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FROM MARKET TO MARKET – EXTENSION OF AXIOMATIC DESIGN TO A HOLISTIC INNOVATION MANAGEMENT APPROACH

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ABSTRACT

The success rate of new products and services can only be increased by a strict orientation to future markets and respectively the (future) stakeholders' and customers' benefit perception. This paper presents a holistic innovation management approach which builds on the principles of Axiomatic Design and Axiomatic Complexity Management and extends the concepts to a cyclic model "From Market to Market". It starts from a new approach in the Customer Domain which helps to predict new market trends, systematically identifies customer needs, and shows how to define on this basis a consistent vision and strategy for the company (from the high-level targets to the lower-level strategies). This approach, based on the combination of different methodologies like the Delphi techniques and Axiomatic Design, aims to systematically identify share-/stakeholders and customer's benefits and requirements. An example taken from the durable goods industry helps to illustrate the successful application of this approach.

Keywords: Axiomatic Design, Customer Benefit, trend analysis.

1 INTRODUCTION

Innovation is one of the most important factors for a firm's long term success [Spath *et al.,* 2001]. Due to increasing customer expectations and growing international competition companies are forced to offer a huge product variety and reduce product life cycles [Matt, 2007]. At the same time, competitive pressure in volume markets is becoming stronger because of increasing economical and technical emancipation of the so called low labour cost countries [Kirner *et al.*, 2006].

The response of many small and medium sized enterprises (SME) to this development is to retreat into niche markets. However, decreasing production volumes, the increasing complexity of the article range and shortening product life cycles make it hard especially for small and medium sized enterprises (SME) to amortize product development related one-time expenditures and investments. Flops on the market are hard to cope with and can endanger a company's survival.

The success rate of new products or services can be increased only by a consequent orientation to customer value: the customer needs to drive the buying decision [Matt and Franzellin, 2008]. However, the identification of customer benefit and customer demand is not simple [Matt, 2007]. Is the customer really always fully aware of the total scope of his expectations?

The review of existing scientific literature in section 2 shows that both academia and industry are discussing these challenges at length. A number of methods were developed for this topic, such as QFD (Quality Function Deployment) and Conjoint Analysis. All of these methods can be meaningfully applied where customer needs regarding an existing product and/or service concept have to be evaluated and/or translated into functional requirements for product development [Züst *et al.*, 1999].

However, these methods are insufficient and sometimes not deployable for novel products, services or product/service combinations. After all, to a large degree, it is about ascertaining what the customer would like, but does not yet exist in this form. How then should he or she be able to verbalize such a requirement?

The challenge therefore lies in the identification of a potential area of benefit, in which benefits can be derived and be translated into demands. Thus, the objective of this research is to develop a theoretic model and an integrated framework for:

- the systematic identification of the customer value perception (the latter consists of a different perception of the value term for each user or group of users)
- the development of scenarios for the analysis of possible future market trends or customer needs
- the evaluation of the probability that the identified trends will become real
- the translation of the most promising trend scenarios into functional requirements and alternative product or service design hypotheses
- the evaluation and modification of the alternative hypotheses on the basis of market and expert feedback, and finally
- the elaboration of concrete product/service design proposals for further product/service development steps.

Furthermore, experimental test cases will be developed to prove the validity of the theoretic framework in different environments and under varying side conditions.

2 LITERATURE REVIEW

The review of existing research work shows that understanding and fulfilling each individual customer's requirements have been recognized as a pressing challenge for companies across industries [Jiao and Chen, 2006]. The following sections (2.1 to 2.4) are mainly based on an accurate literature review in this field, published by Jiao and Chen [2006].

Traditional approaches of market-orientation are mainly focused on the average satisfaction of customer requirements. As customers increasingly demand for individual solutions, companies start to pursue the strategy of offering customer-focused products with a large degree of individuality [Tseng and Piller, 2003]. Customer requirement management thus becomes one of key success factors for a market-oriented product development [McKay *et al.*, 2001]. The poor understanding of customer requirements and inaccurate assumptions made during the elicitation and analysis of requirement information can have significant negative implications on the design and manufacturing of the product in terms of quality, the lead time and cost [Jiao and Chen, 2006].

Extensive studies have shown the importance of careful analysis and assessment of market and customer requirements for the market success of product development [Karkkainen and Elfvengren, 2002]. It involves the understanding of customer preference and relevant target markets, along with requirement prioritization and classification, as elaborated below [Jiao and Chen, 2006].

2.1 UNDERSTANDING MARKET AND CUSTOMER NEEDS

Different customer-related marketing approaches have been reported in response to the increasing importance of customers in today's business environment, including customer satisfaction, customer marketing, customer-based methods, customer-driven evolutionary systems, and customer loyalty [Jiao and Chen, 2006]. Customer relationship management has become a key focus in today's marketing research [Barness, 1997]. Interesting research work has been done to study the potential values of relationship marketing in customer markets, such as neoclassical microeconomics, transaction costing, relational contracting, social exchange, equality theory, and resource dependency theory [Jiao and Chen, 2006].

Curry [1991] proposes a customer marketing strategy for identifying, acquiring, keeping and developing customers by developing a customer pyramid. Besides a clear understanding of customers and markets through marketing research, other factors also must be considered for managing customer requirements in product development [Lancaster and Massingham, 1994]. Bennett [1996] advocates emphasizing customer group segmentation under intensifying competition pressures. Barness [1997] points out the necessity of quantitative customer evaluation and argues that individual customers should be put in more direct contact with manufacturers or organizations via a channel using information technologies. In this context, Khoo and Ho [1996] propose a customer-focused information system to closer link product re-innovation and customer involvement in the process of product conceptualization.

The micro and macro perspectives used by Kotler [1991] help to better explain the different ways of customer requirements evaluation. In the micro perspective, it is shown that the functional correlation between customer requirements and design specifications is largely influenced by engineering considerations. However, the macro perspective considers also a broad range of socio-cultural factors emphasizing the fact that customer requirements acquired within one customer group may conflict considerably with another. The research of Nielson [1998] focuses on the analysis of multicultural customer factors to support organizations in their recognition of individual customer needs and direct interactions with customers. Lancaster and Massingham [1994] emphasize the importance of a precise evaluation for major customer groups and markets regarding competition situations.

2.2 CUSTOMER PREFERENCE

Market researchers have applied regression analysis to compare different customer characteristics and to rank them according to their contribution towards profitability [Jenkins, 1995].

Market analysis techniques are traditionally applied for the investigation of customers' responses to different product design options. In this context, the conjoint analysis is broadly adopted to measure customer preferences for different product profiles and to set up market simulation models [Green and DeSarbo, 1978]. Louviere *et al.* [1990] apply discrete choice experiments to predict customer choices regarding product design options. Alternatively, Turksen and Willson [1992] use fuzzy systems for the interpretation of linguistic meanings regarding customer preferences. Other authors have employed focus groups to provide a reality check on the usefulness of a new product design adopting a qualitative approach [LaChance-Porter, 1993]. Similarly, one-on-one interviews and similarity-dissimilarity attribute rankings are used [Griffin and Hauser, 1993].

2.3 REQUIREMENT PRIORITIZATION

The prioritization of customer preferences regarding a set of customer requirements is fundamental [Griffin and Hauser, 1993]. This can be obtained by assigning different importance weights for customer requirements. The indication of the relative importance of requirements affects the target values to be set for the engineering characteristics. Kwong and Bai [2003] handle customer requirement prioritization as a multi-criteria decision-making problem. Ho *et al.* [1999] determine the importance weights of customer requirements based on group decision making by formulating a set of criteria agreeable to all individuals to aggregate individual preferences into group consensus. Chen *et al.* [2003] derive the relative importance of customer requirements by applying supervised learning with a radial basis function (RBF) neural network. Other authors like Gustafsson and Gustafsson [1994] propose to employ conjoint analysis as a method to prioritize customer requirements through pairwise comparisons. To deal with vague and imprecise requirement information, Chen *et al.* [2003] propose the conversion of the importance assessment of the customer requirements from crisp into fuzzy numbers, based on which the importance weights of customer requirements are deduced by applying an entropy based method. Due to its strength in qualitative decision making in multi-criteria problems, the analytic hierarchy process (AHP) has been broadly applied to determine the degree of importance of the customer needs [Saaty, 1990; Akao, 1990; Armacost *et al.*, 1994; Zakarian and Kusiak, 1999].

2.4 Requirement Classification

By the classification of requirements, product designers are guided in compiling, organizing, and analyzing product design issues [Rounds and Cooper, 2002]. Fung *et al.* [1998] classify customer requirements basing on the affinity diagram to emphasize the advantage of its creative properties, rather than solely relying on logical or intellectual reasoning as with other statistical concepts and methodologies. In [Lin *et al.*, 1996], an ontology for representing requirements is proposed that helps to support a generic requirement management process. It defines objects like components, features, requirements, and constraints by attribute specification applying first-order logic and by the identification of the axioms capturing the constraints and relationships among the objects.

2.5 Transversal Approaches

In the context of customer requirement management, Quality Function Deployment (QFD) and Axiomatic Design (AD) can be considered the most complete and transversal approaches.

QFD combines quality management and product development through an accurate customer needs analysis that is always the very first step in the QFD process and can be considered one of the most important functional fields of QFD. There are many publications in this field that focus on different key aspects of customer needs analysis, such as collecting/translating customer needs (e.g. [Bech *et al.*, 1997; Temponi *et al.*, 1999; Matzler and Hinterhuber, 1998]), customer involvement [Huovila and Seren, 1998], customer preference [Lai *et al.*, 1998], and prioritizing customer needs [Persson *et al.*, 2000].

Axiomatic Design Theory [Suh, 2001] differentiates four domains: the Customer Domain describes the so called customer attributes (CAs), the Function Domain deducts from there the functional requirements (FRs), the Design Domain provides Design Parameters (DPs) for the implementation of the FRs, whose transformation into processes shall be secured by the Process Variables (PVs) in the Process Domain [Suh, 2001]. The passage between the function, the design and the process domain can very systematically be developed by the two axioms and the underlying methodology. In contrast, Nam P Suh does not present a uniform methodological approach for the identification and translation of the customer benefit attributes.

2.6 Research Gap

All of the methods for customer requirement management discussed above can be meaningfully applied where customer needs regarding an already existing product- and/or service concept have to be evaluated [Züst *et al.*, 1999]. However, these methods are insufficient and sometimes not deployable for novel products, services or product/service combinations. After all, to a large degree, it is about ascertaining what the customer would like, but does not yet exist in this form. How then should he or she be able to verbalize such a requirement?

Even if the alternatives are obvious or known (which is an important condition for the functioning of Conjoint Analysis, which tries to evaluate preferred samples by a comparison in pairs), the comparison in a panel or a group of people can lead to mistakes, as Arrow's Impossibility Theorem shows [Hazelrigg, 1996].

The challenge therefore lies in the identification of a potential area of benefit, in which benefits can be derived and be translated into demands.

3 METHODOLOGICAL APPROACH

In this research, Axiomatic Design theory has been identified as a suitable starting point for such a benefit or needs based approach. Axiomatic Design differentiates four so called Design Domains: the Customer Domain describes the so called customer-benefit attributes (CAs: customer attributes), the Functional Domain deducts from there the functional demands (FRs: functional requirements), the Physical Domain provides Design Parameters (DPs) for the implementation of the FRs, whose transformation into processes shall be secured by the Process Variables (PVs) in the Process Domain [Suh, 2001].

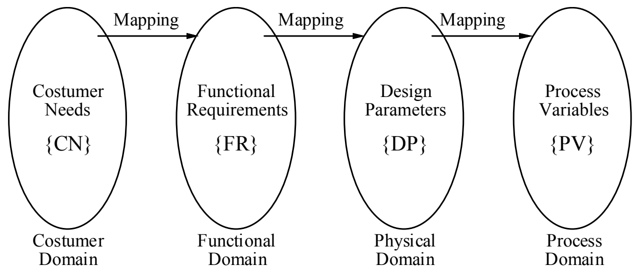

Figure 1. The design domains in Axiomatic Design [Suh, 2001].

The essential core of the Theory of Axiomatic Design is represented by two axioms, the Independence Axiom (1st axiom) and the Information Axiom (2nd axiom), which represent a necessary and sufficient condition for a "good" design of a product or a system. For this purpose, FRs and DPs are mathematically shown as vectors {FR} and {DP}.

The Design Matrix describes the relation between the two vectors:

$$\{FR\} = [DM]\ \{DP\} \quad (1)$$

The first axiom demands the independence of the functional requirements (FRs). A potentially good design exists if exactly one Design Parameter (DP) can be found which fulfils the allocated FR, without influencing the other FRs. To fulfil the Independence Axiom, the Design Matrix must be either a diagonal or a triangle matrix. In the case of a diagonal matrix, it is called an uncoupled design. This represents the ideal case, as every FR can be fulfilled with exactly one DP, without being in any interrelation whatsoever to other FRs. In triangle matrices there is a so called decoupled design. These functions can only be fulfilled independently from each other by adhering to a certain sequence. All other cases represent a (badly) coupled design [Suh, 2001].

The passage between the function, the design and the process domain can very systematically be developed by the two axioms and the underlying methodology. In contrast, Nam P. Suh does not present a uniform methodological approach for the identification and translation of the customer benefit attributes [Matt and Franzellin, 2008]. The analysis of the many examples which are meant to prove the validity of the axioms, does, however, show a logical pattern at the identification of the customer benefit attributes. From a purely economical point of view, the benefit is connected with a measurable value generation. The latter consists of a different perception of the value term for each user or group of users.

3.1 IDENTIFICATION OF THE CUSTOMER BENEFIT

The benefit aspect and its measurability play a fundamental role for the design of innovative products or services. Thus, the first step of the research will be focused on the development of generally applicable logical patterns for the identification of the customer benefit. It will represent a central aspect of the research activities.

The first question to be answered within the research is what drives the customer benefit and thus the buying decision: there must be a "return on investment". But this return cannot always be measured in economic terms. It depends on various factors. First, the different types of user groups and use cases have to be considered. One example: customer attributes that are collected from the real end consumers tend to be linguistic and usually non-technical in nature [Jiao and Chen, 2006]. It is difficult for engineers to translate them into concrete product and engineering specifications. Business customers, however, will have another benefit-perception, depending on their business targets and philosophy. Furthermore, special attention will have to be given to the differences that are inherent to the type of offering towards a recipient: whether it is a product or a service. A service is not storable in contrast to a product, seldom transferable and in every case, personal. Production and consumption of a service mostly coincide [Suh, 2001]. While a product is "tangible" in the truest sense of the word, a service represents only a relatively vague benefit promise. It is therefore especially important to make the value of the service visible and measurable for the customer.

For business-to-business (B2B), the value definition can be precisely determined. The (industrial) user of a product or an industrial service – mostly a producer of goods or services himself – measures the benefit of the purchased product, component or service in its contribution to the increase of economic value added (EVA) to his or her own application, alternatively also describable by the return of investment (ROI, see Figure 2). In both cases, mathematically or analytically connected systems of key performance indicators (KPI) help to decompose the general value measurement indicator to more detailed operational levels. The "leafs" of these KPI-trees represent potential areas of customer benefit on a very detailed CA-level.

Figure 2 shows the CA-tree based on the ROI system [Franzellin *et al.*, 2010]. Generally it can be stated that with a more detailed level of tree decomposition the importance of industry-sector-specific needs increases. According to practical experiences, this usually happens starting from the seventh level.

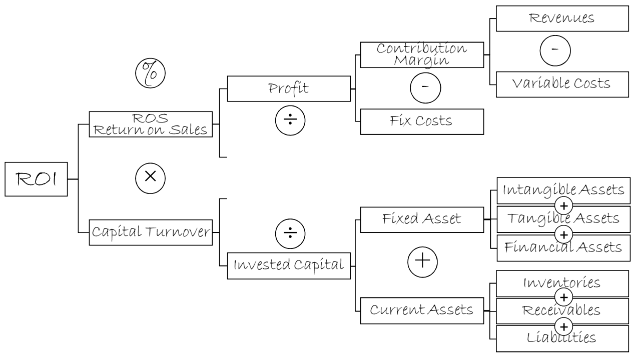

Figure 2. The ROI tree [Franzellin *et al.*, 2010].

Unlike classic Axiomatic Design theory which propagates the decomposition using the so called zigzagging between two domains (usually FR and DP, but also between DP and PV), the development of the CA-tree is decomposed only within the customer domain in order to maintain the solution neutral exploration of customer needs and benefits [42].

Starting from all of the (theoretically possible) areas of customer benefit in the decomposed CA-tree, customer group specific weights have to be defined in the next step. This is done by means of customer interviews using the logic of the CA-tree as an interview guideline.

For example, a producer of bathroom accessories has wholesale, specialized retail and plumber shops as possible customer focus groups in the distribution chain. However, each of these groups emphasizes different key aspects of needs which can be explored only by focus interviews.

In our example, the interviewed focus group of the plumber shops paid particular attention to cost aspects of "design to assembly" in order to reduce their own assembly times, and on revenue side to a good sales support (e.g. regional show rooms). On the cost side, wholesale emphasized efficient logistics (e.g. route related pre-sorted delivery goods on the truck in order to facilitate distribution), and on the revenue side it emphasized the introduction of unbranded products for the completion of their own product spectrum. However, the development of the CA-tree alone does not give enough insight for a customer needs based product or service design and development, as it delivers only "static" areas of customer benefits and needs. Moreover, these might be colored by current economic side conditions, strategic measures, etc.

Besides these static aspects, time-dependent "dynamics" play an important role. Customer attributes may change over time depending on market (Figure 3), environmental or technological changes. Thus, future developments also have to be considered in the interviews. For this, elements of the

Delphi technique [Grisham, 2009] were used in this research. (For further reading see: [Franzellin *et al.*, 2010]). Therefore, customer focus groups related scenarios of future trends and developments are prepared. During the interviews, customers are confronted with these scenarios and asked for their opinions and expertise regarding the probability and the timeframe of their occurrence. At the end of the interview, the customer benefit areas are again discussed, this time under the aspect of the scenarios impacting markets and environmental conditions in the future.

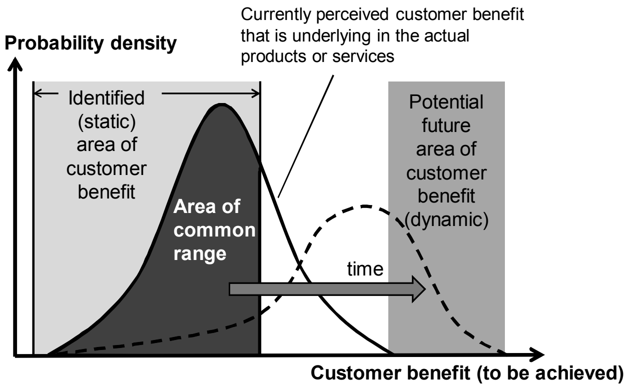

Figure 3. The dynamics of customer benefit perception [Suh, 2001].

In our case example, interviewees in the plumber shop focus group stated that given the scenario of a stronger European trend towards renovation of buildings rather than new constructions, a new need for a simple and modular exchangeability of components would be of interest.

3.2 DEFINITION OF THE HYPOTHETIC DESIGN MATRIX

Once the weighted and scenario proofed CA-areas are available (with comments), the most promising design trends can be identified by starting the definition of the first FR level. The product or service design process then continues with the mapping between the Functional Domain (FR) and the Physical Domain (DM). As previously outlined, the design process converts Functional Requirements (FRs) into Design Parameters (DPs) through an iterative process called "zigzagging" [Suh, 2001]. The decomposition process starts with the decomposition of the overall functional requirement.

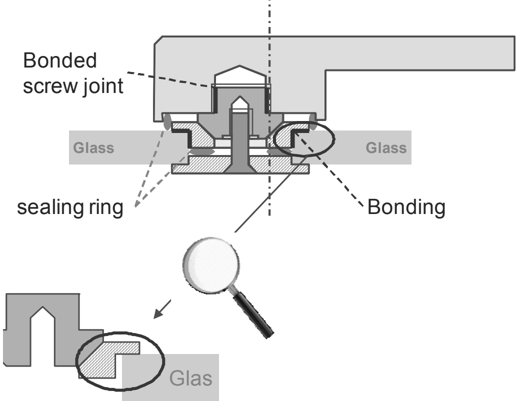

Figure 4. The realized component design.

In practice this should correspond to the top system requirement. Before decomposing to a lower level, the DPs must be determined for that level in the Physical Domain.

This step helps to produce a set of "hypothetical" design matrices: We call them "hypothetical" because they do not represent the final setup for the product or service design but serve to collect customer feedback on the hypotheses of future product or service offerings.

Back again to our example, the evaluation of the interview results with plumber shops had shown – amongst others – a particular interest in the interchangeability of handles at the glass doors of shower envelopes. However, this possibility is currently not given due to different bore diameters and/or their different positions. Combined with the previously described findings, the following CAs may be determined as follows:

- reduction of assembly times at the installation site
- sales support by promotional measures and means, especially by providing exhibition spaces as plumber shops usually do not have such sales related infrastructure
- simple interchangeability of components

Starting from these identified fields of customer benefit, two main focuses can be derived: (a) sales support, and (b) product development/improvement. In this paper, we will just show the example of the product improvement. For this, the customer benefit can be summarized as follows:

"Simple, fast and free of play assembly and disassembly of different handles on glass sheets". As constraints we define the minimization of production cost to preclude expensive high-tech-solutions, and the prevention of glass breakage on the installation site due to faulty assembly.

On this basis, suitable FRs are defined on the highest level of detail:

FR_1 Ensure fast and simple assembly and disassembly on the installation site

FR_2 Allow a detachable and free of play assembly of different handles even with long momentum arm on a sheet of glass with (nearly) freely adjustable mounting angle

In a next step, first level DPs are assigned:

DP_1 With standard tools easy detachable union (slotted headless screw, Phillips screw or socket head screw)

DP_2 Zero-backlash mating of the system glass/fixing device/handle by frictional grip

Now the design has to be checked whether it fulfills the Independence Axiom:

$$\begin{Bmatrix} FR_1 \\ FR_2 \end{Bmatrix} = \begin{bmatrix} X & (x) \\ 0 & X \end{bmatrix} \cdot \begin{Bmatrix} DP_1 \\ DP_2 \end{Bmatrix} \qquad (2)$$

The influence of DP_1 on FR_2 cannot be evaluated at this point in time because a defined force application might request the use of a dynamometric key. However, the design matrix is triangular and thus fulfills the Independence Axiom (decoupled design). For FR_2, the design cannot be finalized on this level of detail; it has to be further decomposed:

FR_{21} Assure frictional connection without breaking or damaging the glass during fixing of door handle

FR_{22} Identical junction for all handle-types with freely adjustable mounting angle

FR_{23} Assure detachability of junction

The following DPs were derived:

- DP_{21} Adhesive bonded joint between glass sheet and adapter with play and conical shape of coupling between glass-sided adapter and handle
- DP_{22} Rotation-symmetric coupling between glass-sided adapter and handle
- DP_{23} Screw fitting with commercially available machine bolt between the bipartite connector system

The design matrix shows a decoupled and thus potentially good system design:

$$\begin{Bmatrix} FR_{21} \\ FR_{22} \\ FR_{23} \end{Bmatrix} = \begin{bmatrix} X & 0 & 0 \\ X & X & 0 \\ X & 0 & X \end{bmatrix} \cdot \begin{Bmatrix} DP_{21} \\ DP_{22} \\ DP_{23} \end{Bmatrix} \quad (3)$$

Coupling in the lower triangle of the matrix still exists as a result of the frictional connection generated by the cone-screw-system and thus calls the designer's attention to the right choice of cone-angle and material combination between the two connecting parts.

As this example (Figure 4) helps to illustrate the methodological procedure, no further details will be discussed.

3.3 CUSTOMER PROFILING

Within this phase, the characteristics of the product/service are correlated to the profile of the customer with the highest potential. This allows the completion and/or revision of the nominated product specifications. On the basis of a representative set of test cases, the cross-functional research team has to check the sellable product values and the affinity of the product concept with the other customer profiles. The product/service specifications are checked further on regarding commercial aspects and targeting objectives. The profile of the customer with the highest potential is clearly defined. The result of this phase is the definition of a suitable procedure for customer profiling and the definition of the specifications for the subsequent start of the innovation and product design process.

In our case example, a first prototype was presented to the heterogeneous visitors of a specialized trade show. The feedback was collected, structured and evaluated. Further research will be dedicated to the testing of different alternative methods regarding their suitability for this step.

Feedback from visitors was very positive; however, skepticism was shown regarding the mechanical characteristics of the system under load. Many visitors thus applied heavy force to the system until the system started to ease. After the trade show, technicians analyzed the effects of the mechanical fatigue and started to optimize the system by using different material combinations and grooved cone-surfaces.

4 CONCLUSION

In this paper an AD based methodology was presented that helps companies in the systematic search for innovative product or service fields. Through a consequent deduction of FRs and first DP hypotheses regarding a promising future product or service from a clearly defined description of (future) customer needs, a lead-user interview guideline is developed. The interview results reflect the customer group specific opinion pattern regarding the benefit perception of a proposed (new) product or service. On the basis of the feedback, more specific inputs for FR definition can be given which helps product designers to really follow a customer needs oriented design pathway.

Future research will be focused on further evaluation and optimization of the approach and applying it to different sectors and industries. Special attention shall be given to the use and testing of different (existing) methods of customer group specific interviews. Moreover, a research focus will be given to the development of a more sophisticated Delphi method based trend analysis to better develop scenarios for the simulation of time-dependent future changes and trends that might influence customer benefit perception.

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