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An explorative approach to deriving future scenarios: A first comparison of the consistency matrix-based and the catalog-based approach to generating future scenarios

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Abstract

The development of robust products, meaning products that are successful regardless of changes in the future, requires an assessment of possible futures. This makes it possible to adapt to negative and unexpected conditions or circumstances. For this reason, future scenarios are developed that reflect possible futures based on influencing factors and their alternative developments on the product or system. For each factor, multidimensional future projections can be found, which are then evaluated for consistency. Up to now, scenarios have been created using the scenario management approach, which is based on consistency assessment of future projections pairs of key factors, or morphological methods (e.g. field anomaly relaxation). Both approaches are based at least in part on a plausibility check. On the one hand this leads to a high expenditure of time in scenario management, and on the other hand morphological methods consider a limited number of factors, which reduces the future space and thus limits informative value of the scenarios. In this research contribution, an explorative approach to deriving future scenarios is proposed that integrates morphological elements into scenario management. This significantly reduces the time required to generate future scenarios without having to reduce the number of considered key factors. First, the proposed approach is described with a process model. Second, the proposed form of scenario generation, the catalog-based scenario generation, is compared with the previously used approach to scenario generation with regard to advantages and disadvantages. Finally, the suitability for PGE - product generation engineering projects is evaluated, in particular regarding replicability, comprehensibility, effort and the completeness of the described future space.
This is done by conducting three structured expert interviews and two case studies. Thereby, scenarios are created with both approaches. The criteria to evaluate the approaches are defined by a panel of experts on PGE.

Keywords: foresight; future scenarios; innovation support; decision making; early phase of product engineering; innovation method

1. Introduction

According to Cooper, companies are only competitive if resources in development are efficiently allocated to projects and customer needs are identified, understood and satisfied by appropriate products [1]. Lindemann adds that "successful products are an important prerequisite for a prospering economy" [2 (p. 20)]. The success of a project is strongly influenced by decisions made in the early phase of the PGE - product generation engineering [3, 4]. Fischer and Ehrlenspiel show that the greatest potential for influencing cumulative product costs lies in the early phase of product engineering [5, 6]. At the same time, the cost of eliminating errors increases exponentially as product engineering progresses [7]. Therefore, it is absolutely necessary to identify the distinguishing product characteristics at an early stage. Hence, the development engineer has to identify requirements of current and future product generations in order to identify and utilize success potentials at an early stage. The resulting product innovations are decisive for growth [8]. Companies

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need thus credible information at an early stage on future needs and interests of their customers, their environment and the constraints of the market and society to ensure long-term success. In complex, highly interconnected and strategic issues, the search for possible (mega) trends is not sufficient due to the dynamic development of the markets [9, 10].

As it is not possible to predict the future, scenarios are developed which describe various development possibilities [11]. The scenarios are derived from future images, which are created by combining different projections of influencing factors. The combination can either be based on a consistency matrix or on a catalog similar to a morphological box. In the consistency matrix, all combinations of pairs of future projections of influencing factors are valued with regard to their compatibility. All potential pairs are rated on a five-point scale, whereby '1' corresponds to mutual exclusive projections, i.e. there is no consistent scenario in which both projections are appear together, and '5' refers to a case in which it is highly conceivable that these two projections appear together [9]. For this reason, an alternative has been developed with which future scenarios can be generated much more quickly without reducing the quality of the scenarios.

2. State of the art

2.1. Motivation for developing future scenarios

A commitment to a certain presumed future is not purposive, as it is impossible to predict the future sufficiently accurate in the long term. For this reason, scenarios are derived that factor in the development of various influencing factors, such as legislation [12, 13]. By combining different possible developments of individual influence factors, known as projections, different future images result. Each of these represents an autonomous and consistent scenario, independent of its probability of occurrence [14]. This allows companies to prepare for several development opportunities, i.e. a "multiple future" [15]. Consequently, future scenarios are an important instrument to enable a responsible handling of risks and opportunities [16]. Additionally, the derivation of scenarios requires a change of perspective, which is very beneficial for the creativity process [17, 18]. This means that scenarios can be used to assess the future robustness of product profiles and to generate or concretize new profiles using creativity methods [19]. In both instances, scenarios are used to identify existing and latent needs and wants for the future or to derive a new need from conditions in the future [14]. Products and ideas that show little or no influence from external influences are robust with respect to the future [12, 20]. Reibnitz defines robust strategies as independent from the external situation. In terms of scenario development, this means that a product is successful regardless of the future (market) situation [21]. Therefore, a robust product profile is successful in several, if possible, all scenarios. Albers et al. define he product profile as the description of a demand situation with regard to all affected stakeholders, whereby both the customer and user benefits as well as the supplier benefits are emphasized [22, 23]. This is achieved by characterizing the core functionality and properties to be fulfilled in a way that is solution-neutral, yet not solution-open, with consideration of relevant use cases.

There are several methods that are used to generate future images [24–26]. Scenario management is an approach that combines several methods. For instance, a, cross-impact analysis is used to identify key factors. The development of future images is based on a trend impact analysis [9], which considers direct and indirect interdependencies of the projections of the key factors [14].

2.2. Modeling the future with scenarios

Systematic foresight refers to the continuous examination of the future. In combination with an efficient integration of the results into planning processes it is a decisive factor for success [14]. The scenario field describes the forecast scope to be described [14, 27]. A scenario is one of several future images and is based on consistent combinations of conceivable developments of the influence factors [27, 28], referred to as future projections. While trends reflect incremental changes, future studies include trend discontinuities, organizational changes, disruptors and external disturbances [29]. Scenario management is an established approach to develop consistent future scenarios that are used for strategic leadership [9]. Another approach widely used to create scenarios is the computer-aided morphological analysis [30, 31]. It is an advancement of the morphological approach to scenario generation [31, 32]. A morphological box is a creative thinking tool in which complex problems are decomposed into sub-problems or parameters. Next solutions or ideas for the sub-problems and parameters are identified and listed in a spreadsheet [33]. In morphological approaches to scenario generation, influence factors correspond to sub-problems and their possible development (future projection) corresponds to solutions to these sub-problems [28, 30–32, 34].

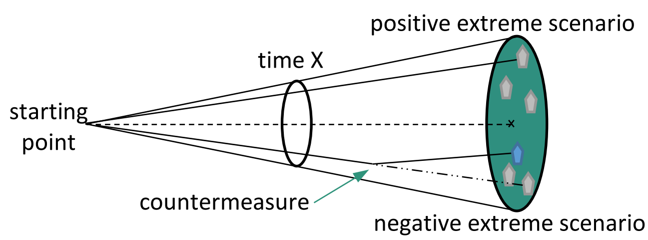

Fig. 1. Funnel model of the multiple future based on Reibnitz [21].

In both methods, future images are created which describe the multiple futures. The funnel model (Fig. 1) is used as a tool to represent the multiple future. It shows all future images for a specific time horizon, originating at a predetermined starting point. Towards the edge of the funnel model, future images represent extreme scenarios. The future image similar to the trend are depicted near the center. Countermeasures to known, expected or foreseeable disruptions can be taken into account during scenario generation by adjusting the characteristics of influencing factors. In this way, future scenarios can be selectively influenced [21]. Future images are created using various projections of, optionally weighted

[35], influence factors on the product or system [14]. The consistency of the individual influence factors must be observed carefully when combining them [32].

2.3. Scenario management

Scenario management is understood as a combination of open, systems thinking and strategic thinking [14]. The overarching approach of scenario management allows scenarios to be generated that can be used purposefully in various areas of the company, such as strategic planning, innovation or product management and qualitative risk management [14].

There are various similar scenario techniques [9, 27, 36–40] that can be traced back to Pierre Wack [41, 42], a planner at the Royal Dutch Shell company.

This contribution focuses on the scenario management (Fig. 2) according to Gausemeier et al., which is divided into five phases [9].

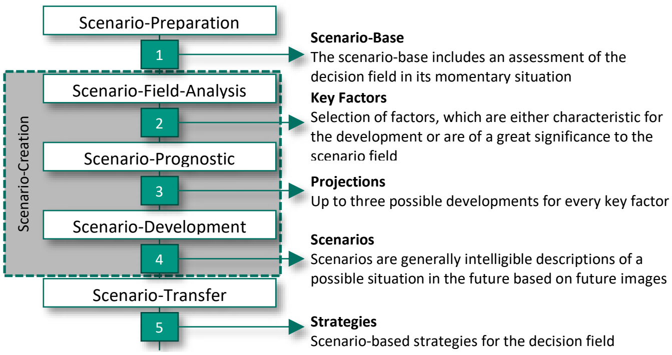

Fig. 2. Phases of scenario management based on Gausemeier et al. [9].

2.4. Morphologic methods to develop scenarios

The field anomaly relaxation (FAR) and its derivatives are widely used methods to develop scenarios [30–32, 43]. The FAR is a morphological method in which scenarios are developed in four steps [28, 32, 34]. Following the creation of the scenarios, these can be used to improve the quality of the future scenarios through reiterating, or to adapt to changed boundary conditions or another design field [34]. The four steps of the FAR cycle are illustrated in Fig. 3.

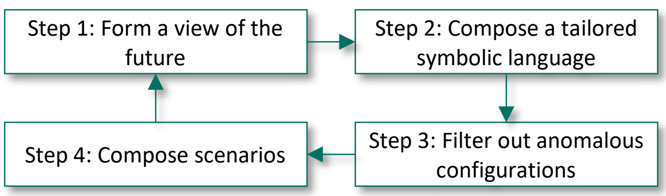

Fig. 3. The FAR cycle based on Rhyne [34].

2.5. PGE – Product generation engineering

Even in the early phase of product engineering, trend-setting decisions must be made that have a major influence on the innovation potential of a product on the market [44]. This means that the greatest influence can be exerted in the early phase of product engineering though without being able to predict the effects [45]. On the other hand, it is easy to retrospectively assess the effects later on, but significantly affects the ability to exert influence [45].

In product engineering, depending on the novelty of a design Pahl and Beitz differentiate between original, adaptive, variant and repeat design [46, 47]. This general categorization is of limited application in practice, as a complete original design is very rarely developed [3] and an adaptive design is considered "trivial" and thus does not meet the standard of innovation [44]. Therefore, Albers et al. proposed the model of product generation engineering (PGE) [44]. It is based on the assumption that any design is based on already existing designs, known as reference system elements, that are variated [48]. This approach distinguishes between three variation types and accurately characterizes product engineering projects [3]. For the carry-over variation, only minor modifications to the RSEs are made, so that they can be integrated into the system in development (SiD) [48, 49]. In an embodiment variation, the solution principle of RSEs remains unchanged while their shape is changed [44, 48]. A principle variation changes the solution principle and the shape of RSEs and thus coincides with an embodiment variation [3, 48].

The model of the PGE is a tool to control the complexity of the product engineering process and to ensure that products have a enough differentiating features [50]. Environment scenarios developed by scenario management can be used to identify specific (customer-experienceable) product characteristics. With these, development demands can be ascertained and prioritized [51]. Subsequently, relevant customer experienceable characteristics and sub-systems are identified. By applying the model of PGE, the necessary type of variation as well as the product generation in which the variation is to be implemented can be determined [51].

2.6. Innovation management

Innovation is indispensable for the long-term success of companies [8, 52]. An innovation is an invention that has successfully established itself on the market [53]. However, market success can only be assessed in retrospect [49].

Companies must adapt themselves and their product development to rapidly changing circumstances. In particular, shortened product times, shorter technology cycles and dynamic customer requirements and markets, as well as ever-increasing interconnectedness and complexity, are forcing companies to adapt their product development processes [54, 55]. At the same time, cyclical innovations are necessary to ensure sales [44, 56] as Fig. 4 illustrates.

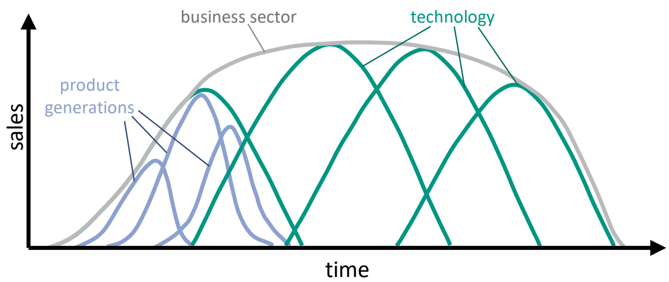

Fig. 4. Life cycle model based on Albers et al. [44].

The change from one technology to another is only possible through a variation of the solution principle. However, the life cycle model shows that innovation and thus market success can often be achieved by improving already used technology and does not necessarily require the transition from one technology to another [3]. Kano et al. developed a model [57], with which the innovation potential can be measured regarding the customer benefit [49]. The associated market success depends on the degree to which the basic, performance and excitement attributes are met [57].

Over time, excitement attributes degrade first to performance and then to basic attributes, yet the degree of functionality increased in each product generation [58]. Thus, new products must adapt to changed current and future demands and boundary conditions of the market [44].

2.7. Identification of strategic potentials

In addition to controlling and monitoring the technology-driven dynamic changes in the market environment, the complexity of product development on both the customer and technology sides must be minimized by means of simple processes. Technology-driven dynamic changes are constantly increasing, especially after the successful market launch of a new technology. This change limits predictability [12, 54]. Therefore, decisions pertaining to product engineering should consider the future viability [19, 51, 59].

3. Research questions and methodology

By developing scenarios, requirements and properties of future products can be identified. The model of PGE, with which the variation portion can be analyzed and controlled, enables a conscious handling of chances and risks in product engineering. Thus, the combination of scenario management and the model of PGE can increase the innovation potential while simultaneously enabling a conscious handling of opportunities and risks.

However, scenario management is relatively time-consuming, especially the creation of future images through a comprehensive consistency assessment is very time-consuming. In product engineering, it is advisable to adapt the scenarios regularly. In doing so, changes of the future projections, e.g. due to already successful measures, of influence factors are considered. However, sometimes consistency matrices are erroneous, which decreases the quality of scenarios [35].

In order to reduce the time required to create the scenarios, an alternative method to create future images was developed, which is based on a catalog, hereafter referred to as catalog-based scenario generation. Both the approach described by Gausemeier et al. and Siebe to generate future images, hereafter referred to as consistency matrix-based scenario generation, and the catalog-based scenario generation are based on the identification of consistencies between the projections and the consistency of the resulting future images, which describe the multiple future. In the following, both approaches are evaluated with regard to their advantages and disadvantages as well as their suitability for PGE, especially regarding their use for several successive product generations in the long-term. This leads to the following four research questions:

- How must the scenario management with the consistency matrix-based scenario generation be modified in order to significantly reduce the required effort to create future images?
- How does the catalog-based generation of future images influence future images and subsequently the future space?
- Which scenario projects of product development are suitable for the catalog-based generation of future images?
- What are the advantages and disadvantages of catalog-based scenario generation for product generation engineering compared to consistency matrix-based scenario generation?

In order to compare the two approaches, three structured expert interviews were conducted. In two instances this coincided with the application of the approaches in order to be able to compare their results (Fig. 5). All interviewed experts had repeatedly employed scenario management using the consistency matrix-based scenario generation. The expert interviews are based on a questionnaire with 24 questions. The questions reflect the requirements on a systematic approach to generating future scenarios that a panel of five PGE experts identified. The fulfillment of these requirements is evaluated through 11 characteristics. The interviewees were asked six questions to ascertain the suitability of the consistency matrix-based and catalog-based scenario generation. The remaining questions address the prerequisites of the scenario generation through the consistency matrix and the catalog.

Both approaches were applied in Study A and Study B Prior to the structured interview. Semi-structured interviews were used to compare the resulting future images were compared (Fig. 5). This is used to identify differences in the future space. Subsequently, the causes for the differences are investigated. In a final step, user-specific aspects such as comprehensibility and intuitiveness are examined.

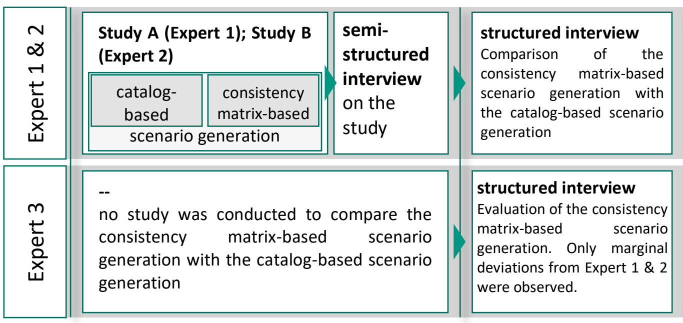

Fig. 5. Research activities to evaluate the catalog-based scenario generation.

Both the structured, and the semi-structured interviews are conducted individually. Therefore, the experts did not know the answers of the other interviewees.

4. Results

In the following, the developed catalog-based scenario generation is described in more detail. Afterwards, the research questions are answered

4.1. Scenario development with the catalog-based approach to creating future images

In general, the scenario management with the proposed catalog-based scenario generation includes the same activities and phase deliverables as the scenario management with the consistency matrix-based scenario generation except for phase 4. In phase 4, the approach to consistency assessment is adapted in order to save time and ensure a stronger distinction of future images. Fig. 6 illustrates this using a process model. The catalog-based generation of future visions is a modification of steps 3 and 4 of the field anomaly relaxation (FAR). As the FAR is based on a cycle that increases quality and informative value of future images by iterating, it is ensured that future images can be adjusted quickly and easily.

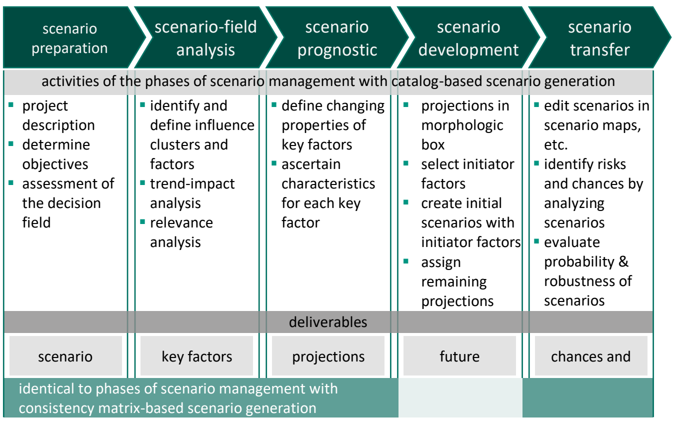

Fig. 6. Scenario management with the catalog-based scenario generation.

The creation of scenarios based on the catalog-based scenario generation differs significantly from the FAR, since the proposed approach uses a sequential process in which retiring phases is only intended as a corrective measure (Fig. 6). For this reason, it is important to check the quality of the deliverables of each phase before starting the next phase.

The steps of the 4th phase of scenario management with the catalog-based scenario generation are detailed in Fig. 7 (steps I-III) and Fig. 8 (step IV). Fig. 7 depicts a section of the template which was used in the case studies. In this approach, the multiple future is treated as a complex problem that is first decomposed into clusters and then into key factors. The future projections represent possible ideas or solutions for these sub-problems. The resulting morphological box becomes a catalog by adding four columns corresponding to the synthesized future scenarios and one column indicating which of these key factors represent the initiators.

After transferring the key factors into a morphological box, initiator factors are determined. For this purpose, the most influential key factor of each influence cluster is selected. Initial scenarios are then based on the initiator factors. The combination of the respective projections is similar to step IV.

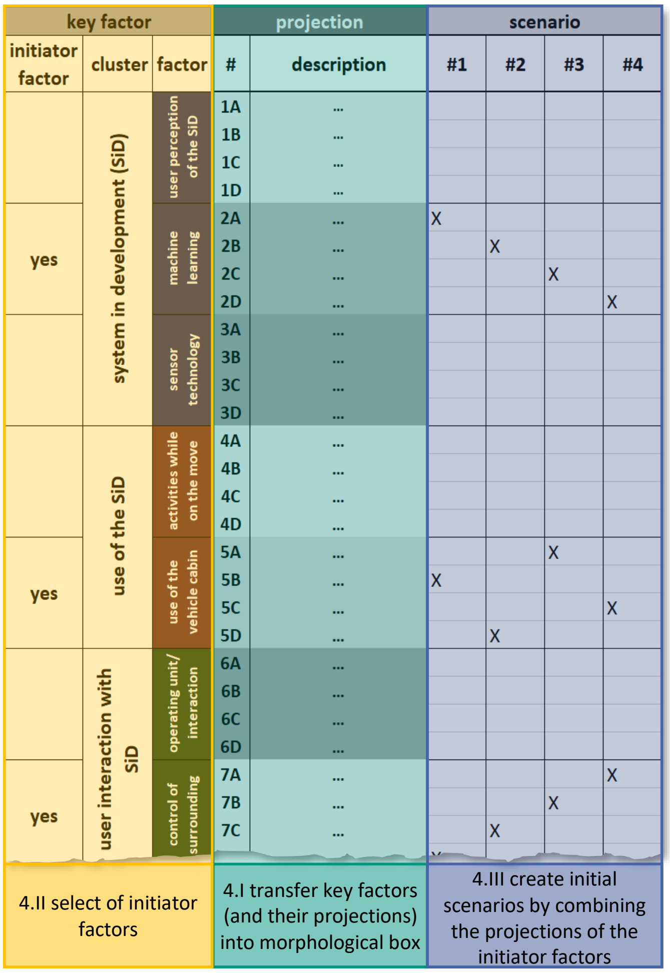

Fig. 7. Section of the template used in the 4th phase of the scenario management with catalog-based scenario generation (step I-III; step IV is illustrated in Fig. 8).

In step IV, the remaining projections are added to the initial scenarios (Fig. 8). Future projections of initiator factors are assigned first, starting with the most important influence cluster towards the less important ones. This results in the initial scenarios.

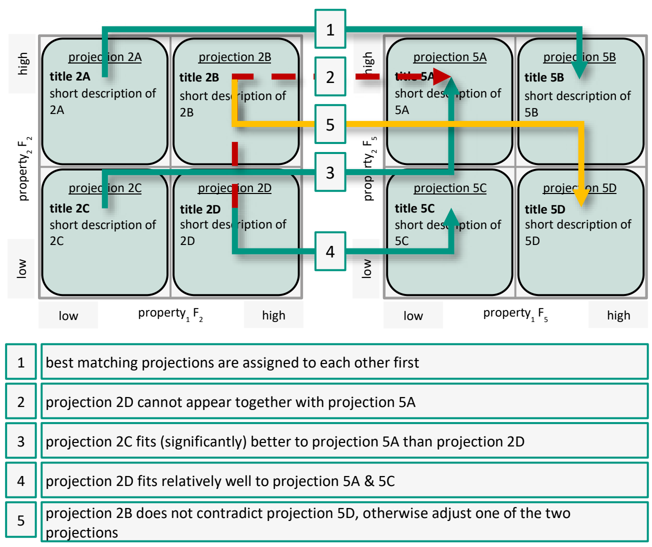

Fig. 8. Assigning future projections to one another (step IV; F = key factor).

The remaining future projections are then assigned to these initial scenarios. For this purpose, the user(s) imagine a multiple future based on the initial scenarios. The assignment is based on plausibility of the combination of initial scenario and future projection to be assigned (Fig. 8). Assigning a future projection to multiple initial scenarios should be avoided as this would lead to less distinct future scenarios. Story-telling and other creativity methods proved helpful to stimulate the imagination of the initial scenarios and helped understand how oneself might behave or live in the respective imagined future. If necessary, future projections may be modified to better fit to a scenario. Whenever several future projections of the same key factor are allotted to the same initial scenario, a dominant projection is to be determined. In the consistency evaluation dominant projections are primarily considered.

4.2. Case studies - Application of the catalog-based and the consistency matrix-based approach

Once the initiator factors were defined, a common understanding of the associated future projections was established. The properties of the future projections of the other key factors were discussed for two to three minutes to build a common understanding.

In Study A, future scenarios on the working environment and conditions in a medium-sized enterprise were developed. For this purpose, 13 key factors were identified in four influence clusters, from which 51 future projections were derived. In case study B, future scenarios for mobility concepts of the future were developed, in which seven influence clusters were defined. In these, 16 key factors with 63 future projections were identified.

The individual visions of the future sometimes differ considerably. The subsequent discussion of the allocation of the projections showed that the different future projections were due to different interpretations of the respective future projection pairs. The initial scenarios were completely identical in both cases. The discussion of the future scenarios showed that the opportunities and risks of the scenarios were identical, even regarding the projections that had been assigned to different future images. However, the causes for the chances and risks were not always identical.

Table 1 lists the results of the comparison of the future images of the proposed approach with the consistency matrix-based scenario generation based on the assignment of the future projections of the key factors.

Table 1. Comparison of the future images of the consistency matrix-based scenario generation and the catalog-based scenario generation.

Comparison with respect to matching projections	case study A	case study B
No match	9	10
Complete match	32	49
Mostly match	8	0
Partly match	1	4
No comparison possible	1	0

4.3. Differences between catalog-based and consistency matrix-based future images and the respective future space

The results of the case studies were used to deduce potential guidelines for the catalog-based approach about the assignment of future projections to future images. These guidelines can be understood as desired values and might aid the user of the catalog-based approach. Table 2 compares these guidelines with the empirical values of the three surveyed experts regarding the consistency matrix-based approach.

Table 2. Comparison of the assignment on projections in consistency matrix-based scenario generation (mSM) and the catalog-based scenario generation (cSM).

characteristic	mSM	cSM
percentage of used projections	60-80%	90-100%
Number of future visions	3-6	4
Number of key factors with overlaps	<60%	<20%
Percentage of future projections that are only used in one future image	<20%	>80%

The guidelines ensure that the future space is not reduced by the catalog-based scenario generation. In addition, the future images generated with the proposed approach are more distinct from one another. This results in a stereotypical future space whereas the future space of consistency-matrix based scenario generation is characterized by future images with shared characteristics.

Another main difference between the two approaches is the effort to generate future images, which is reduced significantly from over 20 hours to less than five hours by the proposed catalog-based scenario generation.

4.4. Suitability of the catalog-based scenario generation in product engineering projects

The suitability of the approaches is assessed on a five-point scale, on which '5' corresponds to excellent suitability and '1' to poor suitability. Fig. 9 shows the results in a radar chart.

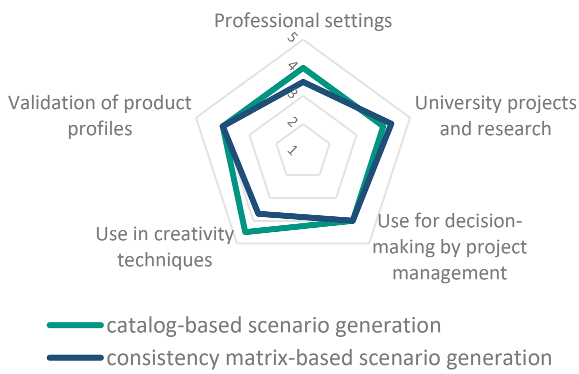

Fig. 9. Suitability of the catalog-based and the consistency matrix-based approach to scenario generation

The experts who participated in the case study agree that consistency-matrix-based scenario generation is slightly more apt for use in professional settings, i.e. companies, than catalog-based scenario generation. They explained their evaluation of the catalog-based approach with the idea that product engineers have very limited time resources and the estimated that for most purposes the quality of the catalog-based scenarios should suffice. The future visions generated with the catalog-based approach are much better suited for use in creativity methods, as this approach facilitates the imagination of the initial scenarios so that projections can be assigned to them. Both approaches to generate future images are well suited for validating product profiles.

4.5. Advantages and disadvantages of catalog-based scenario generation compared to consistency matrix-based scenario generation with respect to product generation engineering

Based on research results on requirements of a systematic approach for modeling objectives [60], a panel of five product generation engineering (PGE) experts discussed the requirements that a systematic approach to generating future scenarios, e.g. a process or a method, must fulfill. With respect to scenario generation this resulted in the following requirements:

- Engineers with little experience in generating scenarios must be able to understand the approach quickly and apply this approach themselves without the help of experts
- As little effort as possible for the creation of future images
- As little effort as possible for the correction or adaptation of already created future images or selected future projections thereof
- Assignment of projections to future images is transparent
- Assignment of projections is based on intuitive procedures
- Suitability for recurring scenario generation, e.g. to assess variation planning over several generations according to the model of PGE

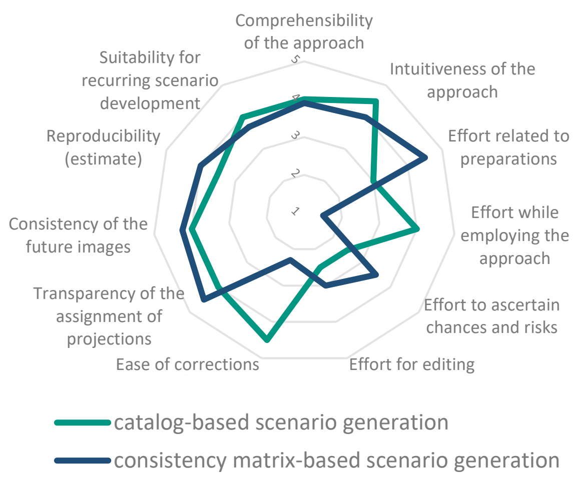

Fig. 10. Evaluation of the fulfillment of requirements by the catalog-based and the consistency matrix-based approach to the scenario generation

The panel of PGE experts considered the first four requirements to be particularly important, especially if the development team is to create its own future images or is at least heavily involved in the process. The interviewed experts rated eleven characteristics that are used to assess the degree of fulfillment of the requirements defined above based on a five-point scale. A radar chart is used to illustrate the evaluation (Fig. 10), in which ‘5’ corresponds to complete fulfillment and ‘1’ to severe shortcomings of the respective requirement.

5. Discussion

This research contribution shows that the scenario management with the catalog-based scenario generation holds potential for the strategic foresight in product engineering. Although, this hypothesis is based on two case studies only and thus further research is necessary. In addition, the requirements and derived characteristics to evaluate their fulfillment are based on five PGE experts, and research on requirements on a systematic approach to modeling objectives. Therefore, further research may be in order to validate the conclusion of the five PGE experts. However, the interviewed experts regarded these metrics as sufficient to evaluate the proposed catalog-based scenario generation and the consistency matrix-based scenario generation.

Especially, if the user has little experience with the generation of scenarios, the catalog-based approach offers some advantages as it is easier to comprehend and the assignment of projections to future images is relatively transparent. This is facilitated by the intuitive procedure for creating the future images with the aid of the catalog. This is because the catalog-based creation of future images is based on the morphological box, which is an intuitive instrument for mastering complexity [33]. For this reason, the transparency of the individual assessments and the resulting future images can be significantly increased. Although, the consistency matrix-based procedure is aided by a graphical unit interface, the assignment is often more difficult as the effects of the evaluations are not directly transparent, and a time-consuming classification of consistency is necessary for every possible pair of future projections. This represents a conflict of interests, as a more granular classification results in a better consistency of the future images, yet the effort in the consistency evaluation increases. In addition, scenarios generated with the catalog-based approach require only a fraction of the effort compared to the consistency matrix-based approach.

However, the scenarios generated with the consistency-matrix approach have a higher consistency as indirect interdependencies between projections are considered, too [14]. Additionally, there is a tendency to systematically exclude combinations of future projections that appear logically impossible or inconsistent, even if they are not, due to the ever-increasing complexity and neglected underlying causalities between key factors [61, 62]. This is more likely to happen if the catalog-based approach is used, as complexity cannot be not reduced to a single evaluation of a pair of future projections, rather the suitability of a future projection for a partly synthesized scenario, i.e. a set of future projections, needs to be evaluated. Therefore, complex systems or highly complex environments still necessitate a completed consistency matrix to attain future scenarios of the highest quality. Yet, this may not be necessary for a significant number of product engineering projects, and thus the effort-benefit ratio justifies the use of the catalog-based approach.

The catalog-based future images use almost all future projections, which reduces the loss of information compared to the future images, which were created using a consistency matrix. This can be explained by the algorithm for generating future scenarios, which uses the calculated plausibility of each potential combination of future projections to cluster them [9]. The degree of information loss determines the number of future scenarios [9, 27], whereas the catalog-based approach yields four future scenarios, albeit more distinct ones. These stereotypical future images facilitate strategic decision-making. However, the catalog-based approach is not superior, as its future images deviate depending on the creator. This is caused by the use of the morphological box [59] as well as by the deviating understanding of future projections by the individual users. The discussions on the future images, especially their differences, results common understanding of the future projections and an adjustment of the future images. During this discussion, two different scenarios may be merged into a new one if this results in new risks and chances that would potentially affect the robustness of the system in development (SiD) or strategic decisions. This time-consuming post-processing is likely to be significantly reduced if a unified understanding of both the key factors and all future projections is established prior to the actual scenario generation as was done for the initiator factors which resulted in identical initial scenarios. If the interpretation of the scenarios is performed by the same group that already created the future images, the interpretation and editing of the future images requires less time. The reason for this is that the users of the catalog-based approaches put themselves in the position of a company or an individual to assign future projections. As a result, the degree of maturity and understanding of the individual future images after allocation of all future projections is high. If the interpreters and the creators of the scenarios differ, the interpreters must first understand the underlying thinking process that governed the scenario creation. This is associated with considerable time expenditure and should therefore be avoided, even if this represents a restriction of catalog-based scenario creation.

Due to the associated software application, the post-processing of scenarios with the consistency matrix-based approach is less time-consuming than with the catalog-based approach. For instance, the multi-dimensional scaling to visualize the future space eases the editing of scenarios in a scenario map [15]. This supports the investigation of interdependencies between the scenarios [14]. Additionally, the consistency matrix can be generated automatically which reduces the effort for the preparation of the scenario generation. These aspects illustrate the shortcomings of the catalog-based scenario generation that is not yet supported by a software application.

6. Outlook

This research is based on two case studies only. While the proposed approach seems to have great potential, further research is warranted in order to ensure the suitability of catalog-based scenario generation, especially with regard to the consistency and quality of the future scenarios.

It still seems indispensable to generate future scenarios for complex systems or highly complex environments based on the consistency matrix which is associated with a substantial time invest. It is therefore essential to investigate the required quality of future scenarios with respect to the project, complexity of the system to be analyzed and the complexity of the environment. These studies may also be used to evaluate when the catalog-based approach is suitable based on the effort and the required quality of scenarios. This of course means that the consistency matrix-based approach serves as a benchmark and thus all case studies should apply both approaches. As there are multiple existing future scenario analyses that are based on the scenario management by Gausemeier et al., one might use these in a comparative study.

Additionally, the approach developed in this research contribution to generate future scenarios requires a relatively large amount of preparation and follow-up work. Future research should therefore investigate how this can be reduced.

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