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# INTEGRATED VALUE ENGINEERING - IMPLEMENTATION OF VALUE OPTIMIZATION POTENTIALS

S. Maisenbacher, D. Fürtbauer, F. Behncke and U. Lindemann

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## 1. Introduction and research methodology

Innovations in product development and international competition demand companies to control their costs. According to Cooper and Slagmulder [1997] the management of the dimensions cost/price, functionality and quality are crucial to compete in nowadays market environment. The creation of valuable products requires high functionality and quality for low costs (e.g. [VDI 2007], [Bescherer 2010]) which results in additional challenges in the design process of products, especially as this has to be done early in the design process [Pahl et al. 2007]. Approaches like value engineering (VE) and target costing (TC) support developers to cope with these challenges by either meeting cost targets or the creation of additional product value, just as the relatively new approach of integrated value engineering (IVE) [Maisenbacher et al. 2013], [Behncke et al. 2014]. IVE uses matrices to combine TC and VE in a structural model to support value optimization within the main stages of engineering design by analysis of the product domains requirements, functions and components. Within these domains value optimization potentials are deduced. The further implementation of these potentials is the focus of this work. The objective is to support the implementation of potentials on all three product domains and to allow a value optimization by a combination of either increasing the functionality for the customer or reducing the product's costs.

Blessing and Chakrabarti [2009] suggest a four step process (research clarification, descriptive study 1, prescriptive study and descriptive study 2) for research in engineering design. Based on this research methodology chapter 2 will use literature to define the term value and introduce challenges in cost management. Approaches like VE, TC and IVE are presented to cope with some of these challenges. This research clarification outlines the objectives for this work: The support of the implementation of value optimization potentials for IVE.

The prescriptive study of the support starts in chapter 3 explaining how to assess and evaluate value potentials in the IVE approach and therewith presents the first results. However, the implementation of the potentials should be further supported. The descriptive study 1 uses a literature review to find measures for cost reduction and functionality (chapter 4 and 5). The measures are structured and classified to allow for the expected support to implement value potentials in IVE (chapter 4 and 5). The results of this second part of the prescriptive study are illustrated in two figures. Finally, a case study discusses the applicability of the results in the descriptive study 2 (chapter 6).

## 2. Value and cost management in engineering design

According to Franz and Kajüter [1996] cost management is the aimed and systematic control of costs.

It has the objective to influence the costs of products, processes and resources to achieve an appropriate success and long-lasting competiveness for a company. In engineering design this implies to develop market-oriented, cost-optimized products within a cost-efficient process [Ehrlenspiel et al. 2014]. The focus of this paper is on the product and to support its optimization. Chapter 2.1 will introduce the term value to explain what makes a product valuable and which challenges result for engineering design. Afterwards a brief overview of TC, VE and structural modelling is given to introduce the IVE approach (chapter 2.2).

### 2.1 A value definition and challenges in cost management

To allow for an optimization of products it has to be clarified what makes a product valuable. The SAVE International Value Standard [2007] defines value as a fair return or equivalent in goods, services, or money for something exchanged. This definition has to be further specified for engineering design. Schuh [2012] includes the customer and refers to customer value as the maximal willingness to pay for a product or service of a company. Further focused on products Cooper and Slagmulder [1997] define the term value as the functionality of a product divided by its costs.

This definition allows for two ways of optimizing a product's value: Either by increasing its functionality for the customer or by reducing the product's costs for the company. In this paper we will refer to these two ways as two dimensions of value. VDI [2007] specifies this to five possibilities for increasing value: High functionality increase with high cost increase, high functionality increase with equal costs, low functionality increase with small reduced costs, equal functionality with a high cost reduction and small functionality reduction with high cost reduction. However, the decision between focusing on either increasing functionality or reducing costs is challenging for companies.

Additionally, the progress in the product lifecycle influences this decision. On the one hand, early stages of the product lifecycle have high impact on the costs of the product and allow for optimization. On the other hand, concrete costs emerge during the progress of the product lifecycle [Ehrlenspiel et al. 2014]. Pahl et al. [2007] mention that the majority of costs are committed when a principle solution is selected and embodied and that later stages only allow for minor potentials. This challenges developers as early stages complicate cost management due to inaccurate cost information. With progress in the product lifecycle cost information becomes accurate and potentials can be deduced. However, the impact of taking measures is reduced. The statement of Ehrlenspiel et al. [2007] that around sixty percent of the value optimizations are cost reductions within existing products confirms the mentioned challenge and the need for further support for early cost management and the value optimization by adding further functionality. Figure 1 illustrates these issues.

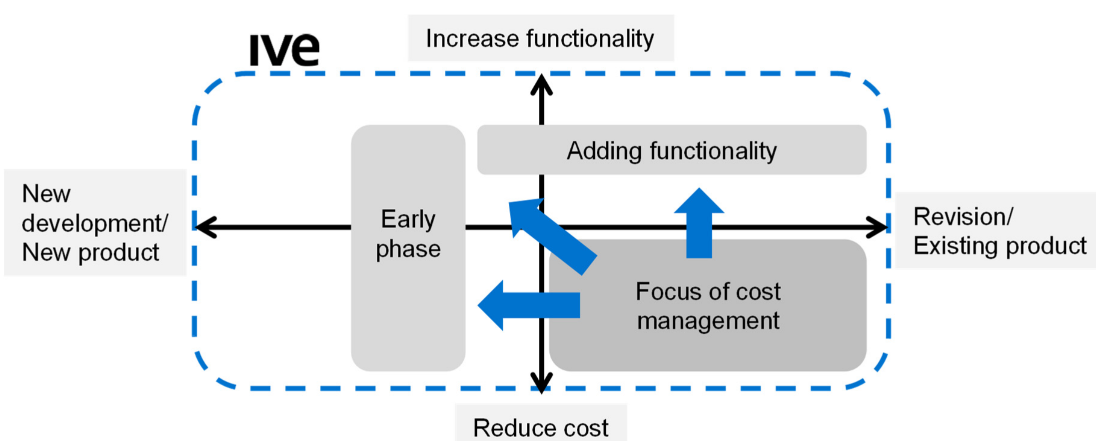


**Figure 1. Challenges for value optimization**

Recapitulating this chapter a value optimization of a product can either be an increase in functionality for the customer or the reduction of the product's costs. An approach for value optimization should support both directions and combinations thereof. Additionally, it should support, besides cost reductions of existing products, a value optimization in early conceptual stages of engineering design.

### 2.2 Approaches in cost management and objective of this paper

The two main approaches in cost management are TC and VE. TC defines the allowable costs for a product based on an obtainable selling price including an expected profit margin the selling company wants to earn [Cooper and Slagmulder 1997], [Filomena et al. 2009], [Kee 2010]. Since the major percentage of the product's lifecycle costs are determined in the early development phase (compare to chapter 2.1), TC defines and manages cost targets for the development and production phases in which costs arise [Ehrlenspiel et al. 2007], [Kee 2010]. VE focusses on the value of a product defined by the ratio between functionality and costs or resource allocation as defined in chapter 2.1. It starts with the identification of the product's components and the functions served by these components. The values and the costs of these components and functions are compared to identify potentials for improvement. This can result in a new product development process or an adaption process of the existing product [Cooper and Slagmulder 1997], [Ehrlenspiel et al. 2007], [Ibusuki and Kaminski 2007].

The IVE approach combines structural system modeling and cost management. Structural system modeling uses matrices or graphs to represent the structure of a system by modeling system elements and their relations. The elements are grouped in domains, which are superordinate classes. Three types of matrices are differentiated: A Design Structure Matrix (DSM) maps the relationships between elements of one single domain, whereas a Domain Mapping Matrix (DMM) describes the relationships between the elements of two domains. A Multiple Domain Matrix (MDM) structures several domains and their subsets which are DSMs or DMMs (for more information on structural system modeling we refer to [Lindemann et al. 2009] and [Eppinger and Browning 2012]). IVE uses a MDM, which includes the domains “Requirements”, “Functions” and “Components” to display the main artifacts of engineering design from the customer input on requirements to final concepts and defined components [Pahl et al. 2007], [Ponn and Lindemann 2011].

Comparable with VE, current cost values are added in the IVE approach to the elements of the domain “Components” to display the product's current costs for the company. Target cost values, which are deduced by subtracting a profit margin from the future product value on the market, the product's price, are added to the domains “Requirements” or “Functions”. The two DMMs “Component fulfills Function” and “Function realizes Requirement” are then weighted and used to calculate the missing target and current cost values for all three domains. Therewith, equal to VE, a comparison of target costs and current costs is possible to find potential components for optimization. Additionally, IVE allows the identification of potentials in the domains “Functions” and “Requirements”, which is the main advantage in comparison to classical approaches. Identified potentials in the domain “Functions” allow, especially for the optimization of new products, for independence in the implementation of potentials and more creativity. Potentials in the “Requirements”-domain give a hint for a discrepancy between customer expectations and technical specifications of the analyzed system. Additionally, the DMMs allow to compare the potentials in the different domains to analyze cause and effect of cost deviations [Maisenbacher et al. 2013], [Behncke et al. 2014].

To conclude, the deduction of potentials for value optimization in the IVE approach is performed on different product domains, which allows for further freedom and higher reduction potentials. The domains requirements and functions imply a solution independent representation of the product and correspond to the early stages of product development. Concepts and specific components are decided later in the engineering design process and represent the final product. The IVE approach enables the identification of value potentials on all three domains and therewith meets the challenges mentioned in chapter 2.1. However, the approach still lacks specific support to implement these potentials. The main objective for this publication is to develop a systematically support for IVE to allow for an implementation of value potentials. Prerequisite is to facilitate early and late development stages as well as both dimensions of value.

## 3. Potentials in the two dimensions of value

After modelling a product or system in the IVE model potentials between target and current costs of each element (e.g. different requirements, functions and components of the product) are deduced. These potentials can be illustrated in two different types of charts for easier prioritization of the most promising elements for value optimization. The first diagram, we call it cost deviation diagram, compares directly each elements target costs with its current costs. The formula is the relative part-cost deviation, as the target-current cost deviation of each part of the system is analyzed. These values can be directly taken from the IVE model. A pareto analysis can be used to prioritize the elements in the diagram. The second diagram compares the share of each element on the overall costs and the overall customer benefit or functionality of the product. It is referred as value control chart in literature (see [Glaser 2002] or [Coenenberg et al. 2012] for more information) and the formula as value index [Horvath 1993]. Both diagrams are illustrated in Figure 2.

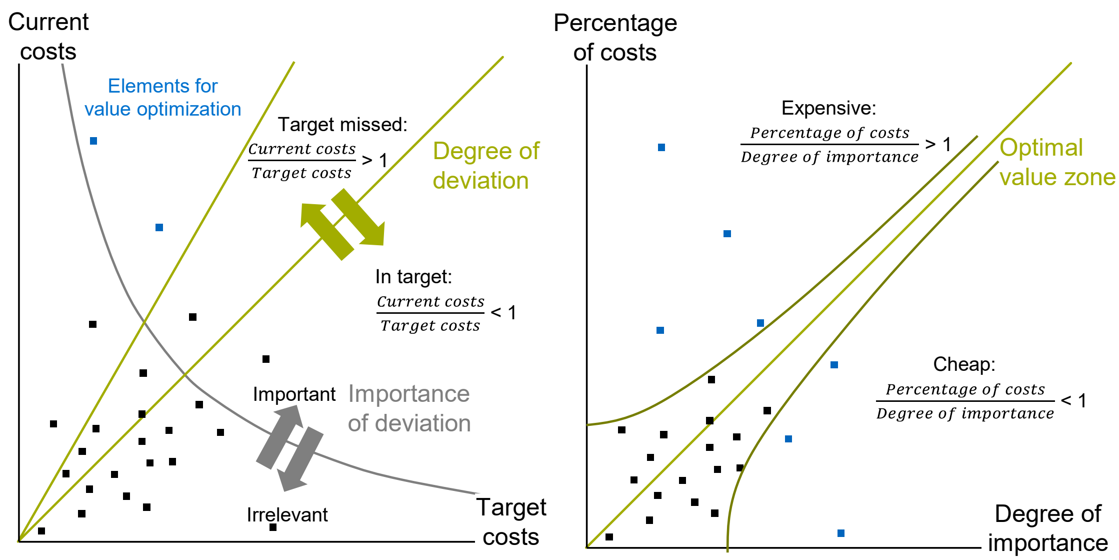


**Figure 2. Cost deviation diagram (left) and value control chart (right)**

Assuming that the overall target costs of the product correspond to the customer benefit of the product and the overall costs are the same in the diagrams, both can be transferred into each other. However, the value control chart focusses on functionality whereas the relative part-cost deviation shows elements missing their cost target. Therefore we suggest to use both for the assessment of the value potentials. Within each diagram the elements are allocated to three different areas: In the cost deviation diagram the relative part-cost deviation can be >1 (target missed), ≈1 (in target) and <1 (in target). The value index in the value control chart can be: >1 (expensive), ≈1 (optimal) and <1 (cheap). Therewith the different system elements in the diagrams can be allocated to one of nine possibilities, which result in six suggestions for further measures (compare to Figure 3).

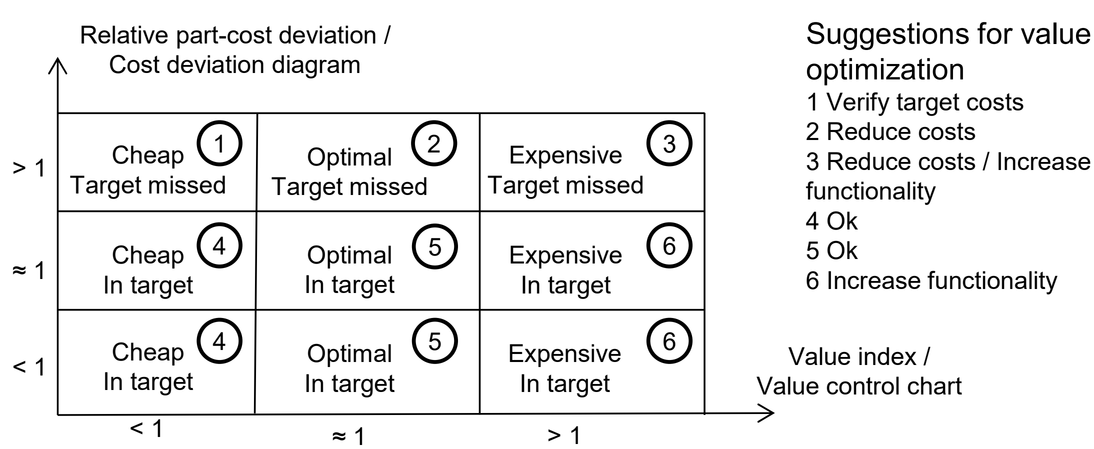


**Figure 3. Issues of cost deviations in both diagrams and suggestions for value optimization**

The comparison has to be done for all three domains. However, components are carrying the product's costs as they represent the final concept and design of the product. Different concepts and designs bear different costs, so cost reductions are only possible on this domain. Requirements represent what a product must be able to do, whereas functions represent its functionality. Both domains represent the customer benefit and should be focused for increasing the functionality of the product.
Challenges occur when a component is allocated in the value control chart for a functionality increase or a function, respectively requirement, for a cost reduction. These potentials can't be implemented directly. A structural analysis in the IVE model has to be performed and might reveal further opportunities. Potentials of one domain can be compared with potentials on other domains by following the relationships in the DMMs [Maisenbacher et al. 2015].
Chapter 2 has briefly explained how value potentials can be identified with the IVE approach. This chapter has shown how these value potentials can be evaluated and when a functionality increase or a cost reduction is most promising (compare to Figure 3). The following chapters will now explain how to implement these evaluated potentials.

## 4. Implementation potentials for the compensation of deviations in functionality

In this chapter implementation potentials (requirement and function domain) for compensation of deviations in utility are determined. First we used literature from engineering design to find out which activities with requirements and functions are theoretically possible. We decided for Ponn and Ulrich and Eppinger [2003], Pahl and Beitz [2007], Lindemann [2009], Lindemann [2011] and Engeln [2011], as all use the terms functions and requirements. These books were analyzed and every passage in the text which represents an activity with a requirement or function is marked and written down as a verb in a list.
After the text analysis was completed, the created list includes 135 terms of activities with requirements and 104 terms of activities with functions. Because many of these activities follow the same meaning, cluster with synonymous terms are built. They are labelled by the one activity which represents the basic statement of the cluster best. Altogether this results in 17 activities with requirements and 15 activities with functions. To avoid misinterpretation, a short definition is added for each activity (not shown here).

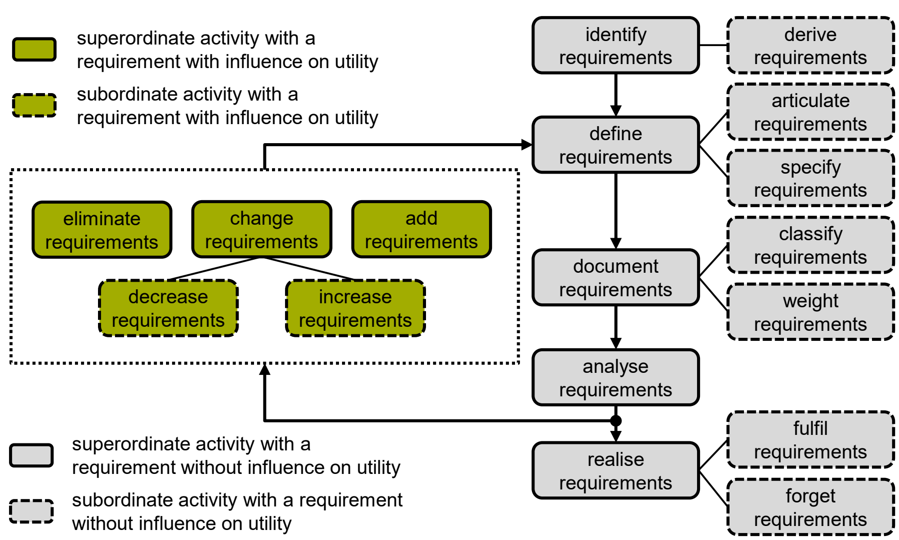


**Figure 4. Measures for the implementation of functionality deviations (requirements domain)**

By looking at the definitions formulated before, two abstraction levels become apparent, that means individual activities can be seen as smaller parts from others. This allows for a differentiation between superordinate and subordinate activities and to give a time logical sequence (illustrated for the requirements domain in Figure 4). A comparison between activities for requirements and functions showed that both became almost identical. The sequence starts by identifying the requirements or functions. Afterwards they are defined and documented. Once requirements or functions were analyzed, either existing ones can be eliminated or new ones can be added. Another possibility is to change requirements or functions. A change of a requirement can take place in two possible ways which is on the one hand a decrease and on the other hand an increase in utility. Functions behave equally, they can be reduced or improved. Eliminating, adding and changing are those activities having an assumed influence on the utility of the product and are consequently implementation potentials for the compensation of deviations in utility. If these activities are executed, the affected requirements or functions have to be defined and documented all over again. This circulation runs as long as the new defined requirements or functions are able to satisfy the customer needs sufficiently and unacceptable deviations in utility exist no more. Only then requirements and functions are realized by the development of new concepts.

## 5. Implementation of cost reduction potentials

In this chapter implementation potentials on the components domain for the compensation of deviations in costs are determined and structured. At the beginning a comprehensive literature research in various areas is done to find a huge number of resources which deal with the topic cost reductions and provide different possibilities to reduce costs. For this purpose primarily literature in the field of product development, cost management and purchase is used but also some out of cross-cutting disciplines. These resources are presented in the following section.

Schmidt [1996] presents suitable activities assigned to different functions which led to a cost reduction in various companies during a value analysis. Comprehensive information about activities for cost reduction is given in Ehrlenspiel et al. [2014]. Therein a huge amount of practical approaches is provided which are assigned to the different cost categories by doing a differentiated cost calculation or activities are mentioned to reduce variants and rules for a low-priced construction in terms of material and assembly. Klein [2010a] refers to several approaches which show a direct or indirect influence on cost categories. Becker [2008] introduces principal solutions for improving processes in production and supply chain. Strategy-oriented und procurement-driven actions for cost reduction are the content in Heiß [2004]. Kremin-Buch [2004] lists some activities for cost reduction which are made in the context of a cost level, trend and structure optimization. Lingohr and Kruschel [2011] dare to create a compilation with activities for different functions. In Kramer and Kramer [1997] several approaches for cost reduction in combination with successful cost management actions are mentioned. A checklist for low-priced constructions is found in Bode [1996]. In the field of purchasing Schuh and Bremicker [2005] provide cost levers in the sourcing and purchasing field. Krampf [2012] shows activities for increasing the pressure in competition to reduce the product costs. Additional Melzer-Ridinger [2008] suggests instruments to reduce acquisition costs. Fresner et al. [2009] is dealing with strategies of cleaner production. A compilation of constructive rules for economical assembly is given in Klein [2010b]. Furthermore Bode [1996], Pahl and Beitz [2007] and Ehrlenspiel et al. [2014] list a huge amount of design guidelines and design rules for design for production and other design for X rules, which indirectly influence product costs.

After a list with several hundreds of activities for cost reduction is generated, only those who are most promising in terms of the IVE approach are further considered. Therefore an assessment for all activities is done by three criteria. The first criterion ensures that only those activities are considered which have a direct influence to costs of the product. This means not necessarily direct costs but costs which are close to the product itself such as material costs, labor costs, personal costs and capital costs. Activities which have an influence in room costs, external labor costs or calculative costs are dropped out. The second criterion guarantees that only activities which are formulated in a neutral way are included, i.e. not a general or rather not a detailed formulation. At last the third criterion ensures that only activities are considered which can be applied in the design phase. As a result approximately 300 promising activities are chosen.

In the next step the activities are grouped to implementation potentials to reduce overlapping. For this purpose activities for cost reduction which are literally identical (double naming), differently formulated (with regards to content the same meaning) or very similar (differentiation not appropriate) are sorted. Some activities can be assigned to more than one group. An appropriate definition is formulated for each group. This results in 88 groups, which can be seen as potential implementation potentials. The groups are now classified into clusters by a cluster analysis. Thereby groups with similar characteristics are clustered among a superordinate class. This resulted in the nine categories production, material, quality, complexity, purchase, disposal of material, strategy, assembly and design. Finally, the categories are split up in classes for better arrangement and applicability. Exemplarily the category material is split in the classes change semi-finished products, change type of material, change quantity of material and reduce material waste. In combination with adding some implementation potentials out of individual experience the number of possibilities to reduce costs increased to 88 activities for cost reduction in 24 classes and 9 categories (see Figure 5).

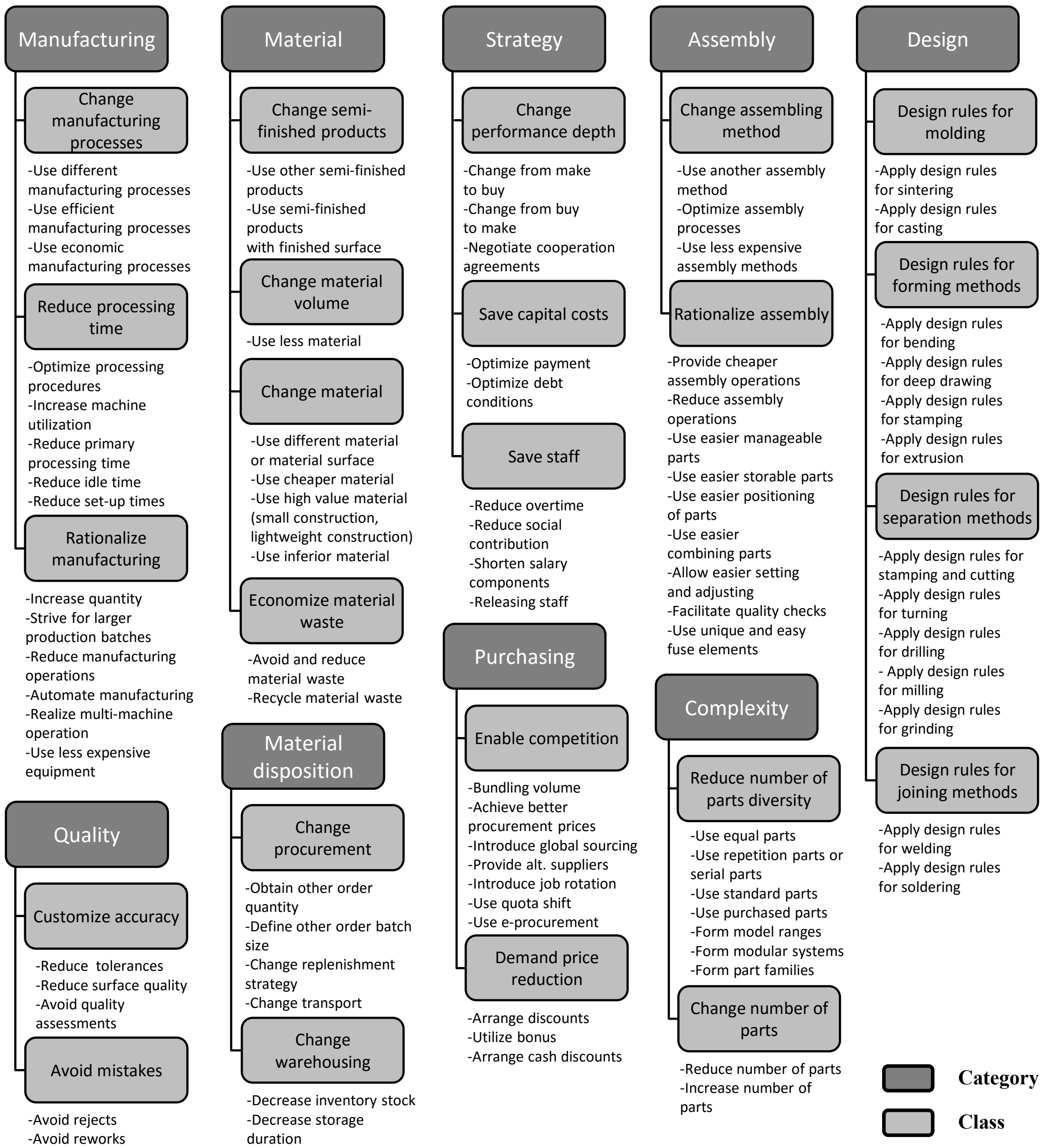


**Figure 5. Measures for the implementation of cost reduction (components domain)**

## 6. Applicability of the implementation of value optimization potentials

The previous chapters briefly introduced the IVE approach (chapter 2.2), possibilities and suggestions for the implementation of value optimization potentials within this approach (chapter 3) and concrete measures to implement these potentials (chapter 4 and 5). The applicability is now shown in the following use case.

The use case for this work is the IVE model of a hairdryer. The reason for this selection is that a hairdryer is a relatively simple product. The information for the IVE model was acquired by using reverse engineering, which means to systematically decompose a product in its merest parts. For the creation of an IVE model the component domain as well as requirements and functions have to be considered. The elements of the components domain could be easily set by decomposing the physical hairdryer in its smallest elements. Functions have been modelled in using different types of functional models. A final hierarchical functional model was deduced in discussions with several engineering students and engineers. This hierarchical model allowed a proper selection of functions for the IVE model. The requirements have been deduced from the data sheet of the hairdryer and revised in several experiments and discussions. Finally, 21 requirements, 24 functions and 38 components have been selected. The current cost values of the components have been determined by searching similar components in spare parts catalogues and in the internet. If no similar components were found the current cost values have been estimated by consideration of the manufacturing effort for this component. Economics of scale have been discussed and also estimated. For target cost values a fixed cost reduction percentage has been considered. The two matrixes (one illustrated in Figure 6) to calculate the missing cost values have again been modelled by several engineering students and discussed with students and engineers (compare to [Maisenbacher et al. 2015]).

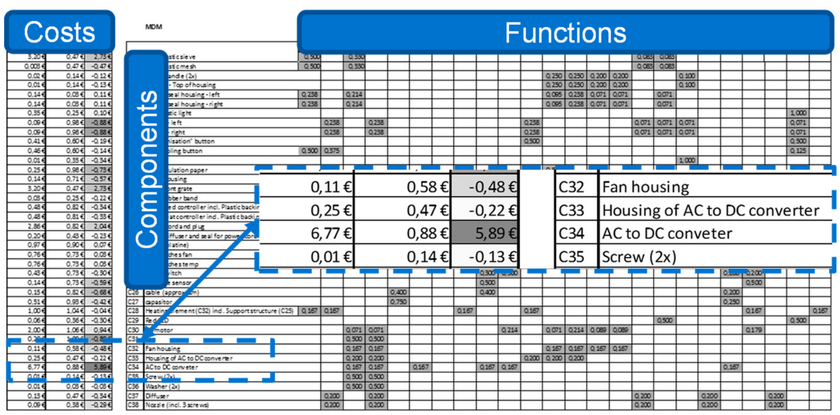


**Figure 6. Part of the IVE model of the hair dryer use case (DMM component fulfils function)**

| | | Relative part-cost deviation | Value index | Number | Suggestions for value optimization |
|---|---|---|---|---|---|
| C1 | Rear plastic sieve | Target missed | Optimal | 2 | Reduce costs |
| C15 | Black front grate | Target missed | Optimal | 2 | Reduce costs |
| C19 | Power cord and plug | Target missed | Optimal | 2 | Reduce costs |
| C34 | AC to DC conveter | Target missed | Expensive | 3 | Reduce costs / Increase functionality |

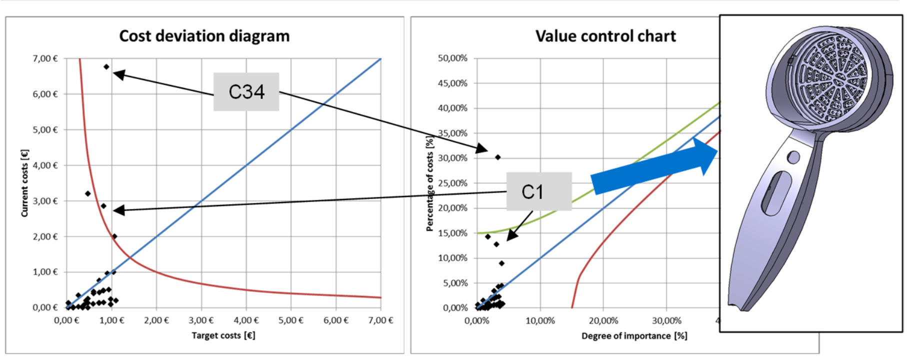


**Figure 7. Cost deviation diagram (left) and value control chart (right) of the components domain as well as new design of the component C1 and others**

Figure 6 (and Figure 7) exemplarily revealed that the component "C34 AC to DC converter" has target costs of 0,88€ and current costs of 6,77€. It offers high potential for value optimization. Figure 7 shows the four most potential components, the cost deviation diagram and the value control chart of all components, as well as the suggested measures. The component "C34 AC to DC converter" was a purchasing part. Among others, measures from Figure 5 in the category purchasing are suggested for cost reduction. Exemplarily an alternative supplier might deliver the component for a cheaper price. For this work this measure hasn't been followed as now contact to suppliers was not available.
The component "C1 rear plastic sieve" was also one of the components with high value optimization potential. It is an inhouse part and a wide range of measures from Figure 5 seem to be promising. As a functionality increase was also suggested (in addition to the cost reduction), a closer look on the functions of this component was taken by looking at the DMM "Component fulfils Function" (compare to Figure 6). "C1 rear plastic sieve" was connected to the functions "F3 accelerate air" and "F4 regulate air flow", which both are also suggested for cost reduction. It was decided to focus on the functions to have a higher impact for cost reduction, as they are solution neutral. A new concept was developed and some other components fulfilling these functions ("C1 rear plastic sieve", "C2 rear plastic mesh", "C5 rubber seal housing - left", "C6 rubber seal housing - right", "C8 handle - left" and "C9 handle - right") have been integrated in two components. The cost reduction measure is equivalent to Figure 5, category complexity, class change number of parts, reduce number of parts or Figure 4 change function with the additional steps to ensure that changed components are analyze and the function is finally realized in two new components (drawing in Figure 7, right).

## 7. Conclusion and outlook

This work discusses two major challenges in cost management: The challenge of implementing value optimization in early conceptual stages of engineering design and the challenge of either increasing functionality or reducing costs to achieve the desired product value. The IVE approach, which combines ideas of TC and VE in a structural model, was selected as promising approach for these challenges as all development stages from requirements to concrete components are included in the model. The cost deviation diagram and the value control chart are discussed as potential support for the decision on either increasing functionality or reducing costs. A further result is the assumption that cost reductions take place on the components domain and functionality increases focus on the requirements and functions domain. Therefore measures are systematically deduced from literature to support both dimensions of value optimization within the IVE approach. Especially the collection of measures for cost reduction and there classification can be basically applied for cost reduction initiatives. Finally, the results are briefly applied on an exemplarily use case of a hair dryer system to show the applicability of the diagrams and measures within the IVE approach.
Main limitation of this work is the evaluation. As it is only an application evaluation (compare to [Blessing and Chakrabarti 2009]) the monetary success of the measures hasn't been proven right now. Therefore, we will focus on an industrial case study for future research to allow for a calculation of the monetary impact of the suggest measures. Additionally, we suggest to further investigate the possibilities of functionality increase as a way to optimize a product's value as this dimension is only briefly described in this work and other literature. We assume that this dimension of value optimization has higher monetary impact than cost reductions.

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Sebastian Maisenbacher, Dipl.-Ing.
Technical University of Munich, Institute of Product Development
Boltzmannstraße 15, 85748 Garching, Germany
Email: maisenbacher@pe.mw.tum.de