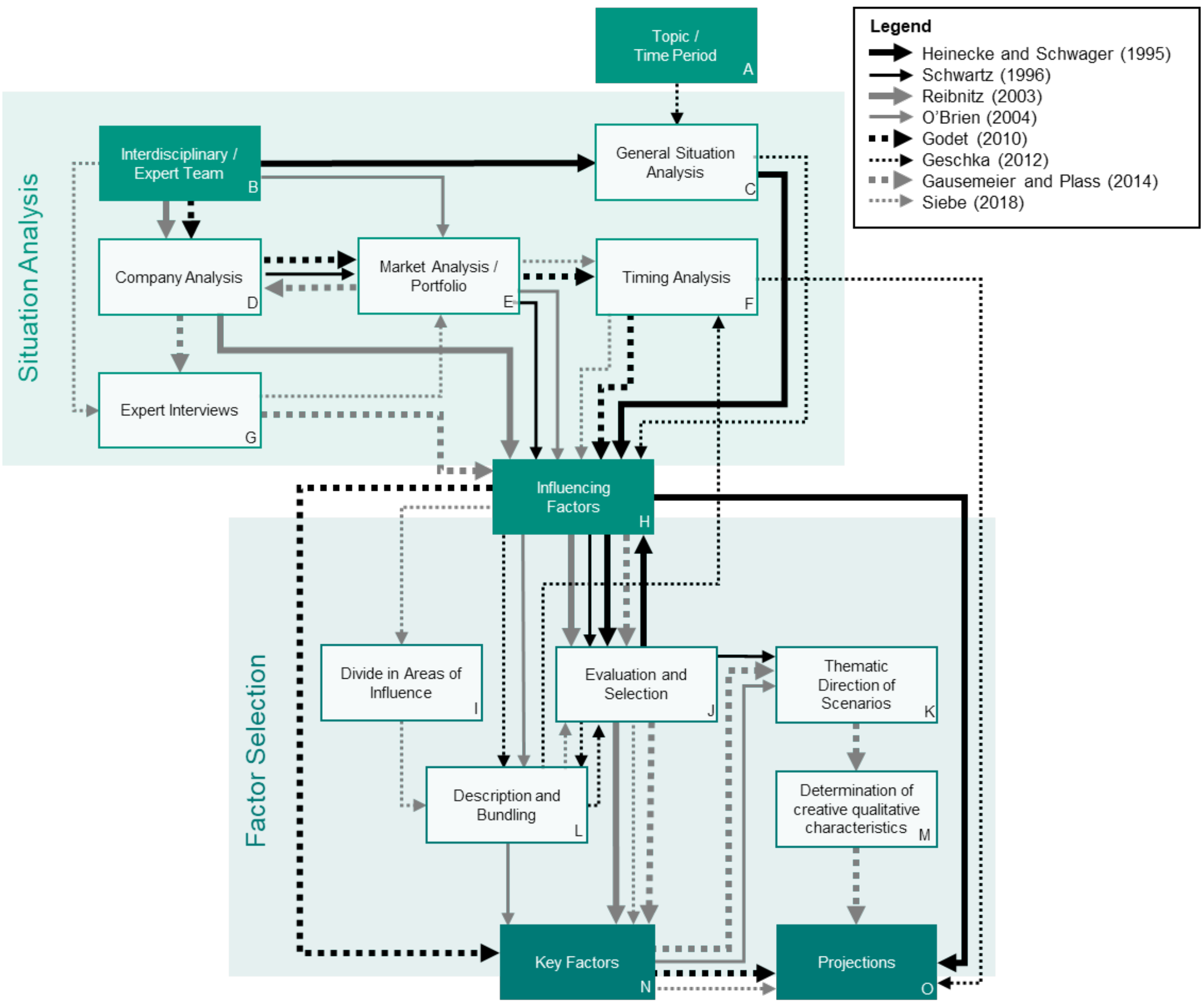


Figure 5. Flowchart of different approaches for scenario creation

4.3 Findings of the Analysis

All methods have a very similar approach, which is why they can be consolidated well in one figure. This could suggest that they are all based on an early, original form and have evolved based on it. Alternatively, the approaches may have evolved independently and come to similar conclusions. In the analysis section, the authors start at different points and perform analysis in different ways until they all form influencing factors during their approach. After that, factor selection begins, which is handled differently by each author. Many form key factors or projections before scenario building. In the analysis of this comparison, it is noticeable that in those methods which officially do not form key factors, also a factor selection takes place. In doubt an iteration loop is led by the influence factors. According to the view of a key factor as influencing factor with a high degree of interconnectedness and high relevance (Fink and Siebe 2011), this can be interpreted as key factor formation, only the terminology has not been used yet.

Thus, influencing factors, key factors, and projections can be identified as possible starting points, of which, however, the key factors lend themselves as particularly relevant factors for monitoring. These could help to identify changes at an early stage and to estimate the impact on product properties. This answers the second research question.

5. Analysis of Approaches of Foresight Monitoring and Possible Integration in the PEP

5.1 Procedure of the Analysis

To analyze which approaches are possible for a subsequent integration of strategic foresight into the PEP with a supporting monitoring method, known approaches are examined. For this purpose, the eight approaches listed in Figure 6 were analyzed.

Figure 6. Overview of the analyzed approaches of monitoring

When comparing the individual methods, five main aspects emerged in which the procedure differs: reference element, reference material, adjustments, review procedure and documentation. The item's reference element and reference material represent what is compared in the corresponding procedure. This procedure is an essential part of a monitoring method. The comparison is usually followed by an adjustment of the areas under consideration, which varies depending on the project and the area of application. Depending on the procedure, the method is applied continuously or at defined intervals. Here all methods agree, a random application of monitoring methods only using samples is not sufficient, this point was listed here only for the sake of completeness. Some methods also address the fact that after the active monitoring process, the documentation of the action is an important part, which still belongs to the method itself. Thus, the individual approaches extend differently through the methods of the five areas.

5.2 Results of the Analysis

For a unified overview of the monitoring methods, a layout based on a morphological box was chosen. In this, the five identified main aspects are worked out as categories and the different characteristics of the different approaches are listed next to each other per category. A path is drawn for each approach, showing the thematic-logical sequence. The overview flow chart is shown in Figure 7.

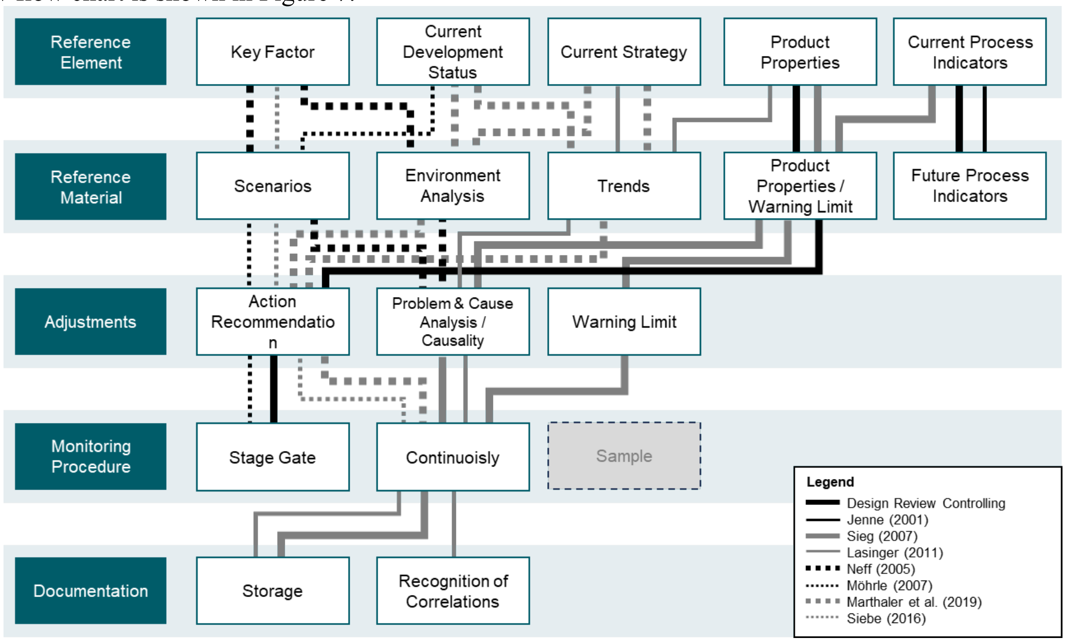


Figure 7. Flow chart of different approaches for monitoring

5.3 Findings of the Analysis

Various approaches for monitoring exist, but they have different procedures and structures, which makes integration into the PEP difficult. An approach that directly addresses the PEP could not be identified. The different methodological approaches come from different areas with different needs to be solved. This is especially evident in the elements that are compared. These are addressed areas of corporate strategy, product development, production procedures or departmental monitoring. Each method carries out a comparison, which is followed by a result. This comparison should take place as continuously as possible and be documented for later purposes. For this process to be successful, comparable data is required. For this elaboration, this means that factors alone will not be sufficient for a comparison to be made during the PEP. This answers the third research question.

6. Need for Research in Monitoring Future Changes and Impact on the PEP

From the findings of the systematic literature review and the subsequent analyses of the approaches to scenario generation and monitoring, it can be deduced that no suitable approaches exist to date to enable continuous monitoring of future developments in connection with the PEP. Various approaches to scenario creation aim to describe possible, plausible future alternatives. There are also various approaches to monitoring. These address a wide variety of areas, although not all of them aim to match future developments. Those that match scenarios with the future as it occurs are not appropriately tailored to the PEP and are at the foresight level along with scenarios. There are initial approaches for using scenarios for the PEP to incorporate foresight to initiate a PEP. However, there is no further integration of methods and approaches of foresight in the sense of monitoring. This would be necessary, to adapt products to actual future developments that have changed compared to the expected future focused on at the beginning. Otherwise, there is a risk that the product will fail on the market because the needs of future customers have not been met.

This is already addressed by Thümmel et al. (2023) with described fields of action on *Changes of Plans for Future Products in the Product Engineering Process* and *Recognizing Changes in the Future Development*. None of the analyzed methods identified based on of the systematic literature review point to such monitoring in the context of the PEP. Therefore, there is a need to develop a supporting approach by linking and integrating monitoring, scenario creation methods, derivation of product properties and the PEP.

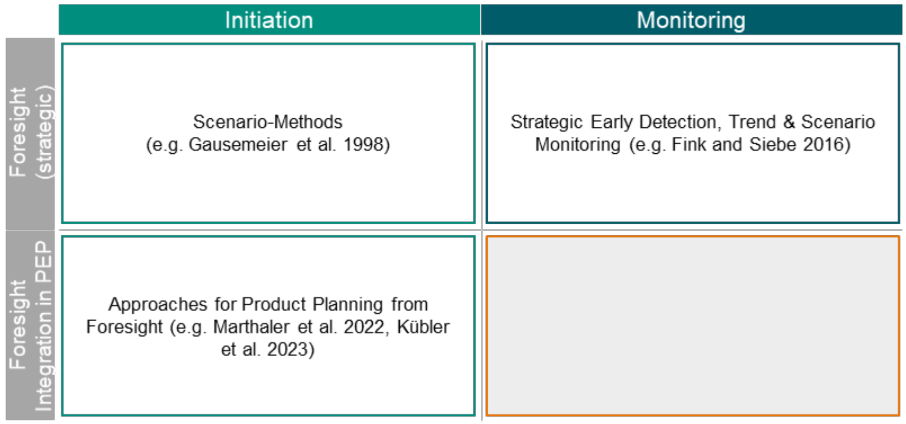


Figure 8. 4-field portfolio of research need and connecting areas

The described division is shown as a 4-field portfolio in Figure 8. Here, there is a division in terms of addressing into strategic foresight vs. integration of foresight in the PEP as well as a corresponding time-based division into initiation at the beginning of a PEP vs. monitoring for surveillance and review at later points in the PEP.

7. Conclusion and Outlook

To identify and analyze existing approaches to foresight for use in PEP, a comprehensive systematic literature review was first conducted. Using 3 modular search strings with a common basis and different additions, 1,664 results were obtained in two iterative steps in a total of four search engines. After a stepwise evaluation and selection process, relevant 12 publications were identified. From these, 8 approaches to scenario creation and 8 approaches to monitoring were extracted. The analysis of the approaches took place separately. In each case, the methods and sub-steps used were listed in their thematic-logical order. To create comparability, some steps were combined. Based on the resulting flow charts, a common overview of the approaches could be generated in one representation. From there, it can be deduced that key factors are a potential starting point for linking methods of foresight and monitoring and the PEP. Based on the analyses and in particular the methods of foresight examined, a research gap emerges. No approaches for the targeted use of monitoring in the PEP could be identified. Research projects should therefore address this issue to introduce changed boundary conditions from foresight into ongoing PEP and, vice versa, to make indicators from the PEP available for targeted monitoring.

A possible starting point for linking and developing an approach was found with the key factors. An ongoing investigation aims to combine trends with key factors to simplify the identification of changes within the future space created with scenarios. Trends and tools like trends radars and trend managers are already well known and used in companies which make it easy to work with and get information from. Further on, suitable indicators from the product development could be used to specifically monitor future developments, identify changes at an early stage and implement them in the PEP. In this way, it can be prevented that products are developed for a focused but not occurring future and ultimately fail in the market. An ongoing research project focuses on this topic and aims to develop a systematic approach as well as a model to describe changes within the future space and the amount of change affecting the product in development. With updates and upgrades, changes identified in this way could also be implemented in existing products late in the PEP or in the market. Therefore, another research project focuses on planning updates and upgrades based on foresight. However, early validation of developed concepts and prototypes with customers in the sense of testing to ensure market acceptance remains essential.

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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, Prof. Albers 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 on 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.