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COST BASED DESIGN OF MODULAR PRODUCT FAMILIES USING THE EXAMPLE OF TEST RIGS

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Abstract

Companies with a wide range of variety on the markets have to reduce their internal variety for reducing their costs. This can be reached through modular product families, where more than one concept is possible. A decision making based on costs is missing for the choice of the developed concepts. In this Paper an approach for developing modular product structure concepts based on cost is presented. Based on literature review the Integrated PKT-Approach for developing modular product families is adapted for analyze cost, process and product structure for developing and cost prognosis of concepts and modified tools for analyzing cost are explained. This approach is used in a case study for an industry company where three cost-efficient variety optimized concepts were developed. The approach is helpful for developing cost-reduced concepts based on cost analyses and gives a cost prognosis for rating the concepts.

Keywords: Case study, Product families, Decision making, Design costing

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1 INTRODUCTION

Globalization and individual customer demand force companies to offer a wide variety of products on the market. This high external variety leads to high internal variety, accompanied by high costs for the company. One possible way to cope with this challenge is to use modular product structures, as they offer high external variety with low internal variety. Due to the gradual property of modularity, more than one modular product structure concept is possible; it is necessary to include the resulting cost of the alternative concepts to support decision making. Several approaches to developing modular product structures exist, but none sufficiently support the decision-making process based on cost.

The Integrated PKT-Approach for developing modular product structures aims to keep external variety constant while reducing internal variety and complexity costs. Three of its method units are designed for this purpose: Design for Variety, Life Phases Modularization, and Complexity Cost Management. The successful application of this approach has previously been demonstrated through the development of alternative modular product structure concepts and the resulting prediction of complexity costs (Ripperda and Krause, 2015; 2016).

The aim of this paper is to present an approach based on the three named method units of the Integrated PKT-Approach to developing alternative modular product family structure concepts along with a cost analysis and prognosis. The concept design is based on the resulting cost. The approach is applied to a case study on a product family of test rigs made by a production company that has high external variety and high material costs.

The paper starts by introducing methods for developing modular product families, focusing on the Integrated PKT-Approach. The following section explains the proposed approach to developing modular product families, which considers cost during the design phase. The fourth section presents the application of the approach to the product family of test rigs, before a conclusion finalizes the paper.

2 METHODS FOR DEVELOPING MODULAR PRODUCT FAMILIES

Several methods for developing modular product families are presented in the literature (Krause and Ripperda, 2013; Krause et al. 2014). These methods can be divided into two types of strategies: technical-functional modularization, and product strategy modularization. For example, design structure matrices (Pimmler and Eppinger, 1994) and structural complexity management MDM (Lindemann et al., 2009) are based on modularization by technical-functional relations. Modular Function Deployment (Erixon, 1998) is an example of modularization by strategic aspects.

With these methods, more than one modular product structure concept can be developed. But none of these sufficiently support the decision making process based on cost (Krause and Ripperda, 2013).

One method for developing modular product families according to cost is the Integrated PKT-approach. The main approach and three select combinable method units are described in detail in the following.

2.1 Integrated PKT-Approach for Developing Modular Product Families

The Integrated PKT-Approach for developing modular product families was developed at the Institute of Product Development and Mechanical Engineering Design (PKT) at the Hamburg University of Technology and is still being built on (Krause et al., 2014). It combines technical-functional and product strategic modularizations, and includes several methods units for reducing internal variety (Figure 1).

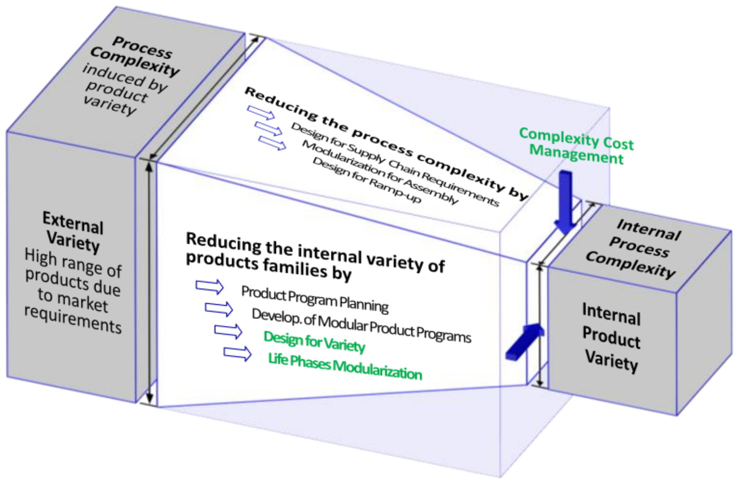


Figure 1. Integrated PKT-Approach for developing modular product families (Ripperda and Krause, 2014)

Several tools were developed to visualize variety to support the methods. The Modular Interface Graph (MIG) shows all components of a product family as its rough shape, position and variety. The flows between the components are also shown, e.g. structural, electrical and media (Blees et al., 2010). The Product family functional structure (PFS) shows the variant and optional functions. This paper focuses on the effective combination of and interfaces within the method units Design for Variety, Life Phases Modularization, and Complexity Cost Management of the Integrated PKT-Approach.

2.1.1 Design for Variety

Design for Variety brings a product family closer to the ideal of a variety-oriented product structure. The first step is to analyze the existing external variety of a product family using the Tree of External Variety (TEV). It includes variant product properties relevant to customers and the offered product variants. Internal variety can be analyzed using the product family functional structure (PFS) and the MIG for the variety of components and connecting flows. The variety allocation model (VAM) includes this information in a form that shows the connections between the differentiating properties, functions, working principles and components. In the VAM, all variety problems are identified and solutions are found for an optimized variety product family, which can result in a new product structure (Krause et al., 2014; Blees et al., 2010).

2.1.2 Life Phases Modularization

Based on the variety optimized product structure of Design for Variety, Life Phases Modularization develops a harmonized modular product structure for all relevant life phases. Therefore, a technical-functional modularization based on for example a DSM is developed, in addition to product strategic modularizations for all relevant product life phases based on module drivers in network diagrams. In the Module Process Chart (MPC), the different modularizations are combined and harmonized to develop alternative concepts that fit the needs of all life phases (Krause et al., 2014; Blees et al., 2010).

2.1.3 Complexity cost management

With the method unit Complexity Cost Management, cost prognosis, cost assessment and cost reduction are included in the Integrated PKT-Approach. The approach predicts the cost of developing alternative product family structure concepts based on the Time Driven Activity Based Costing (TD-ABC) (Kaplan and Anderson, 2007) approach and combining relevant changes per concept. It starts with the acquisition of product, process and cost structure, and the estimation of cost driver processes. The changes for each concept are then detected as a basis for cost prognosis. To evaluate the concepts, a semi-quantitative assessment of product structure concepts is performed to include qualitative aspects in concept selection. For further cost reduction, measures are defined in the last step based on the analyzed cost intensive components and processes. As a result, a cost supported product structure decision can be made (Ripperda and Krause 2014, 2015, 2016).

3 APPROACH FOR DEVELOPING MODULAR PRODUCT FAMILIES THAT CONSIDERS COST DURING THE DESIGN PHASE

This section introduces the approach for developing modular product structure concepts that consider cost during the design phase. It is based on the method units Design for Variety, Life Phases Modularization, and Complexity Cost Management of the Integrated PKT-Approach. The main steps of the approach and how they interact are shown in Figure 2.

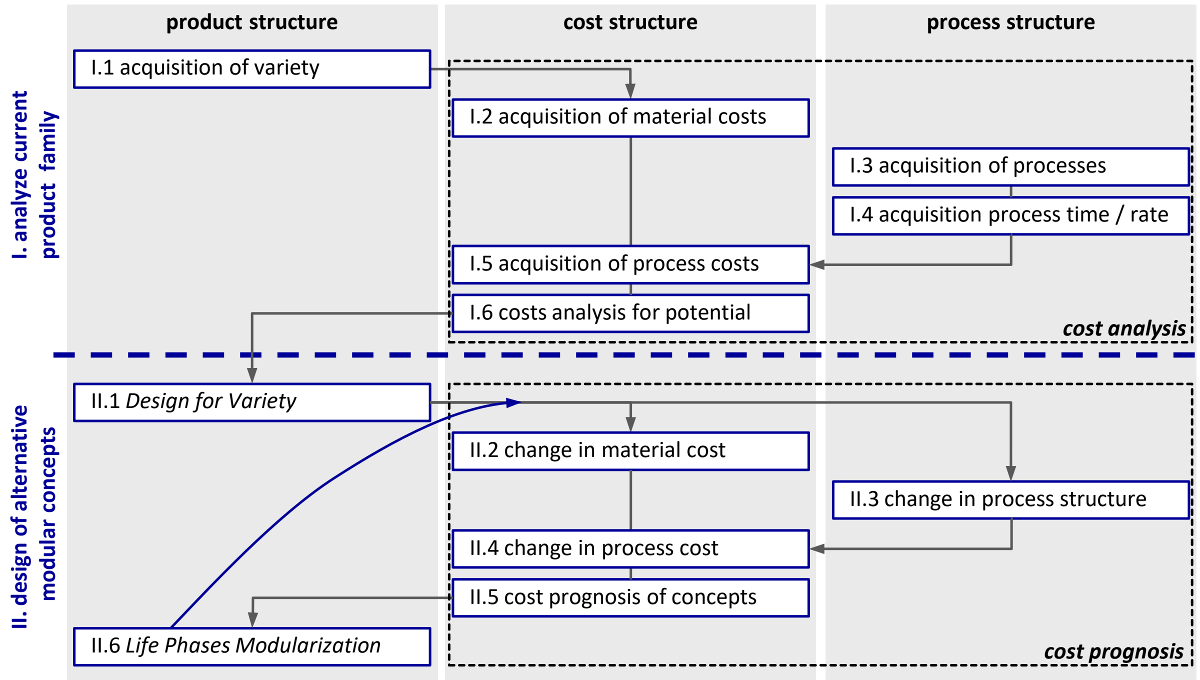


Figure 2. Main steps of the approach for developing modular product families, considering cost during the design phase

The main steps are divided into product structure, cost structure, and process structure. The upper half of the figure shows the analysis of product process and cost structure of an existing product family. The lower half shows the development and cost prognosis of Design for Variety and modular concepts. Tools for analyses and visualization are assigned to some of these steps.

3.1 Analysis of existing product family

The first step (I.1) of the approach is analyzing external and internal variety using the tools TEV, MIG, PFS from the Integrated PKT-Approach. These tools are used to compile the Variety Allocation Model (VAM). Costs are divided into material and process costs to determine the cost structure of the current state. Step I.2 is the acquisition of material cost taken from purchase. The process structure has to be determined in step I.3 to acquire process costs. Next, the acquisition of process time and hourly pay rates for employees follows. This is necessary when estimating cost with the TD-ABC. Therefore, in step I.5, process time multiplied by the hourly cost rate of each process equals the process cost. The sixth step is cost analysis and the deviation of potential. To analyze material cost, the variety components are combined with the material cost. A product structure list is used to list all components, as well as their type, cost and how often they are used in the product variants of the product family. This results in the relative share of cost of standard, variant and optional components. Additionally, visualization is used that shows the relative cost percentage as a heat map in the MIG. To analyze the process cost, the processes were combined with the process cost. A process structure list is used to list all processes, their hourly cost rate, and the duration of each process per product variant. The sector that has the highest percentage of process cost can be identified. A flow chart is used to visualize the process cost. With these results, the costs are analyzed and the potential cost reduction can be identified. Thus, acquisition and analysis of the existing product family is complete.

3.2 Design of alternative product family structure concepts

In the development of variety optimized product family concepts, step II.1 is Design for Variety. In addition to the proposed method in the Integrated PKT-Approach, Design for Variety is based on the VAM and identified problems, as well as on the analyzed cost saving potential (from step I.6), the developed visualizations of product and process structures, combined with the current cost structure. In this context, the cost saving potential means the costs that can be reduced through a modular product structure concept.

The developed variety optimized concepts and how they result in changes in product and process structures are analyzed in the following steps. In step II.2, the change in product structure and the resultant change in material costs are estimated. The changes in process structure are estimated in step II.3 for the estimation of change in process cost (step II.4). In step II.5, a cost prognosis of the concepts supports decisions around which concepts to select for modularization. The cost saving potential of the modular product family is estimated using the cost prognosis.

The concepts of Design for Variety and their cost saving potential are used to compile network plans and MPC in step II.6. The coordination of MPC is carried out to develop modular product structure concepts. The identified cost saving potential is also used. Modular product structure concepts are developed. These concepts are also analyzed for how much of a change in material costs has been achieved as well as a change in process structure. The change in process structure is estimated. Finally, a cost prognosis for the modular product concepts is realized with the change in material and process costs. A cost evaluation is carried out at this step and forms the basis for the selection of a modular product family structure concept.

4 COST-BASED CONCEPT DESIGN OF A TEST RIG PRODUCT FAMILY

In this section the introduced approach is applied to the test rig product family of a production company. Due to confidentiality, the values and results shown have been modified. The approach follows the main steps shown in Figure 2.

4.1 Analysis of the existing test rig product family

17 different test rigs produced in the last three years are analyzed with the Tree of External Variety (TEV). Ten variant product properties relevant to the customer and 26 options are identified. Details of the TEV, MIG and VAM are shown in Figure 3.

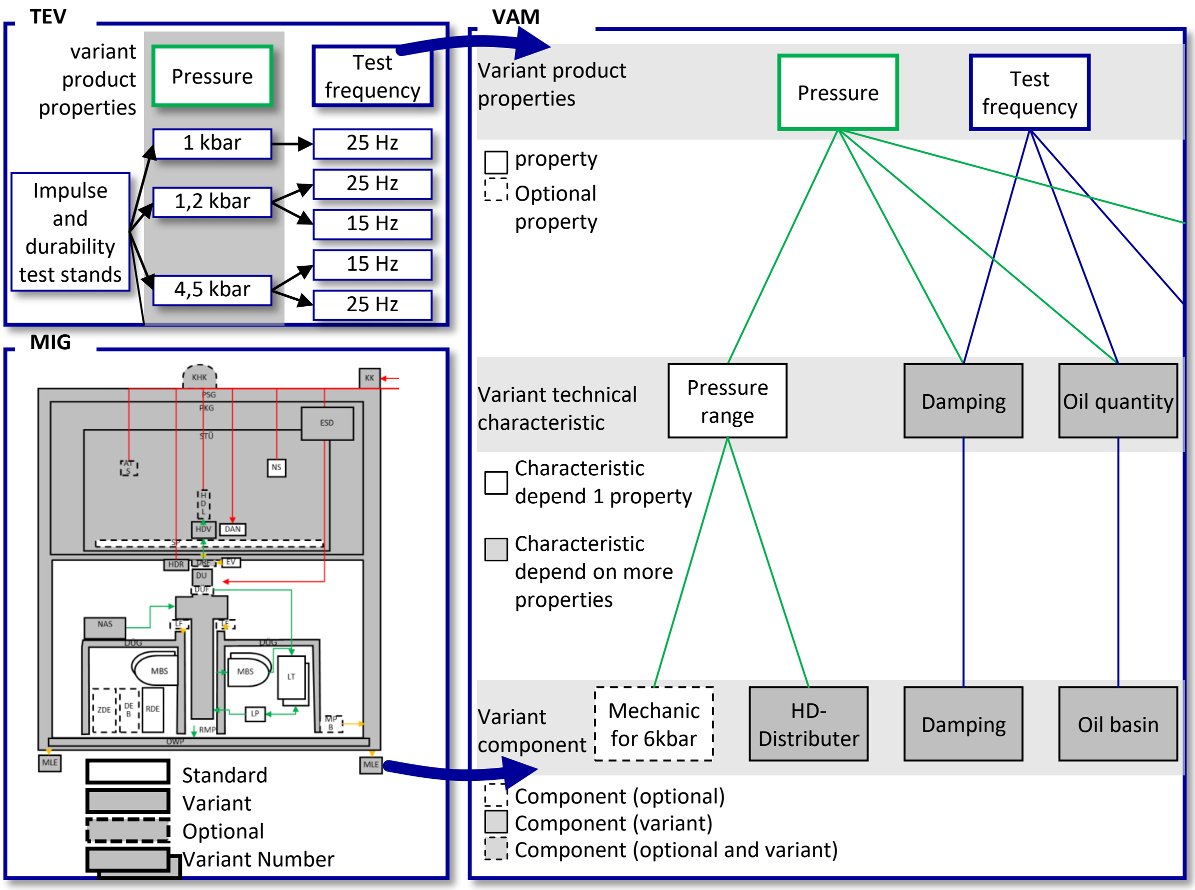


Figure 3. Details of tools used to analyze the current variety of the product family of test rigs

At the top left of Figure 3 there is a detail of TEV pictured with the important variant product properties and their characteristics. On the left, a detail of the MIG is shown, with a cut through the test stand to show the important variant components. On the right of Figure 3 is a detail of the VAM. The variant properties are combined with the variant characteristics and the variant components. The product structure is not ideal, though most options are. The material and process costs are collected in steps I.2 to I.5. An excerpt of the product structure list for two product variants is shown in Figure 4.

Name of component	Component type	Variant	Material costs	Product variant 6 kbar	Product variant 4 kbar	Quantity	Material costs per component
basin hydraulic unit	variant	variant 1	1,351 €	1		2	2,702 €
	variant	variant 2	1,575 €		1	2	3,150 €
hydraulic support components for 4 kbar	optional		119 €	1		2	238 €
mechanic support components	standard		2,212 €	1	1	4	8,848 €
air spring	variant	variant 1	1,904 €	1		3	5,712 €
	variant	variant 2	1,806 €		1	3	5,418 €
weld flange	variant number		39 €	1	5	8	312 €
link	optional		15 €		4	12	185 €
						material costs	
			material costs per product variant	156,051 €	93,450 €	of product family	635,992 €
			material costs of standard components	14,112 €	14,112 €		65,702 €
			material costs of optional components	17,150 €	5,285 €		57,365 €
			material costs of components variant numbers	14,119 €	8,673 €		66,725 €
			material costs of variant components	110,340 €	65,380 €		445,886 €

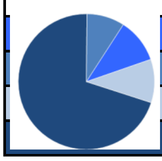


Figure 4. Excerpt of product structure list details for two product variants

The product structure list is used to analyze material costs. Summarizing all costs per component type, it becomes clear that variant components form the highest percentage of material costs. Optional, standard and variant number components only make up a small percentage of material costs. The analyzed material costs from the product structure list are included in the MIG following heat maps. The red components are the components with the highest percentage of material costs, at more than 30%. The blue components are the components with the smallest percentage, at less than 10% of material costs. In between there is a interpolation with components that constitute 10-20% of material costs are coloured yellow; components that contribute 20-30% of material costs are coloured orange. The percentage of the material costs of the variant components are a range.
The MIG combined with material costs for test stands are shown in Figure 5.

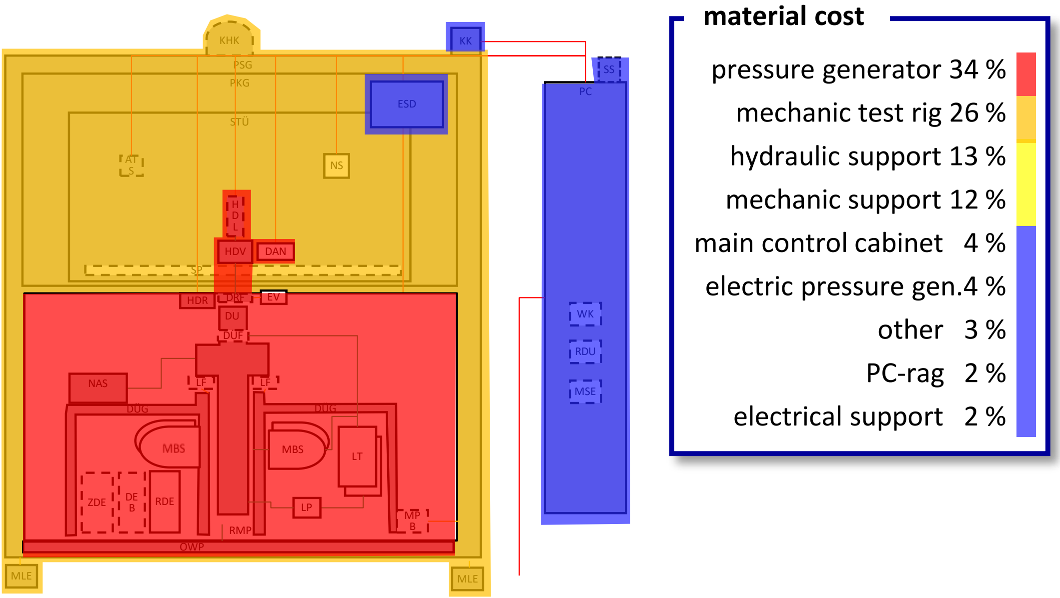


Figure 5. Material costs in the MIG of the test rig product family

The component pressure generator, placed on the base of the test stand, is the most expensive component at 34% of material costs. The second most expensive component is the mechanic test rig, coloured orange. Both hydraulic components are coloured yellow because they make up 12 and 13% of material costs. The remaining components are only a small percentage of material costs.
The process flow combined with process cost is used to analyze the process cost (Figure 6).

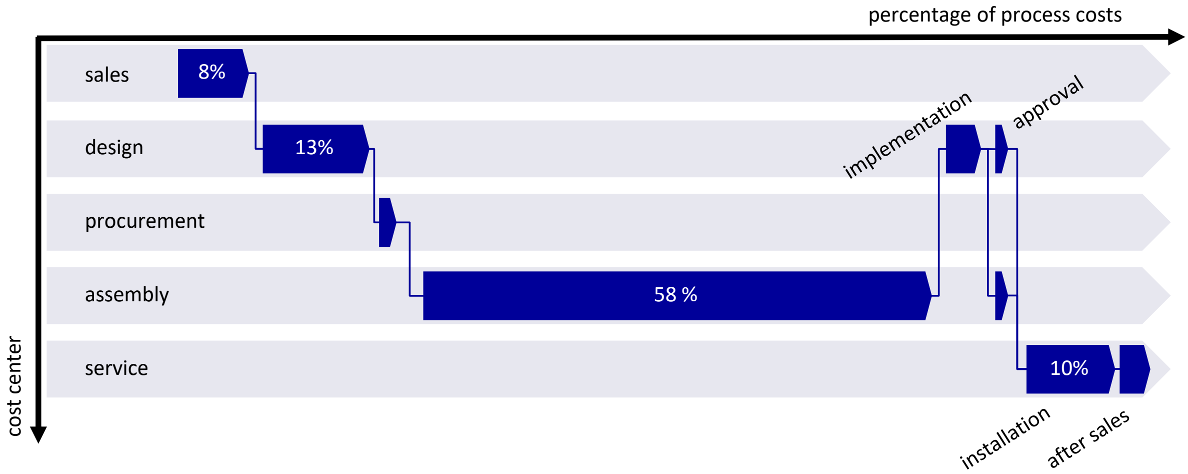


Figure 6. Combining process and process costs of test rig product family

The process sequence is visualized. The percentages of the process costs are shown as bars. Assembly has the highest process cost. Design, installation and sales also make up a high percentage of the process cost. Procurement, implementing and approval form only a small percentage of the process costs.

The potential of Design for Variety and Modularization is determined with these tools. Some variety components form a high percentage of material costs, for example, the pressure generator. These components have higher potential for cost reduction than components that form a lower percentage of material costs. The component type (standard, variant or optional components) combined with their material costs are helpful when identifying potential. Cost savings with modular product structures can be achieved through higher quantities by scaling effects. The highest process cost is assembly; therefore, the most process cost savings, using modular product structure concepts during Life Phases Modularization, can be achieved by focusing on requirements of the assembly phase.

4.2 Design of alternative product family structure concepts for test rigs

On the basis of identified problems in the VAM and the identified cost potentials, Design for Variety concepts are developed in a workshop with company product experts. The workshop results in different concepts with components of varying commonality. The cost prognosis is carried out based on changes in the product and process structure. Due to the company strategy of implementing changes quickly, a concept was chosen that had no relevant process changes and a reduction in material costs of about 1% as the base product structure for modularization.

The processes design, assembly, sales and after sales make up the highest percentage of process costs therefore, their modularizations are considered and their network plans are developed with the company experts. The results are shown in Figure 7.

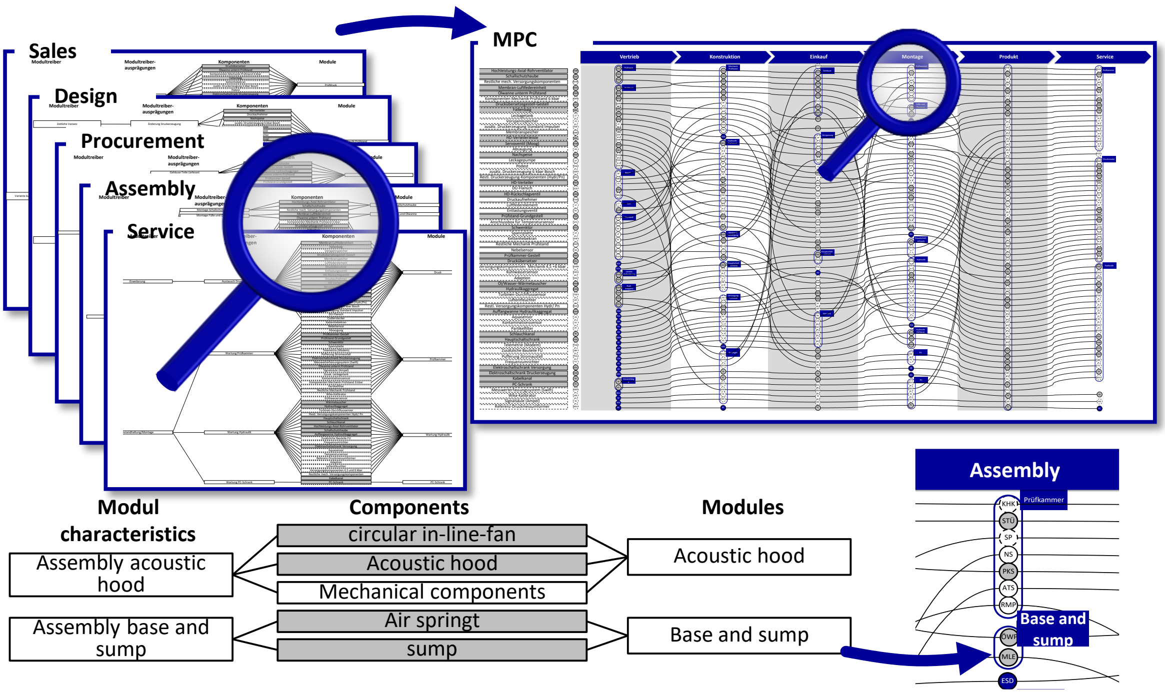
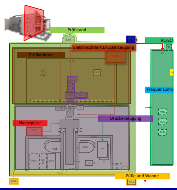
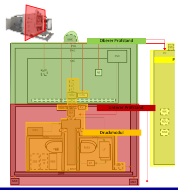
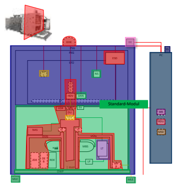


Figure 7. Life Phases Modularization tools for test rig product family

Modularizations are harmonized in a second workshop with company experts of all investigated processes. Three concepts are developed for cost reduction of the cost intensive processes through modularization. Concepts for sales, assembly and after sales are developed. A cost prognosis is carried out for these three concepts. First, the changes in process times are estimated by the experts for each concept. The changes in process cost are calculated using the changes in process times and the hourly cost rate. Changes in material costs are also estimated. The resulting changes in the cost structure per concept relative to the current state are shown in Table 1.

Table 1. Change in cost structure of the modular product structure concepts

life phase	concept assembly	concept service	concept sales
sales	100 %	100 %	95 %
design	100 %	100 %	100 %
procurement	95 %	100 %	100 %
hydraulic assembly	80 %	87 %	103 %
electric assembly	100 %	104 %	100 %
implementation	98 %	97 %	100 %
approval	93 %	95 %	100 %
installation	97 %	67 %	100 %
after sales	100 %	27 %	100 %
process cost	92 %	90 %	99 %
material cost	100 %	97 %	100 %
total cost	**98 %**	**95 %**	**100 %**

This table illustrates that all of the concepts developed reduce costs. The concept developed for reducing assembly cost effected the highest cost reduction for the assembly phase. In the same way, the concepts for service and sales reduce the cost for their life phases. In total, concept service is predicted to have the highest process cost reduction, as well as the highest material cost reduction and, with that, the highest total cost reduction.

Additional criteria are selected to evaluate the concepts from a qualitative perspective. Beside process and material costs, process time, transport, failure detection and upgradability are criteria. A spider chart is used to visualize the results (Figure 8).

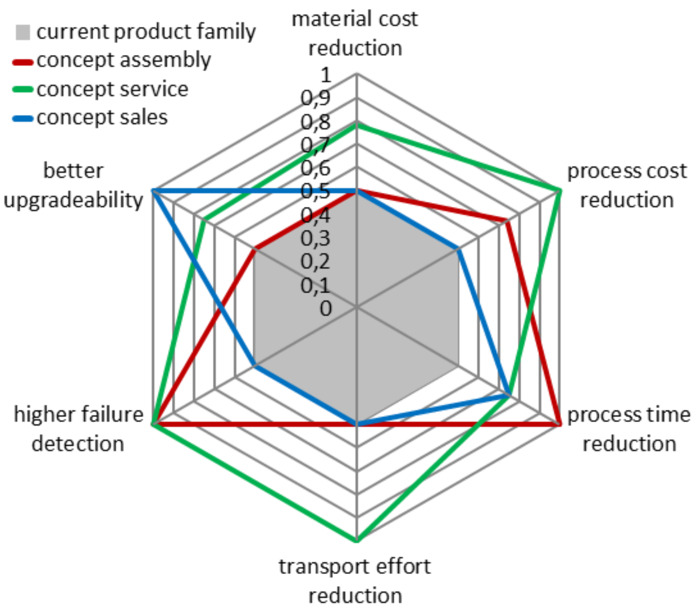


Figure 8. Spider chart of evaluated concepts

The current product family is shown in the middle of the spider chart. Relative to it, the concepts are rated for the 6 criteria. The concept 'service' best achieves the criteria 'transport effort reduction' and 'higher failure detection'. It is also good for reducing process and material costs. Concept 'assembly' is the best for reducing process time and has the highest failure detection. The concept 'sales' is the best for upgradability

5 CONCLUSION

The approach for developing modular product families that considers cost during the design phase supports the development and selection of cost-efficient product family structure concepts. This closes a gap in current design approaches. The analyzed cost of the current product family and the accompanying cost prognosis supports concept development.
The Integrated PKT-Approach and its method units Design for Variety, Life Phases Modularization, and Complexity Cost Management were presented. An approach for developing modular product structure concepts accompanies a cost analysis and was explained in detail using modified tools for analyzing material and process costs. How these tools support the development of Design for Variety and Life Phases Modularization concepts was demonstrated. The approach was used in a case study on an industry example. For the case study, three cost-efficient, variety-optimized modular product structure concepts were developed and rated.
Application to the case study shows that the introduced approach is helpful when developing cost reduction concepts based on cost analyses. Further research on including possible external variety adaptations and the resulting effects on company revenue would be beneficial.

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