SELECTION OF REFERENCE SYSTEM ELEMENTS IN THE MODEL OF PGE - PRODUCT GENERATION ENGINEERING: METHOD FOR THE INTEGRATION OF CUSTOMER AND USER SATISFACTION IN PRODUCT PLANNING

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ABSTRACT

In the development of mechatronic systems, it is important to differentiate the products to be developed from those of the competitors, but also from the own product generations already available on the market. However, there are uncertainties regarding the correct features to be differentiated from the customer and user perspective and how these features should be designed. Nevertheless, despite the high impact, decisions must be taken early in the development process. Within this publication, a method to support in this respect was derived based on the findings of the Model of PGE – Product Generation Engineering and the Kano-Model. Therefore, experienceable product features and reference system elements as characteristics of these are evaluated according to the Kano-Model and thus made comparable with regard to the customers and user satisfaction. The objective is to select the product features to be differentiated and the corresponding reference system elements in such a way that a desired level of customer and user satisfaction is achieved. In order to evaluate the method, it was applied in a real development project. It was found that the application of the method led to a reduction of the existing uncertainty.

Keywords: Design methods, Product Planning, Uncertainty, Customer Satisfaction, Knowledge management

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1 INTRODUCTION

Coca-Cola made the first and only adjustment to the recipe after 97 years of business in 1985, after Pepsi had gained market share in the 1970s and a blind tasting had shown that test persons preferred the sweeter taste of Pepsi. In addition, the decision to redesign the can was made. When the new product was placed on the market, there was an uproar because customers missed the typical Coca-Cola taste and did not want the Pepsi taste. After 79 days, the original recipe and the old design were used again (Cole, 2017). This example shows impressively how important it is for companies to identify and implement the right differentiating features from the customer's perspective. This leads to the dichotomy that it is essential for companies to establish successful products on the market, as this is the only way to achieve long-term profits (Hippel, 2007). At the same time, however, it is difficult to set the right distinguishing features. Especially companies in the field of mechatronics system development, which can never sell products with the same recipe or system design for years, must set differentiating features in comparison to the predecessor product and in comparison to the competition. However, it can be observed that companies often vary the wrong properties from the customer's or user's point of view or choose unsuitable characteristics and the product does not achieve the desired success on the market afterwards (Cooper, 2011). From the view of companies that develop products, there is a high degree of uncertainty in the product definition, since it is not guaranteed whether the defined product generates the desired market success especially because of high competition and the increasing dynamic in the market.

2 STATE OF THE ART

2.1 Product development and uncertainties

Product development can be considered as a problem solving process. Dörner (1976) describes a problem as the deviation between the present Actual-State and the planned Desired-State, where these two elements, as well as the path from Actual-State to Desired-State are at least partially unknown and uncertain. According to deWeck et al. (2007), uncertainty includes both the probability that assumptions will turn out to be incorrect and the occurrence of completely unknown facts, which in turn have an influence on the product, its development or its success in the market. This influence can be both negative and positive. McManus and Hastings (2004) describe the impact of uncertainties by opportunities and risks and thus, just like according to deWeck et al. (2007), uncertainties can have both a positive and negative influence. Furthermore, they describe uncertainty as the difference between available and necessary knowledge. According to their comprehension, however, uncertainties not only include a lack of knowledge, but also a lack of definition that implies pending decisions or specifications. They distinguish between statistically characterizable uncertainties that prevail due to empirically distributed conditions, known unknowns whose existence is known and unknown unknowns of which the existence is unknown. In this respect, Wynn et al. (2001) differentiate between epistemic uncertainties, a lack of knowledge and definition, which can be closed for example by testing, and aleatory uncertainties where this is impossible. In the context of product development, a distinction is often made between technology and market uncertainty (Koppelmann, 2001). While technology uncertainties describe the lack of knowledge and definitions regarding the technical feasibility of a product, the term market uncertainty primarily comprises uncertainties regarding the target markets (Cao et al., 2008), customer needs (Logue et al., 2008) or their willingness to pay (Verworn and Herstatt, 2007).

2.2 The Modell of PGE - Product Generation Engineering

The model of the PGE - Product Generation Engineering by ALBERS describes any development of products regardless of whether it is a completely new product, which is called G_1 (Albers et al., 2020), or the phenomenon of a subsequent generation, which is more widespread in industrial practice (Albers et al., 2015). Thereby, the development of a new technical system, product or variant and is called a new product generation G_n and is based on a "reference system" (Albers et al., 2019) which marks the starting point of the development. If the development is a subsequent generation, the preceding product generation G_{n-1}, which might be already available in the market, is an element of the reference system. However, there are also other reference system elements, for example from other products of the company or from products of other companies, even competitors, also from other industries (Albers et al. 2019).

The risk associated with the development of the corresponding system or subsystem is closely linked to the properties of the reference system element (RSE). In this context, the origin of the RSE is an important property (Albers et al., 2016). Thus reference system elements from the same company, which is developing the current generation, for example, the preceding generation, usually have fewer risks than reference system elements from other companies, industries or research. The main reasons in this respect are, that on the one hand in case of internally available reference system elements, the availability of product documentation and implicit knowledge should be much more pronounced than in the case of externally available RSE, for example from competitors or other companies. This is of course especially evident when the RSE comes from the same development team. On the other hand, in the case of internally available RSE, the ability to understand and identify key aspects of the functions of the system is usually better. Thus, systems from their own scope are better understood. However, the use of reference system elements from outside the company can, on the other hand, increase the innovative potential of a new product generation. However, not only the properties of the reference system element are a source of risk but also the type of variation with which the reference system element is transferred to the new generation. The development can be seen as a process of mapping the reference system elements into the solution space of the new product solution (Albers et al., 2019).

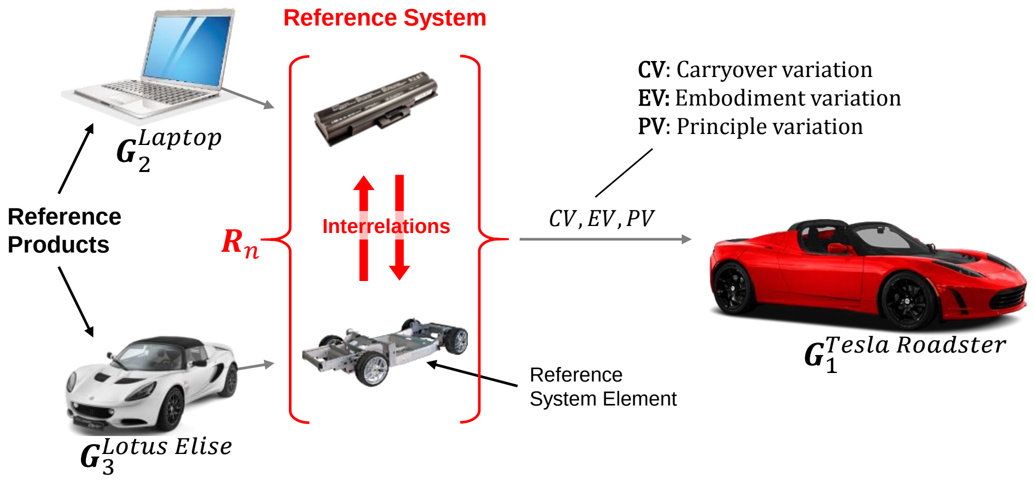


Figure 1. Simplified illustration of the PGE Model; modified based on (Albers et al., 2019)

Thereby there are three types of variation:
Carryover Variation describes the transfer of the RSE into the new product generation, whereby only small adjustments are made to the RSE, which affect its interfaces and are necessary for integration.
Embodiment Variation refers to the adaptation of the embodiment to achieve development objectives, while the solution principle of the reference system element remains unaffected.
Principle Variation describes adjustments to the solution principle, for example by adding or removing components or connections. In the case of a Principle Variation, an Embodiment Variation must always be executed too, because the components and connections must be designed.
The risk associated with the development of the corresponding subsystem is closely linked to the chosen type of variation. Thus, it can be stated that Embodiment Variation and Principle Variation tend to bear significantly more risks due to technical uncertainties. However, carryover variations can lead to risks as well, for example, if boundary conditions change significantly (Albers et al., 2017).

2.3 Approaches to product generation planning with a focus on customer and user orientation

The successful establishment of a new system to the market is called an innovation. Besides a new technical solution an innovation requires a successful market entry and a description of the expected benefits for customers, users and the provider modelled in the so called product profile (Albers et al., 2018a). Product profiles are an elementary component of the initial system of objectives and thus form the starting point for the development of a product. They contain additional information such as information on possible reference systems, players involved and intended product features (Albers et al., 2018b). For the prioritization of such features, there are several approaches:

Buy a Feature (Rein and Münch, 2013) is an experimental activity to measure the financial value of features. Therefore, a price is assigned to all potential features, which is based on the development costs and time. Then customers or product managers with a certain budget can buy features. This leads to a prioritization of the features. Another experimental activity is the so called **Gap Analysis** (Redling, 2003) where customers are asked to rank features according to their importance to them. In addition, they are asked to indicate how satisfied they are with this feature in the current product. Thus, the method identifies and prioritizes features with high importance and low satisfaction. While **Affinity Grouping** (Byrne and Barlow, 1993), the product developers brainstorm on various features on sticky notes. These are then clustered in terms of similarity. The team then reviews the ideas together and begins to vote on them. **Story Mapping** (Patton, 2014) is based on mapping out the customer journey. In this context, the customer journey is considered from the starting point to the end of use. Then the relevant aspects are extracted from beginning to end, broken down into different versions of releases according to prioritisation. The **systematic for model-supported product identification in product generation planning** (Albers, 2019) is designed to enable companies to find promising additional features. In a first step, the reference model-based brainstorming, existing system models are analysed with regard to additional property ideas. Based on this, in a second phase promising additional features are identified based on the customer's needs, which create a direct customer benefit. These are then evaluated in a 3-step procedure, whereby first the strategy conformity is analysed, then the customer potential is evaluated. Finally, a utility value analysis is carried out. The **Value vs. Complexity model**, which is based on the Value vs. Cost (Wiegers, 1999) or Value vs. Risk model known in software development, prioritises features with the highest value and lowest complexity. For this purpose, features are mapped according to their importance for the customer and the difficulty of implementation. The **Weighted Scoring** method is based in its core on a tool like the House of Quality (Hauser and Clausing, 1998). The product managers weight each feature according to its relative importance. Factors such as customer value, risks etc. are therefore taken into account. While conventional quality theories are based on a one-dimensional relationship between quality and customer satisfaction, the **Kano Model** (Kano et al., 1996) is based on a two-dimensional concept of quality. With a one-dimensional quality concept, customer satisfaction increases proportionally with the level of quality. Kano et al., (1996) on the other hand, make a distinction, as they believe that customer satisfaction also depends on the type of feature. They distinguish between must-be quality elements, one-dimensional quality elements und attractive quality elements.

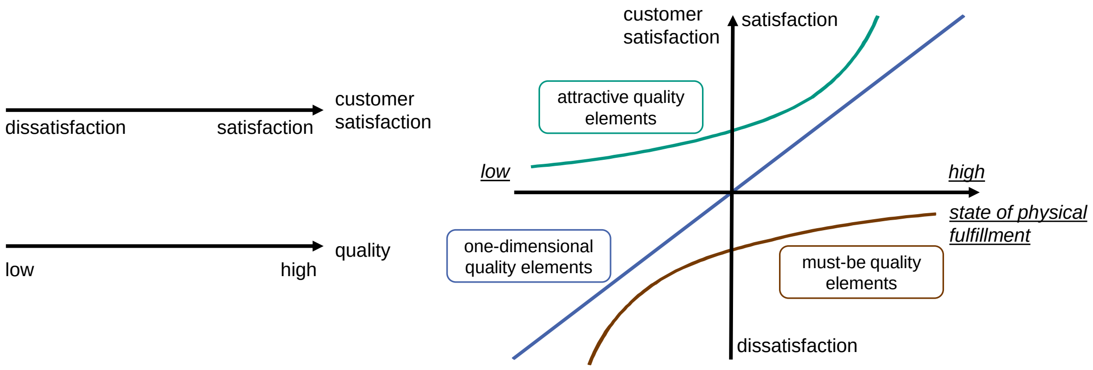


Figure 2. Left: One-dimensional understanding of quality; Right: Two-dimensional understanding of quality; modified based on (Kano et al., 1996)

One-dimensional quality elements originate from the one-dimensional understanding of quality. Here, customer satisfaction increases as the degree of quality fulfilment increases. Must-be quality elements are absolutely expected by the customer, and result in great dissatisfaction if they are not fulfilled. However, if the fulfilment is given, there is no effect on satisfaction, but the quality is seen as neutral. With attractive quality elements, this applies in the case of non-fulfilment. However, if these are fulfilled, they trigger a high level of customer satisfaction. To assign the features of a product to the different categories, Kano et al. (1996) propose a questionnaire technique in which all relevant quality features of customers are evaluated using functional and dysfunctional questions. The objective of this approach is to define the best possible quality for a product from the customer's point of view, which does not have to correspond to a very high degree of quality fulfilment, but rather to a quality that results in high customer satisfaction (Kano, 2001).

3 RESEARCH DESIGN

For product development companies, it is of crucial importance to introduce products to the market that create high customer and user satisfaction profile (Albers et al., 2018a). However, there are uncertainties in the process of product planning, especially with regard to which features of a product are important to customers and users, what influence these features have on customer and user satisfaction and how these features should be optimally designed to create a high satisfaction. The Kano method is a suitable method for the evaluation of a product generation from the perspective of customers and users, which enables a categorization of the relevant product features. The associated model enables a valid estimation of the resulting satisfaction. The model of PGE - Product Generation Engineering supports product developers planning a new product generation regarding the handling of uncertainties by managing the share of new development. Reference system elements help to systematically minimize uncertainties, since the development of a new product generation, which starts with the development of the associated product profile, can be based on already existing systems and conclusions regarding the success in the market of a new generation can be drawn by analysing the reference system elements and their environment. The goal of the research in this publication is to support product developers to plan future products cross-generationally. In this context, the graphical representation of the Kano model (see Figure 2) and its associated interpretation are intended to support the selection of reference system elements for a new product generation, which are suitable from the customer's and user's point of view. The focus is to support product developers during the selection of product features, which are to be varied, with the goal of improving their satisfaction. Furthermore, the product developers are to be supported in defining a suitable characteristic of these features by selecting reference system elements.

Therefore, the following research questions are to be answered:

1. How to design a method for the selection of reference system elements in the model of PGE - Product Generation Engineering based on the Kano model in order to reduce market uncertainties?
2. Which changes in the subjectively perceived uncertainty of product developers can be observed by using the method?

In order to answer the research questions, a methodical approach for the systematic selection of reference system elements was derived in a first step based on the previously described state of the art. This approach was subsequently evaluated in a development project of Hekatron Brandschutz. For this purpose, the method was applied within a product development project and 15 employees of the departments R&D (Research and Development) and PM (Product Management) evaluated the results of the method based on questionnaires. The participants included two department heads, seven project managers from development or product management, three group leaders and three developers. Using a three- and six-level scale, the participants assessed how their certainty has changed, that the "correct" differencing features and the "correct" expressions of these have been selected by applying the method and how their certainty is or has changed, that the right product is being developed from the customer and user perspective.

4 RESULTS

4.1 Method for the Selection of Reference System Elements in Product Generation Engineering

In order to support product developers systematically in the selection of differentiating features, which is afflicted with uncertainties, a method was derived, which in its core is based on the understanding of Product Generation Engineering, the Kano Model (Kano et al., 1996) and the understanding of problems according to Dörner (1976). In the context of this method, the Actual-State refers to the satisfaction of customer and user, which they experience through the product generation G_{n-1} and its features and the Desired-State refers to desired or planed satisfaction of the generation G_n. Thereby there are uncertainties regarding which product feature should be varied and how these should be realised in order to achieve the Desired-State. The Kano model assists in creating an objective evaluation of products and their features. The model of Product Generation Engineering and in particular the work with reference system elements supports product developers in planning a new product generation in order to deal with uncertainties as it can be set up on already existing systems. Through systematic evaluation using the Kano model, a path from Actual-State to Desired-State can be planned using the reference system elements. The objective of the method is to support the selection of differentiating features and solutions for the realization of these in the form of reference system elements based on an analysis of the product generation G_{n-1}. The analysis of customer and user needs takes on a crucial role in order to minimize the uncertainties that product developers are faced. The derived process is based on four consecutive steps. These are shown in the following figure and are explained in the afterwards.

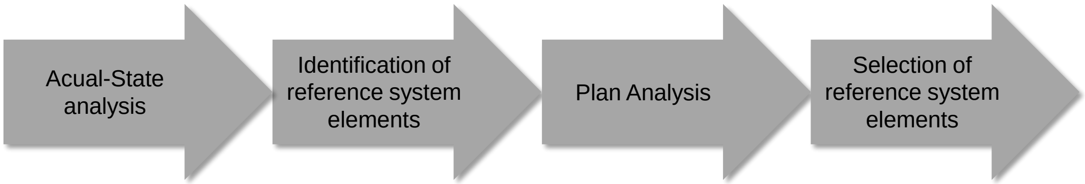


Figure 3. Process for selecting reference system elements

In the first step, the so-called Actual-State analysis, the product generation G_{n-1}, which is already available on the market is analysed and described by product features, which can be evaluated. For each of these features, which can be experienced by the customer and user and are not technical features of the product, a detailed description is created. Afterwards customers and users evaluate the product features via a questionnaire. This evaluation is based on the Kano Model (Kano et al., 1996), whereby the curves are divided into 9 sections and these sections are then described by words. (See figure 4) The assignment of the features to the curve sections helps to systematically identify optimization potentials. This enables the identification of unfulfilled must-be quality elements, which can then be optimized afterwards. Customers and users evaluate all relevant features according to the nine-level scale.

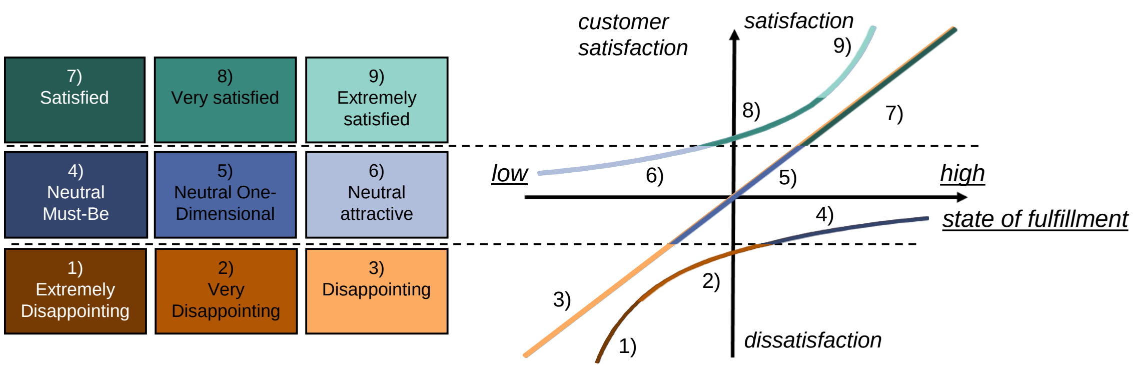


Figure 4. ACTUAL-State Analysis within the framework of the Kano Modell

Subsequently, in step 2 of the method, the product developers look for reference system elements that provide solutions for realizing the described features. These can either be available internally, for example by being used in another product offered by the company, or they can be available externally. From the customer and user perspective, the reference system elements represent the realization of a feature. Therefore, customer and user evaluate the reference system elements that have been found within the third step of the method, the so-called Plan-Analysis. In the course of the research of this publication, a direct conversation has proven to be helpful, as the intention can be explained more clearly. Thereby the existing product generation is presented to the interviewees. Based on this, the considered product feature is explained and then evaluated according to step 1 regarding the satisfaction the modified product generation would achieve regarding the analysed feature. This is carried out for all selected product features and all reference system elements (see figure 5). This step provides information on how to adjust the Actual-State in order to achieve the Desired-State of satisfaction. In this context, it is important to notice, that the Desired-State does not represent the maximum of customer and user satisfaction, because according to the bundle of benefits of the product profile consisting of customer benefit, user benefit and provider benefit, the other stakeholder has to be considered as well. Too much variation would perhaps result in a high customer and user benefit, but in particular the development costs and product costs would also be higher and thus the provider benefit lower. However, before starting the development the provider may also accept the higher risk and develop a potential G_1 with many potential attractive product features.

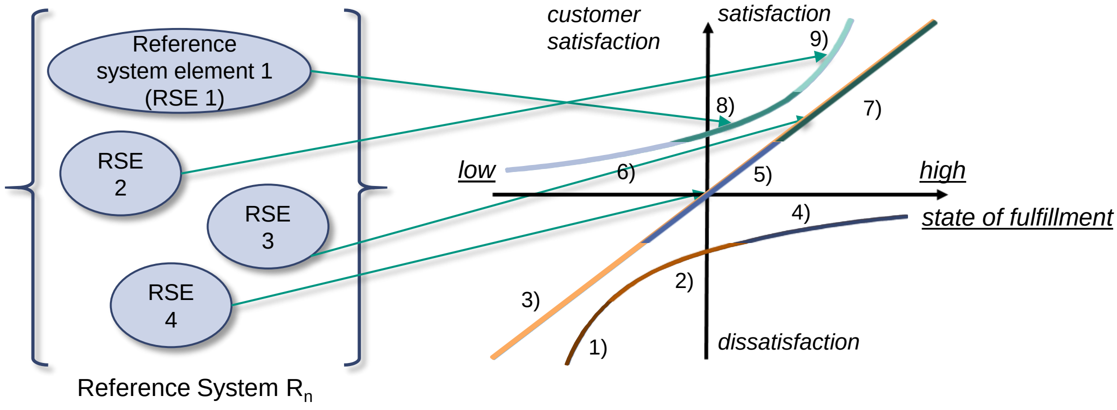
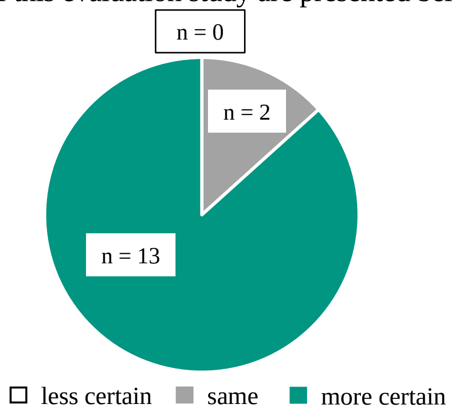


Figure 5. Framework for the assessment of reference system elements

In the last step, the product generation G_n, which is currently under development, is defined. The aim is to find a suitable combination of differentiation features and the assigned characteristics to achieve the planed Desired-State. For this purpose it is necessary to select suitable reference system elements, which are subsequently used as references for the development of the new product generation. In this step, it is also important to consider that customer and user satisfaction is only one indicator for the selection. It should also be analysed, for example, where the reference system elements come from. External reference system elements pose challenges for developing companies. When defining a product, it should therefore be ensured that the selection of reference system elements is not only based on the analyzation of customer and user satisfaction, but also takes the benefits for the provider into account.

4.2 Initial evaluation in a product development project at Hekatron Brandschutz

In order to evaluate the methodical approach described previously, the approach was carried out in a product development project of Hekatron Brandschutz, in which a new testing device was developed. In a first step, the existing product generation G_{n-1}, available on the market, was analysed and described in terms of customer-experienceable product features. In the context of the Actual-State analysis, the 10 most relevant features from the method users' point of view were evaluated by 57 customers and users using questionnaires. After reviewing this first survey, relevant differencing features were selected, and in a workshop with ten members of the technical customer service staff, reference system elements were presented and subsequently evaluated according to the scheme presented. Finally, experts evaluated the subjectively perceived certainty of having selected the "correct" differentiating features and the "correct" characteristics, in form of reference system elements, from a customer and users point of view. In order to achieve comparability, the evaluation was related to the status before the method was carried out. The results of this evaluation study are presented below.



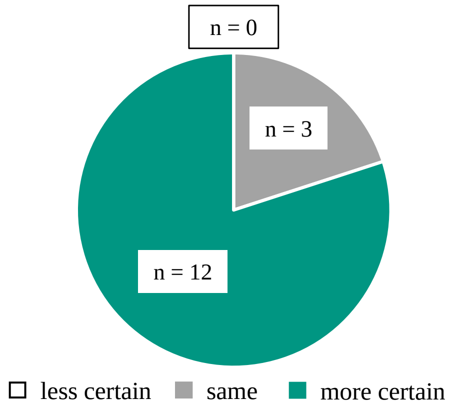


Figure 6. Left: Change in the level of subjectively perceived certainty before and after the method is implemented whether the correct differentiating features have been selected; Right: Change in the level of subjectively perceived certainty before and after the method is implemented whether the correct reference systems elements have been selected

Figure 6 shows that 13 of the 15 people surveyed indicated that they felt more confident the right differentiators had been selected from the customer and user's point of view after the method was carried out. Two of the test persons feel the same certainty and none of them feels less certain than before. Regarding the selection of reference system elements, twelve of the participants stated that they were more certain that the right reference system elements have been chosen from a customer and user perspective after carrying out the method. Once again, none of the respondents indicated to be less certain after the method was carried out.

In addition, the experts were asked to give their opinion on how certain they are that the right product can be developed from a customer and user perspective based on the information gained by the method. In order to make the results comparable, the evaluation was carried out both before and after the execution of the method. Thereby, the existing certainty was assessed in 20% steps, whereby for the evaluation of the method, the absolute certainty is not as relevant as the change of it. As the participants did not have any insight into their previously given result, it was also asked for their assessment regarding the change in certainty that the right product will be developed from the customer and user point of view.

Thereby the average value of 50.7% (before the method was carried out) increased by 28.7% up to 79,4%. Most participants mentioned in both the qualitative and quantitative evaluation that they feel more confident afterwards. Ten participants indicated a higher sense of security after the method was carried out in the quantitative evaluation. Five participants felt no increase. All of them rated the certainty as "certain" (80 %) already before the method was carried out. In the qualitative evaluation, using the three-level scale, 13 of the participants said that they feel more certain, that the right product will be developed, after the method has been carried out, while none felt more uncertain. Two of the respondents did not perceive any change in their subjectively perceived certainty.

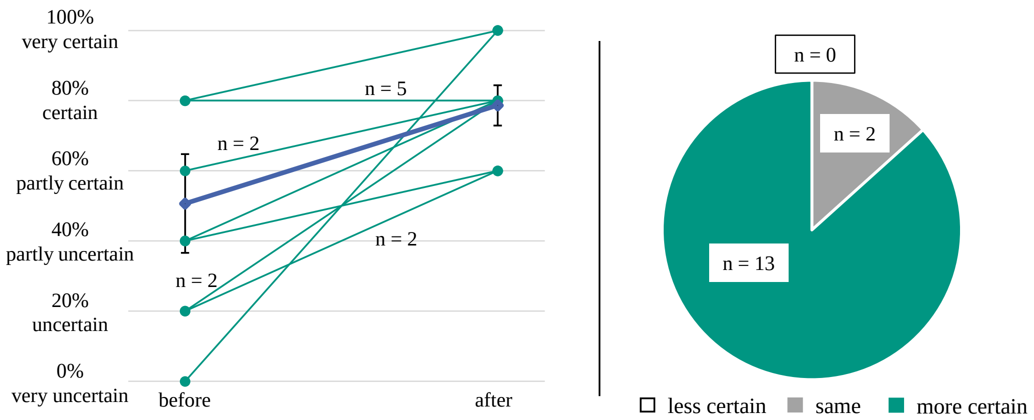


Figure 7. Left: Results of the qualitative assessment of uncertainty before and after method implementation; Right: Results of the quantitative evaluation of uncertainty before and after method implementation

5 DISCUSSION

In the quantitative evaluation regarding the general certainty whether the "right" product from the customer's and user's point of view will be developed, it can be seen that five participants did not perceive any change in the level of certainty and stated their degree of certainty before and after the method was carried out as 80%. It can be assumed that their feeling after the method was not at 100% certain and they therefore reported the same value before and after the method was carried out. This is also supported by the fact that in the qualitative evaluation only two test persons stated that they felt the same sense of certainty. These two were included in the five experts who stated 80% in the quantitative analysis before and after the method was carried out.

In the course of the survey for the Actual-State analysis, the interviewed customers and users additionally filled out a conventional Kano questionnaire in order to evaluate which potentials for the G_n could arise from the variation of a feature and thus support the selection of differentiation features. Many of the participants pointed out, that there is an uncertainty regarding what an optimised technical solution might look like, which obstructs an adequate evaluation. Through the reference system elements and the imaginary integration of these into an existing and above all known system, a visual presentation is generated for customers and users, which simplifies an evaluation. However, it was found that this evaluation is preferably carried out in the context of a workshop, as the explanations better address the topic discussed earlier than textual explanations. With regard to the first research question, it can be stated that the Kano model is suitable for evaluating and comparing reference system elements from the customer and user perspective with regard to their suitability for fulfilling customer and user requirements. More profoundly, it can be stated that the model of Product Generation Engineering and the use of reference system elements simplifies the questioning of customers and users, since the evaluation of an existing product generation G_{n-1} is easier than the evaluation of described ideas. The mental integration of reference system elements into an existing, known system makes it also easier to evaluate the characteristics.

The application of the method presented in a development project made it possible to systematically select differentiation features and matching reference system elements that represent the characteristics of these features. Experts interviewed on the method results stated that the method specifically reduced uncertainties as to whether the right features and correct reference system elements were selected. Therefore, the method is suitable for generating knowledge about customer and user satisfaction at an early stage in the development project based on previous product generations and reference system elements. Thus, market uncertainties can be reduced. Nevertheless, the method in no way replaces early and continuous validation of product properties by customers and users, as for example by using Minimum Viable Products.

It should be mentioned that the method can also be used for the development of a G_1, even if it was used for a G_n with n>1 in the described use case. However, the ACTUAL-State analysis will then not be carried based on the preceding product generation G_{n-1}, but rather on the other reference system elements.

Although the method helps product developers to select the right reference system elements in order to optimise the product in terms of customer and user benefits, it does not focus specifically on the provider benefits. Thus, in particular reference system elements from outside the industry were assessed as potential sources of customer and user satisfaction. However, it should be noted that their implementation naturally entails a significantly higher technical and economic risk than product development based on industry or even company-internal reference system elements.

6 CONCLUSION AND OUTLOOK

In summary, based on the model of PGE and the Kano Modell, an approach was found which supports product developers systematically in the process of product planning. The focus is to reduce uncertainties regarding customer and user benefits. For this purpose, customers and users evaluate existing product generations available on the market. Based on this, they evaluate reference system elements that represent a solution for the variation of the described features from the customer's and user's point of view.

With the help of the consistent application of the method in a development project, it was possible to select differentiating features and corresponding characteristics of these in the form of reference system elements. Interviewed experts evaluated the use of the method in a consistently good manner and stated that the use of the method systematically reduced uncertainties, whether, from the customer and user perspective, the product to be developed generates a high level of satisfaction. These uncertainties had existed before the method was carried out.

In the future, it will be necessary to carry out further validation steps with the method in order to investigate the benefit in other industries and applications. Furthermore, a development-environment-specific database for reference system elements is to be created. The aim is to record how reference system elements develop over different product generations and what influence they still have on user and customer satisfaction after variation. Of particular interest here is to analyse the effects of the variation of reference system elements within other industries, and the effect of this variation regarding the own customer and user satisfaction. Thus, in the long run such a database for reference system elements will enable product developers to reduce uncertainties in the planning of product generations.

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