CASE STUDY: INDIVIDUALIZATION OF A FULLY AUTOMATED COFFEE MACHINE

Kosiol, Maike; Böhmer, Annette Isabel; Lindemann, Udo
Technische Universität München, Germany

Abstract

People aspire to individuality and look for products that correspond to their needs as much as possible. In the InnoCyFer project the complete process of individualization - starting with the personalization by the customer and ending with the individual manufacturing - is implemented on the basis of a fully automatic coffee machine.
This paper focused on the individualization of an existing product based on the given product architecture and developed a system of criteria to evaluate the existing product with reference to possibilities for individualizations.
Approaches to develop customized products are shown. Both modular and customized product development, as well as the product creation process of customized products, are discussed. An analysis of the fully automatic coffee machine is outlined and a possibility to evaluate standardized and customized components. Further options for individualization, like add-on modules or the restructuring of the product architecture of the fully automatic coffee machine are discussed.

Keywords: Design to X, Design practice, Open Innovation, User centred design, Collaborative design

Contact:
Annette Isabel Böhmer
Technische Universität München
Mechanical Engineering
Germany
boehmer@pe.mw.tum.de

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1 INTRODUCTION

People aspire to individuality and look for products that correspond to their needs as much as possible. The attempt of companies to fulfill these desires clearly leads to the trend that the number of variants increases disproportionately compared with only steady or moderately increasing sales (Ericsson and Erixon, 1999). Companies react to increasingly demanding customers and their desire for individuality through product variants that are supposed to improve the customer´s satisfaction with products. Other reasons for the continuous rise in the number of product variants are increasing innovation and technology dynamics, massively shortened development and product life cycles as well as the aftermaths of the information and knowledge society (Ponn and Lindemann, 2011).

Since end-products composed of predefined elements and standardized modules do not answer the actual needs of customers (Piller, 2001), providing many different variants still usually does not meet customer requirements. The spectrum of individualized products on the contrary results from a multitude of possible product characteristics that follow from the degrees of freedom that are given to the customer for the individual design (Lindemann et al., 2006). It is an aspiration to allow a customization of especially relevant product characteristics from the customers' point of view, to offer variance in such parts where traceable economic convenience is generated (Gräßler, 2003).

The joint research project "Integrated design and production of customer innovated products in cyber physical production systems" (InnoCyFer, german: 'Integrierte Gestaltung und Herstellung kundeninnovierter Produkte in Cyber-Physischen Fertigungssystemen') is motivated through the desire for increasing personalization of consumable durables, in as much as an increasing number of companies strive for the complete satisfaction of customers' preferences. This is supposed to be made possible through an 'Open Innovation' platform which provides great freedom for the customer to actively participate in the product development process. In this way the customers' ideas and wishes can already be integrated in the development of an individual product. By changing geometries and functions the customer is able to determine the product´s design within a set of defined design limits and include his or her own ideas. It is planned that the costs associated with the design and the impact on delivery timing are calculated through a direct link to the manufacturing planning.

In the InnoCyFer project the complete process of individualization - starting with the personalization by the customer and ending with the individual manufacturing - is implemented on the basis of a fully automatic coffee machine. With the aid of the 'Open Innovation' platform the customer is able to be inspired by other users' drafts or to design the layout for his fully automatic coffee machine himself. The integrated toolkit on the web page will enable the customization and also the communication with the production planning and control. It enables the user to iteratively work with his requirements and turn these into a concrete solution without making personal contact with the company. In this manner the trial and error process is assigned to the customer and his 'trial attempts' become useful for the future development of customized products.

To develop such a toolkit with which a customized product can be designed and finally produced, the product must first be prepared for this purpose (Holle, 2014). In the context of the joint research project InnoCyFer the fully automatic coffee machine presents a perfect example of its use. The product´s architecture is currently not configured for the adaption of various components or for adding extra modules. Even though the machine is already produced in modules, the key focus of these modules is to enable the cost effective and economic production of various variants. The modules are not conceived to enable the customization of the product but instead are standardized for an efficient and economic fabrication of product variants.

As an introduction chapter 2 shows approaches to develop customized products. Both modular and customized product development, as well as the product creation process of customized products, are discussed. Chapter 3 outlines the analysis of the fully automatic coffee machine and illustrates a possibility to evaluate the potential for adapting various components. The outcome of this is the separation of standardized and customized subcomponents. Chapter 4 discusses the further options for individualization, like add-on modules or the restructuring of the product architecture of the fully automatic coffee machine.

2 INDIVIDUALIZATION METRICS IN LITERATURE

2.1 Individualization – Basic approaches

According to Fixson (2006) there are various descriptions and interpretations of the concept 'modularity'. Göpfert (2009) defines modularity as the physical separation of a product in mutual independent components, so-called modules. With this the internal interfaces within a module are significantly more pronounced than the interfaces towards another subsystem (Ulrich, 1995; Baldwin and Clark, 2000). The outcome of this is that a module is largely independent of changes made to other subsystems and that a change in one module does not automatically make necessary a change in another module (Göpfert, 2009). In this way modular designs are a useful means to manage complexity (Ethiraj and Levinthal, 2003). Thus modularity plays a particular and decisive role in every mechatronical application area due to the fact that through modularity it is possible to achieve high product variety despite standardized components (Gräßler, 2004). Above and beyond this the principle can be used for the development of customized products, since it offers the possibility to vary single modules without necessitating the adjustment of preassigned standard modules. For creating modules and also working with them it is necessary to define precisely the interfaces (Ehrlenspiel, 2014). Standardized interfaces provide for interdependency between modules.

Ulrich and Tung (1991) distinguish between six different types of modularization (figure 1), which influence the variability of the basis architecture: 1. component swapping: alternative types of components can be combined with the same basis product; 2. component sharing: the same basis component is used in different products and product lines; 3. fabricate-to-fit: one or more standardized components can be combined with one or more continuously varying components; 4. bus: components are connected to a common bus by similar interfaces; 5. slot: different types of interfaces per mating of components which are incompatible among themselves and 6. Sectional: every interface is of the same type, but there is no single element which is combinable with every other component at the same time.

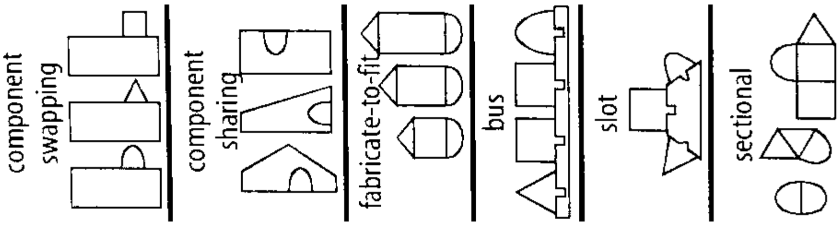

Figure 1. types of modularization (In: Gräßler, 2004)

Meyer and Lehnerd (1997) describe different strategies of platform constructions. One of their strategies called 'Vertical Scaling of Key Platform Subsystems' allows a reasonable application in the area of modular construction. The strategy is based on a differentiation between two types of scaling: scale up and scale down. Scale up refers to an upgrade of a low price layout of a product by enhancing and amending the product range. The scale down of a product reduces its range by omitting and/or reducing system functions, based on a high-capacity layout of that product (Gräßler, 2003). By scaling it is possible to cover a great amount of diverse categories of price, power and dimension and in combination with the types of modularization it gives the opportunity to create customized variants of a component with minimal effort. Martin and Ishii (2002) developed the 'Design for variety' method to generate a product architecture that uses the advantages of modularity. The aim of the method is to aid engineers in creating designs that build on current design effort for future products and thus reduce development costs. Therefore it is necessary develop architectures that require minimal changes to meet future marketplace needs. In the process they use the so-called generational variety index (GVI), a measure for the amount of redesign effort required for future designs of the product and the coupling index (CI), a measure of the coupling among the product components.

In contrast to the mere offering of product variants the spectrum of individualized products results from a multitude of possible product characteristics that follow from the degrees of freedom that are given to the customer for the individual design (Lindemann et al., 2006). Indeed, modules of a variant assembly can be part of customized products, but the most important differentiating factor of customized products towards simple product variants is, that customized products can also possess completely individual components (Lindemann, 2003). The diversity of elements and combination possibilities should be enabled specifically by flexible product-, process- and corporate structures. Since it is not possible to consider and estimate every thinkable and still unimaginable individual specification of a product previously, it is a principal task of the product development to record the customers' needs, to translate them into product requirements and by using this knowledge develop a product architecture, which allows the customer to individualize the product in a range that is relevant from his point of view (Holle, 2014). If the additional expenses to develop a customized product are captured, it is possible to generate products with attributes that are perfectly tailored to the requirements of a single customer. To accomplish this customers can and must be integrated actively in early phases of product development by expressing their preferences (Bachvarov et al., 2009). Customers become part of the creative process instead of passively receiving the end product designed by the producer (Bártolo et al., 2009). That is why they are now often named 'prosumers' (Rayna and Striukova, 2014). Through this increasing interaction it is possible to create or improve customer loyalty and to gain access to innovative ideas (Lindemann et al., 2006).

2.2 Individualization - product engineering process

Customized products are supposed to satisfy the requirements of a customer in the most optimal way. To realize the highest possible amount of satisfaction the product creation process is divided into two stages: 1. a preceding planning of the product structure and the adapting process planning and 2. the custom-built adaptation stage. Within the structural planning the basic product requirements are checked and main product functions become assigned. Likewise the main components of the product are defined as elements of its structure. Thereby the particular degrees of freedom of its components are rated for subsequent individualization. Elements and interactions are considered and optimized in such a way that individual product changes have as little impact on other parts of the product as possible and that product adaption can be executed easily. In this context particular importance is laid upon clearly defined and consistent interface design. The result of the structural planning is a product structure that contains all essential product elements and their links within the context of the product architecture and that is appropriately robust when considered in the context of changes demanded later due to customer wishes (Lindemann et al., 2006).

Subsequently, the information from customer requests is linked with the earlier defined product elements and structures from the structural planning stage. The individual product adaptation by the customer follows this, the actual individual product changes be they either functional or design aspects. Depending on the customers´ requirements the individual adaption of a product may take place on different levels (Lindemann et al., 2006).

At a functional level the functionality can be determined by adding or leaving out product functions. Further possibilities of adaptation at the functional level are amplification or reduction of functions, integrating of functions, separation of functions and reversal of functions as well as the changing of the function order. At the level of operating principles it is possible to create a product adaptation by alternative operating principles with the same functional effect as well as the increasing or reducing of principles in their impact. At the structural level the product adaptation can be realized by adding or omitting product elements and links. Product modules can be replaced by others and the amount of the structural area can be adjusted by integration, splitting, or recombination. Furthermore, location, position and arrangement of product elements as well as the type of interfaces can be changed. Modules can be outsourced or sub-groups and major groups can be built. In this way a new product architecture arises. At the level of the product design product attributes can be varied directly. Changeable features can be form, number, location, dimension, surface, material, material processing of design elements and so on. The characteristics of product features can for example be changed, enlarged, minimized or inverted (Lindemann et al., 2006).

The result of the adaption process is finally the customized product definition with the determination of functions, geometries and materials as well as their constructional design. This information, including the resulting drawings and bills of materials, provide the basis for the planning of the subsequent production processes. The planning and finally the production of the customized product are made considering available resources and existing capacities.

On some occasions during the product configuration process an assessment of the production planning can take place in order to calculate a customer specific delivery date or the resulting costs (Piller, 2006).

By following this concept of customized products it is possible to differentiate from products on the market, to create additional value, to create experience for the customer through the configuration process, to improve customer loyalty towards the enterprise and to avoid overproduction (Bock and Linner, 2010).

3 INDIVIDUALIZATION – CASE STUDY

As an example, the procedure to design the product architecture of a mechatronic product in such a way that the foundation is laid for enabling later custom adaptation, is developed and described for a fully automatic coffee machine.

The main function of the fully automatic coffee machine can be described as follows: water is delivered by a pump to a flow heater and is heated up there. At the same time coffee beans are crushed by a grinding gear. Afterwards the generated coffee powder falls directly into a compartment of the so-called brewing unit. In this unit the coffee powder is compressed in front of a filter by a piston. At the exit of the flow heater hot water is available (temperature: <97°C) and able to finally cross the compartment of the brewing unit in order to brew coffee. The brewing temperature should be between 90°C and 96°C. As a result hot coffee is produced, that can be filled into a cup, and besides coffee grounds remain that are disposed of the compartment into the coffee grounds container. The temperature of the coffee beverage should be at least 67°C (Tsantidis, 2008; Steinbrunner et al., 2007).

The main function of the fully automatic coffee machine is ‘percolate coffee’. The decomposition of this function in sub-functions helps to divide the complexity of the system in manageable parts. The analyzed model in this paper is according to the company divided into twelve virtual function units of which the first ten regarding the main function “Dispense of coffee” will be considered: 1. Provide coffee powder, 2. Brew coffee, 3. Deliver beverage, 4. Provide hot water and steam, 5. Enclosure machine/design, 6. Support components structure, 7. Interact with user, 8. Control machine, 9. Store and provide milk, 10. Provide water and dispose residue.

Every physical component of the fully automatic coffee machine can be allocated unambiguously to one of the function units. The function units of the fully automatic coffee machine allow a first representation of the functional structure of the machine. By matching the function units with the assemblies that fulfill the functions one gets the product architecture of the fully automatic coffee machine shown in figure 2 on a highly abstracted level.

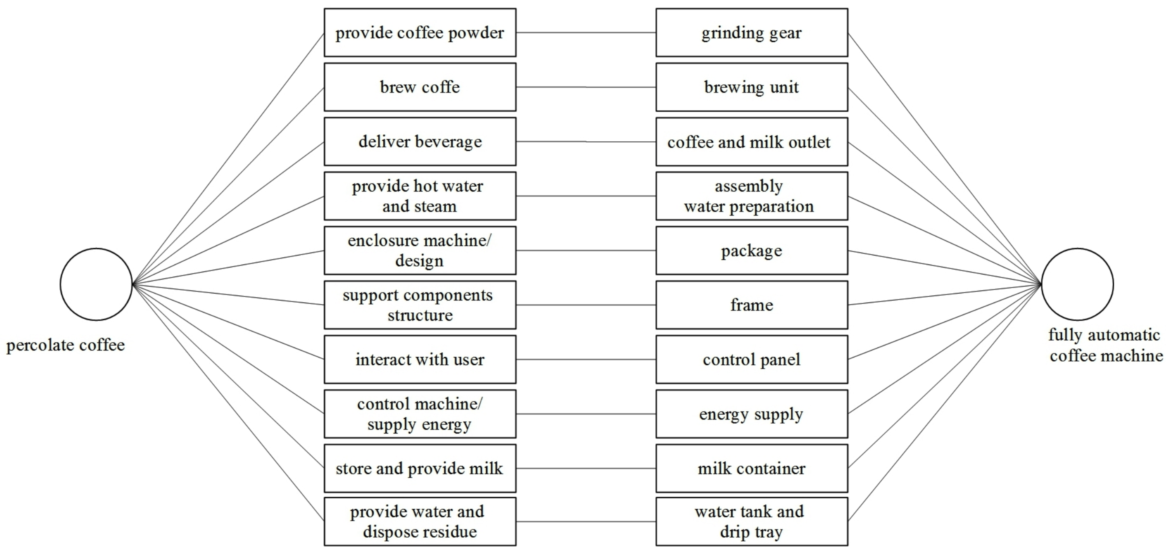

Figure 2. highly abstracted product architecture of the fully automatic coffee machine

If one not only deconstructs the overall function ‘percolate coffee’ in the ten mentioned sub-functions, but deconstructs these sub-functions as well in further sub-functions, one gets a more and more detailed structure. With increasing accuracy it is possible to reach a level of detail, in which it is possible to not only relate sub-functions to assemblies or modules, but to translate sub-functions into elementary physical components.

3.1 Methods

The assemblies are linked among themselves in various ways as well as the components of each assembly among each other. These connections have to be outlined through interfaces. An interface can be used for communication, data transfer or flow of material. Possible interfaces are direct constructional interfaces, functional, spatial, physical or aesthetic interfaces (Baumberger, 2007). How the components of the fully automatic coffee machine are connected with each other is extremely important for the conceptualization of a customized machine, because it highly depends on the type and the number of interfaces, to which extent the individual change of one component affects other components.

Interdependency networks are a method to determine and present graphically elements of a system and their interactions. The method serves especially for systems that are not too extensive, as the illustration quickly becomes too complex when using it for extensive systems. The interdependency network shown below is structured in such a way, that elements which are strongly connected to several other components are positioned in the center of the network. In contrast weakly cross-linked elements are located in outlying areas. In this way a component can be evaluated quickly regarding its interactions with other components.

Interdependency networks are always based on a cross-impact matrix. With such a matrix it is possible to obtain the type and the intensity of the mutual interaction of elements that are part of a system. By that complex systems may be analyzed and the impact of modifications can be seen. For this purpose the elements are opposed in the form of a matrix and every connection of an element in the row is rated in reference to its impact on the elements in the column (Lindemann, 2009). Figure 3 shows an interdependency network in which firstly all components of the fully automatic coffee machine are attached to their assembly and secondly the linkages of the components of an assembly amongst each other as well as the connections between the components of different assemblies are considered. By the arrangement of the components it is possible to easily extract information from the network, about which components are strongly and which are more weakly connected.

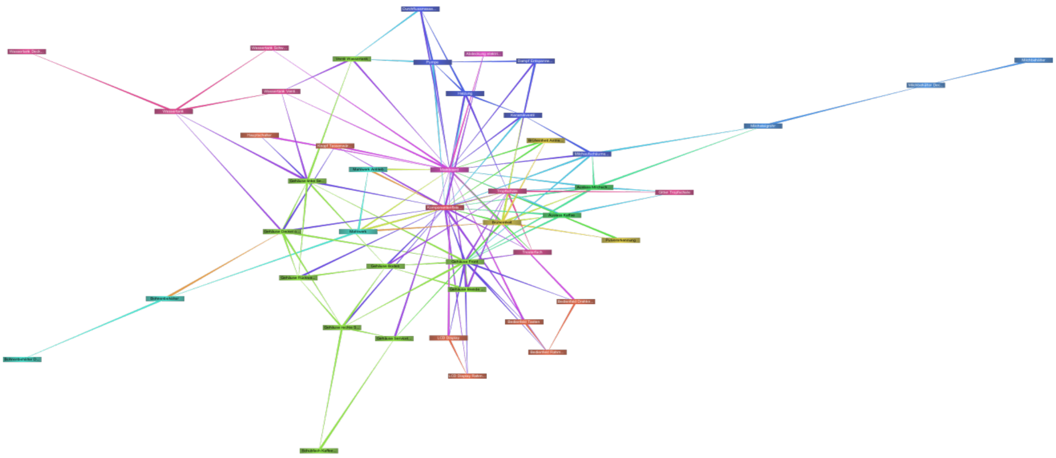

Figure 3. simplified presentation of the interdependency network of a fully automatic coffee machine

The objective is to identify components, that are suitable for individual customization, but at the same time to define components, that should be declared as standardized components, because of their strong network interaction and their minor relevance for the customer. Requirements that are largely homogeneously posed by a multitude of customers should be implemented in form of a standardized solution principle; in contrast, product functions whose custom adaptation creates a significant additional value for the customer should be possible to modify (Gräßler, 2004). As part of the joint research project InnoCyFer a survey about possible design wishes of customers was conducted for a first rough assessment. As a first result of the examination it can be pointed out, that customer wishes generally refer to outward appearance and extended functions, but not to the complex core of the fully automatic coffee machine, which enables the fundamental and for the customer self-evident functionality. This corresponds to the results of Lindemann (2009) that besides additional functions, coloring and patterning as well as the modification of the outer contour are most widely admired features that significantly influence the customers' satisfaction and therefore can also have a great impact on the purchase decision. These findings allow a first preliminary conclusion regarding the definition of standardized elements: all components that are simply part of the fulfillment of the basic function and moreover are not visible for the customer can be defined as standardized components, since the customer would not gain any additional benefit by customizing these components (figure 4).

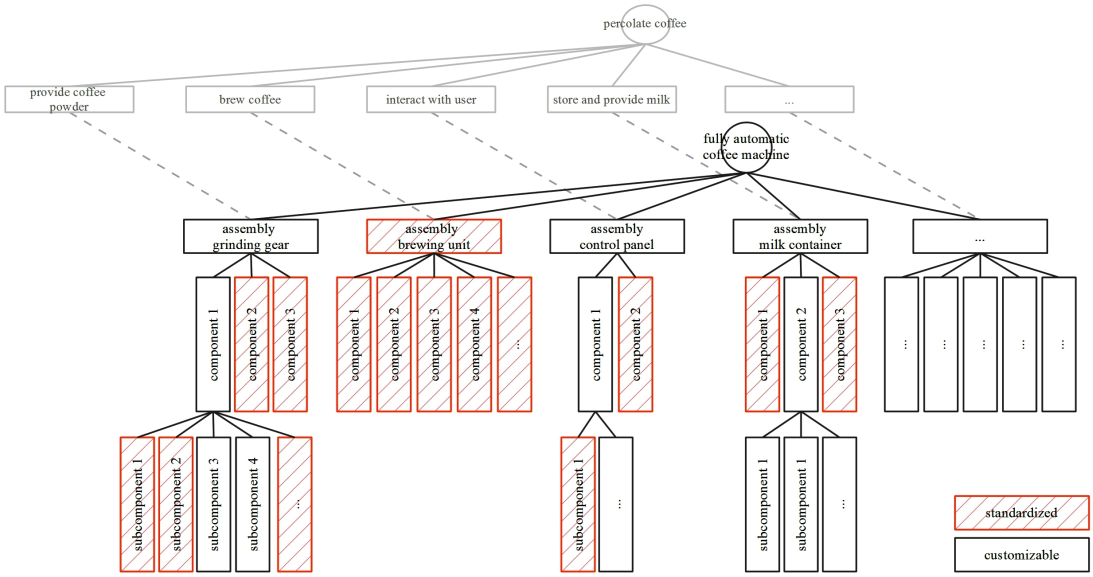

Figure 4. definition of standardized components

It is important to emphasize that in the survey 16 of a total of 55 submitted design suggestions related to the category "general functions" and corresponded to additional functions that the respondents would have liked to be implemented.

On the basis of the remaining 39 ideas of that survey which refer to the current functions of the fully automatic coffee machine it is possible to define a first evaluation criterion regarding the customer relevance for the adequacy to customize a component. The criterion **customer relevance** was weighted by the number of mentions of design wishes to an assembly, while the most mentioned assembly got most and the least mentioned assembly received the lowest number of points.

The already considered **cross-linking of the components** describes a further evaluation criterion.

If a component fulfills just exactly one function it is functionally independent to the largest extent possible. In contrast, if a component is necessary to fulfill several functions - that is integration of functions in one component, then it is functionally dependent. With regard to the suitability of a component to be customized then it is better if it is functionally independent, because the change of this component would have a less impact on other components, providing that the interfaces are designed appropriately. For this reason the evaluation was extended by the criterion **functional independency**.

Physical independency describes the extent to which an assembly is removable from the machine even after the assembly process. It refers to the method of construction of an assembly. In the context of individualization it is preferable, if a component is physically independent, which leads to the criterion of physical independency.

According to Gräßler (2004) a custom product design is particularly attractive to customers. The evaluation criterion **visual appearance** rates to which extent the product design can be influenced through the customization of that particular component.

The potential a component possesses to increase customer use through its customization is considered in the criterion **potential of benefit enhancement**.

In a final step the **manufacturing effort** of a component's customization is included in the evaluation. To be considered is, for example that the effort involved in manufacturing a component is strongly dependent upon how far modifications of the geometry are tolerated. The variation of the shape leads to a significant higher manufacturing effort than only color changes, scaling of a component or the selection of a different material does.

3.2 Results

For each assembly the aforementioned criteria of customer relevance, cross-linking of components, functional independency, physical independency, visual appearance, potential of benefit enhancement and manufacturing effort are applied and each is rated. The criteria customer relevance and cross-linking of components are rated relative to their number of mentions and connections with points between zero and six. The other criteria are rated with points between three and zero referring to a high degree of, an ordinary degree of, a low degree of or no potential for individualization. These criteria are multiplied with two to obtain a non-weighted evaluation. If one considers one or more criteria to be more important other emphases are possible. By adding the number of points for each assembly, a ranking regarding the suitability for individualization arises. Figure 5 shows the results of the evaluation matrix by the criteria outlined above. The assemblies rated with higher number of points are most suitable for individualization, components with a small number of points are less suitable.

	customer relevance	cross-linking of the components	functional independency	physical independency	visual appearance	potential of benefit enhancement	manufacturing effort	**sum**	**grade = adequacy to customize**
quantifier	1	1	2	2	2	2	2		
package	6	2,5	0	4	6	0	6	24,5	6
water tank	2,5	6	6	6	4	4	6	34,5	1
bean tank	1	6	6	4	4	4	4	29	3
control panel	5,5	5	0	4	2	2	2	20,5	7
drip tray	2	5	4	6	4	4	2	27	4
milk container	1	6	6	6	4	4	6	33	2
coffee and milk outlet	2,5	4,5	4	2	4	6	2	25	5

Figure 5. evaluation matrix about the suitability for the assemblies' individualization

Up to this point only the current assemblies were considered. With the networking of assemblies then the components and the networking of the components has been considered however the subsequent suitability of components within an assembly for individualization and what they have to offer must still be checked. Although the evaluation shown in figure 5 provides a good first impression of which assembly is adequate for individualization, it would be necessary to extend that evaluation to the components that form these assemblies to detect, which specific components of an assembly are suited in particular. The interdependency network illustrates that not every component of an assembly is necessarily equally strongly or weakly connected. This means, that in individual cases the evaluation must be repeated for the particular component.

3.3 Visualization of Individualization

Figure 6 shows as an example the modification of some parameters of the fully automatic coffee machine model: “water tank width”, “water tank depth”, “water tank height”, “diameter bean tank”, “height bean tank”, “radius water tank”, “radius coffee outfall”. In the created model a continuous variation of the parameters is possible, but it should be noted, that in the actual realization in form of the toolkit the chosen parameters and the resulting dependencies from this must be documented carefully since otherwise one can quickly lose the overview. Used parameters and the resulting dependencies as well as their range have to be part of the documentation. In many cases it is necessary to set limits for the parameters from which the customers can freely choose. Reasons for this limitation can be because of its geometry but also because of technical requirements. For example it should not be possible to define the diameter of the bean tank bigger than the width or depth of the casing (geometrical cause). On the other hand the angle between casing cover and bean tank must be 20° at least in order that the beans can slide down smoothly (technical requirement). Baumberger (2007) suggests three possible categories for limiting the selectable parameters. 1. The definition of several permitted parameters, out of those one can be chosen. 2. The definition of a permitted range or the exclusion of a specific range (permitted range above, below or within defined boundaries). 3. Freely selectable boundaries. Which type of limitation makes most sense has to be analyzed and decided for each component separately.

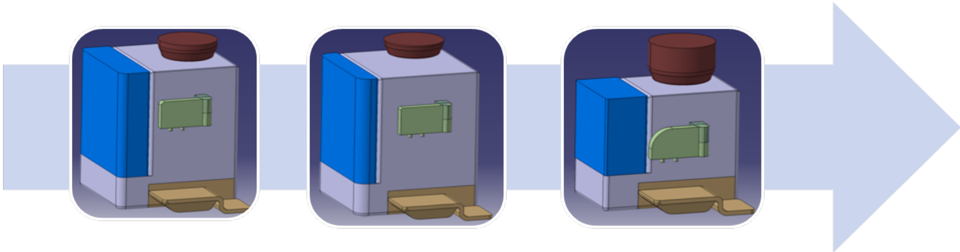

Figure 6. exemplary variation of some shape parameters

4 DISCUSSION AND OUTLOOK

This paper focused on the individualization of an existing product based on the given product architecture and developed a system of criteria to evaluate the existing product with reference to possibilities for individualizations. Beyond the given example there are several possibilities to achieve a certain level of customer individuality. On the one hand custom requirements could be realized by developing additional modules. Additional modules can be used to fulfill further custom wishes that could not be integrated into the fully automatic coffee machine without further treatment. Therefore the product architecture must be designed partially open for the use of interfaces, but the rest of the existing fully automatic coffee machine could be used largely untouched. Interfaces should preferably be standardized to make it possible to integrate different types of additional modules by the same interface to provide as much flexibility as possible.

It should be mentioned, that building additional modules to implement custom wishes cannot be realized at the existing fully automatic coffee machine. Furthermore, the development of an additional module for every specific custom requirement would correspond to a new product development but not to customized development. Nevertheless, the offer of various additional modules denotes a certain level of individuality because the customer can decide – according to his individual preferences – whether and which additional module he wants to add.

A further possibility is to redesign the structure of the fully automatic coffee machine. By restructuring modules in regard to the aspects of individualization a structure could be created, that allows the custom variation of single modules within defined boundaries, while they do not impact other modules. Several methods exist to newly combine the components to modules and to define components as ‘standard’ or ‘customizable’. The aim of creating a (new) product structure is according to Lindemann et al. (2006) to guarantee a maximum of customer individuality that is reflected in the outer variant diversity that does not directly affect the technical documentation of the inner variant diversity if an order is placed. This must be obtained by a suitable product modularization and product standardization. During the process of structural planning of custom products special importance should be attached to ensure that the influence of custom product modifications to other parts of the product are as small as possible and that the adaptation of the product can be implemented easily. A clearly defined separation of unchangeable and variable parts of the product should be pursued.

Ericsson and Erixon (1999) developed an alternative method to (re-)structure a product: the ‘modular function deployment’. It aims to modularize products by characterizing function owners, effects, operating principles or components in form of a systematic procedure based on matrices according to criteria of module formation. Subsequent to the evaluation a statement can be made about which technical solutions should be combined to a module. An essential element of the method is the ‘module indication matrix’ (MIM). In this matrix each technical solution is assigned to the degrees of fulfillment of twelve criterions that are defined within the method of ‘modular function deployment’.

For every possible technical solution the values are added, whereupon the solutions with the highest total amount of degrees of fulfillment represent candidates for building a module. The aim of this method is not the creation of an optimal product architecture but a scheme of a flexible product design which makes it possible to fabricate variants of a product without making it necessary to change the whole product with every newly modified product variant. In this process components of the product that should be varied strategically to satisfy the customers' needs are clearly defined and separated from the rest of the product that should remain as a mutual basis (Ericsson and Erixon, 1999).

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