Model-Based Assessment of Variety-Induced Cost of Complexity in Modular Product Families

Maximilian Ridder[1,*], Markus Christian Berschik[1], Dieter Krause[1]

[1] Institute of Product Development and Mechanical Engineering Design, Hamburg University of Technology

** Korrespondierender Autor:*
Maximilian Ridder
Technische Universität Hamburg (TUHH)
Institut für Produktentwicklung und Konstruktionstechnik
Denickestraße 17
21073 Hamburg
☎ *+49 151 188 36 126*
✉ *maximilian.ridder@tuhh.de*

Abstract

Managing variety-induced cost of complexity in modular product families is increasingly difficult due to rising data volumes and limited transparency in traditional cost models. This paper presents a model-based approach that uses a generic cost structure model to classify cost elements along the product lifecycle and map company-specific data systematically to it. The process involves data acquisition, transfer into a system model and lifecycle-wide analysis. By digitally integrating cost data into a model-based system, the approach supports the early identification of cost impacts in the development of modular product families.

Keywords

Cost Model, Cost of Complexity, Model-based Product Family Engineering, Data-Driven Engineering, Design Decision Support

---

| DOI: 10.35199/dfx2025.13

1. Motivation

Due to increasing customer and market demands on product development, additional effort is required in the structuring of product architectures. Manufacturing companies often respond to these changing conditions by introducing new product variants in order to better address the altered market environment [1]. As a result, the amount of data that must be managed throughout the entire product lifecycle increases significantly. A key parameter for evaluating product variants within product portfolios are the associated costs. However, given the growing complexity of available data, these costs are becoming increasingly difficult to track. While production costs can usually be determined with relative ease in manufacturing companies, variety-induced cost of complexity are often not captured at all - or only through labor-intensive manual processes [2].

2. Research Problem and Research Objective

The identification of variety-induced cost of complexity in the development of modular product families presents a particular challenge [3]. The literature offers numerous approaches for cost-based evaluation of modular product families. However, these approaches primarily focus on direct manufacturing costs when assessing product structures at the concept stage, whereas indirect costs arising in various phases of the product lifecycle are often aggregated as undifferentiated overheads. Existing cost structure models generally do not allow for a structured and detailed representation of these overhead costs [4], making it particularly difficult to identify and evaluate variety-induced cost of complexity in industrial practice.

Furthermore, extant calculations of cost of complexity are generally conducted manually in standard practice, an approach that is associated with a considerable expenditure of time and resources. This, in turn, complicates the decision-making process. The increasing digitalization of development processes - enabled, for example, by model-based approaches [5] - offers potential synergies to address this issue. This leads to the following research questions addressed in this contribution:

1. How can the identification and representation of variety-induced cost of complexity during the development of modular product families be supported efficiently?
    a. What generic cost elements exist within the product lifecycle, and how can they be classified?
    b. How can the identification and documentation of cost of complexity in the context of modular product families be supported digitally?

3. Research Background

The increasing product variety in industrial value creation systems poses growing challenges for manufacturing companies about the transparency and controllability of the resulting lifecycle costs. Against this backdrop, the following chapter elaborates on the state of the art concerning variety-induced cost of complexity, relevant cost models, and model-based approaches.

3.1. Cost of Complexity

The increasing diversity of products is a central trend in industrial value creation. Manufacturing companies respond to rising customer demands and global competitive pressure by offering more differentiated product portfolios [6]. This leads to increased internal variety within companies and results in additional organizational and operational effort [7]. The resulting variety-induced cost of complexity represents a significant and often insufficiently transparent cost category that can substantially impact the profitability of product families.

Cost of complexity typically refer to indirect costs that arise, for example, from increased setup times, additional coordination efforts, or redundant documentation [4, 8]. Variety-induced cost of complexity emerge throughout all lifecycle phases of a product and thus affect the entire value chain [9]. In contrast to direct costs, they are difficult to assign to individual product variants and are often not explicitly represented in conventional cost accounting systems. Consequently, strategic and design-related decisions may be made without adequate cost transparency regarding potential complexity-related implications.

Existing approaches for capturing cost of complexity predominantly support retrospective evaluation of alternative product family concepts [10]. However, there is currently a lack of methodological support for integrating cost of complexity during ongoing product development [11].

Since the majority of cost of complexity originate from decisions made in the early concept phase, it is essential to integrate these as a target variable into product generation development [12, 13].

3.2. Cost Models

Numerous cost models can be found in the literature, which differ significantly in terms of their defined cost elements and the level of detail in their cost structure. It becomes evident that a standardized cost structure model for classifying existing cost structures across different companies - particularly regarding the assessment of variety-induced cost of complexity - is currently lacking.

Against this background, existing cost models and their defined cost elements were analyzed within the framework of a structured literature review. The objective was to identify commonalities and to derive requirements for a generically applicable cost model that accounts for cost of complexity. To ensure a comprehensive perspective, the analysis is based on three central thematic areas: *Total Cost of Ownership* (TCO), *Cost Estimation Models* (CEM) and *Lifecycle Costing* (LCC). For each of these thematic areas, two representative search strings were developed, as shown in Table 1.

Table 1: Search strings used in the literature review according to PRISMA

Number	Thematic Area	String
String 1	TCO	("Total Cost of Ownership" OR TCO) AND (Model OR Framework OR Approach)
String 2	TCO	("Cost of Ownership" AND (Acquisition OR Operation OR Maintenance OR End-of-life)) AND (Model OR Framework OR Approach)
String 3	CEM	("Cost Estimation" OR "Cost Modelling") AND (Model OR Technique OR Method)
Stinrg 4	CEM	("Cost Prediction" OR "Cost Forecasting") AND (Accuracy OR Reliability OR Validity)
String 5	LCC	(Lifecycle AND Cost OR LCC) AND (Acquisition OR Operation OR Maintenance OR End-of-life)
String 6	LCC	("Lifecycle Cost" OR LCC OR "Life Cycle Costing") AND (Analysis OR Assessment OR Evaluation)

Based on these search strings, three independent literature reviews were conducted in accordance with the PRISMA methodology [14]. A total number of 18 publications were identified as thematically relevant and examined in detail regarding the cost structures and cost elements presented (see Table 2). The citations of the publications analyzed in Table 2 are published in an accessible database as well as the used search strings [15].

Table 2: Literature review regarding cost structures and cost elements

● Strongly considered
◑ Partialy considered
○ Not considered

Title	Year	General Overview	Broad Classification	Life Cycle Consideration	Design-Cost Data Integration	Complexity Cost Integration
Product life cycle cost analysis: State of the art review – Y Asiedu	1998	○	●	●	●	○
Developing of a generic framework for collecting whole life cost data for the building industry – MA El-Haram	2002	○	●	●	○	○
Total Cost of Ownership Models: An Exploratory Study – BG Ferrin	2002	○	●	◑	●	○
Development of a production cost estimation framework to support product family design – J Park	2005	●	○	○	●	○
Total Cost of Ownership in the Services Sector: A Case Study – K Hurkens	2006	◑	○	○	○	○
Cost-transparent Sourcing in China Applying Total Cost of Ownership – P Bremen	2007	●	○	○	○	○
A Produkt Lifecycle Costing System with Imprecise End-of-Life Data – JG Kang	2007	○	●	●	○	○
Detailed cost estimating in the automotive industry: Data andinformation requirements – R Roy	2011	○	●	●	○	○
Life Cycle Cost Estimation of Robot Systems in an Early Production Planning Phase – C Zwicker	2016	●	○	●	●	○
Aircraft Disposal and Recycle Cost Estimation – Z Xiaojia	2016	●	○	◑	○	○
Life Cycle Cost based Modeling and Economic Evaluation of 10kV Aluminum Alloy Power Cables – T Yi	2016	○	●	●	○	○
Feature-based estimation of preliminary costs in shipbuilding – C Lin	2017	○	◑	○	●	○
The total cost of ownership of durable consumer goods: A conceptual model and an empirical application – N Saccani	2017	◑	○	◑	○	○
Methodical Support for cost based selection of modular product structures – S Ripperda	2019	●	○	●	●	●
A framework for analytical cost estimation of mechanical components based on manufacturing knowledge representation – M Mandolini	2020	○	◑	○	●	○
Cost Analysis of Driverless Truck Operations – A Engholm	2020	●	○	○	●	○
A life-cycle asser management model by response surface method based optimization – KJ Wang	2023	○	◑	○	○	○
Life Cycle Costing of Food Technologies: A Case Study of a Milling Plant – G Casella	2024	●	○	○	○	○

The analysis reveals that a significant proportion of the reviewed studies exhibit shortcomings in the detailed and holistic classification of costs. The types of costs captured are often closely tied to the industry-specific context of each publication. The classification of the presented cost structures is typically not comprehensive. While many studies take relevant lifecycle aspects into account, only seven of the analyzed publications conduct a thorough analysis across the entire product lifecycle. Other publications allow detailed cost analysis but do not enable a clear assignment of costs to the different lifecycle phases of a product.

The integration of cost data into design decision-making processes represents a key success factor for the competitiveness and profitability of industrial companies. Nevertheless, only eight of the reviewed studies demonstrate a complete linkage between cost information and design decisions within product development. This highlights a deficit in interdisciplinary collaboration between engineering departments and other organizational functions.

The explicit consideration of variety-induced cost of complexity is largely absent in the reviewed literature. Only Ripperda et al. incorporates cost for complexity within the approach presented.

In summary, the reviewed literature exhibits limited depth in cost classification in the context of product development. Only about half of the cost models examined address a continuous consideration across the full product lifecycle. Cost of complexity is rarely addressed explicitly, and the systematic integration of cost data into engineering activities is significantly underrepresented. Moreover, most of the cost models focus on specific industry applications. A detailed, generic cost model that is applicable across industries is not identified within the analyzed body of literature.

3.3. Model-Based Approach

In addition to the growing number of offered products, the degree of connectivity and interdisciplinarity of products continues to increase [16]. This development not only affects the product development process - which must become increasingly broad and cross-functional - but also impacts on the associated engineering data, which is becoming more interconnected and is available in significantly larger volumes. In this context, model-based approaches have been developed to holistically link such data through the use of system models [17]. Originally derived from systems engineering, this approach is now applied across a wide range of domains [18]. It relies on the use of a modeling language, following a modeling method within a modeling tool, to create system models that represent the described structures and behaviors [19].

Approaches such as model-based Product Line Engineering (mbPLE) have demonstrated how even large product portfolios can be modeled by incorporating customer-relevant features and the resulting variability [20]. Various methodologies exist that address specific aspects of these foundational modeling concepts across multiple products [21] or extend them to the modeling of modular product families [22]. The latter focuses on representing the structure of modular product families within a modular platform. These approaches can be expanded to include behavior modeling and cost considerations. The modeling language enables parameterization of the system model, which allows for the representation of potential costs across the modeled product variants.

Based on such parameterization, simulations can be conducted to calculate the costs of individual components across entire variants independently of specific product instances. These simulations are implemented in the modeling tool Cameo Systems Modeler using roll-up patterns. These patterns allow for the recursive simulation of parameter-based calculations along a product structure, from the leaves to the root. This enables the calculation of properties such as weight, energy consumption, or cost [23].

4. Result

To reduce the manual effort involved in determining variety-induced cost of complexity, the approach illustrated in Figure 1 was developed. The following chapter presents the results of a model-based approach for capturing variety-induced cost of complexity. Emphasis is placed on the collection of existing cost data from companies, the subsequent data preparation, and the final analysis of the data.

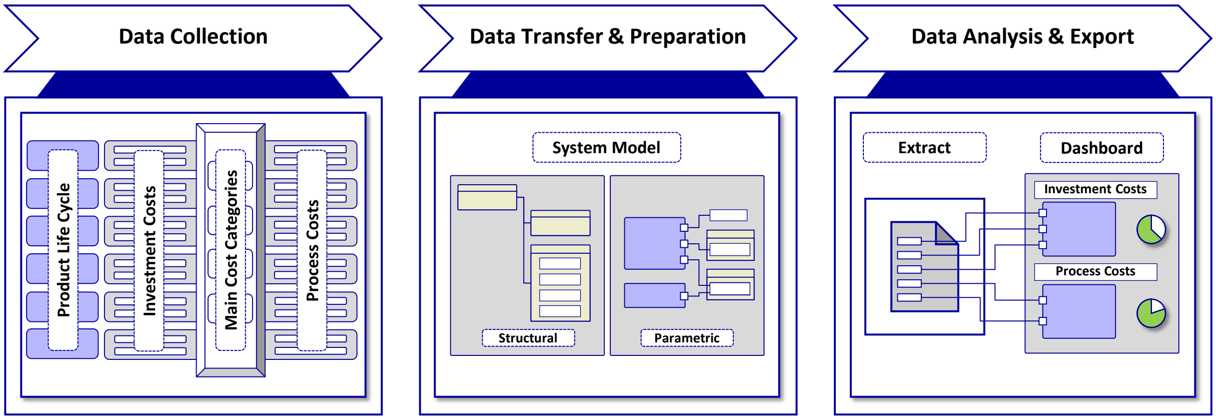


Figure 1: Approach for the Model-Based Identification of variety-induced cost of complexity

The proposed approach is illustrated using the example of a vacuum cleaner robot product family (see Figure 2). For this purpose, the brush module of the product family is used to exemplify the approach shown in Figure 1. As depicted in Figure 2, the brush module consists of the standard components Control Board, Brushed Motor, and Main Brush, as well as the variant components Auxiliary Brush, Brush Gear, and Brush Housing.

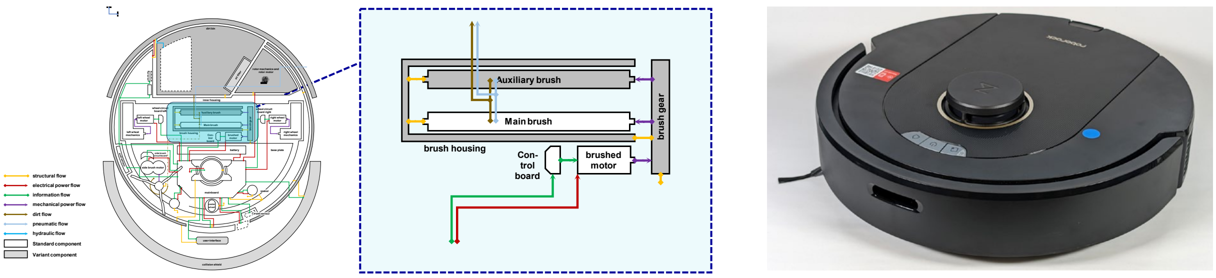


Figure 2: Module Interface Graph and front view of the vacuum robot

4.1. Data Collection

To enable the assessment of cost impacts resulting from product changes already in early product development phases, a transparent and lifecycle-spanning structuring of the associated costs is required. In this context, a generic cost structure model has been developed that breaks down the total cost of a product along its lifecycle into specific cost elements assigned to each product lifecycle phase (see Figure 3).

The development of this model is based on a comprehensive analysis and consolidation of existing cost structure models from the literature. The identified cost elements are assigned to overarching, lifecycle-independent *Main Cost Categories* to facilitate efficient structuring and visualization of the represented costs.

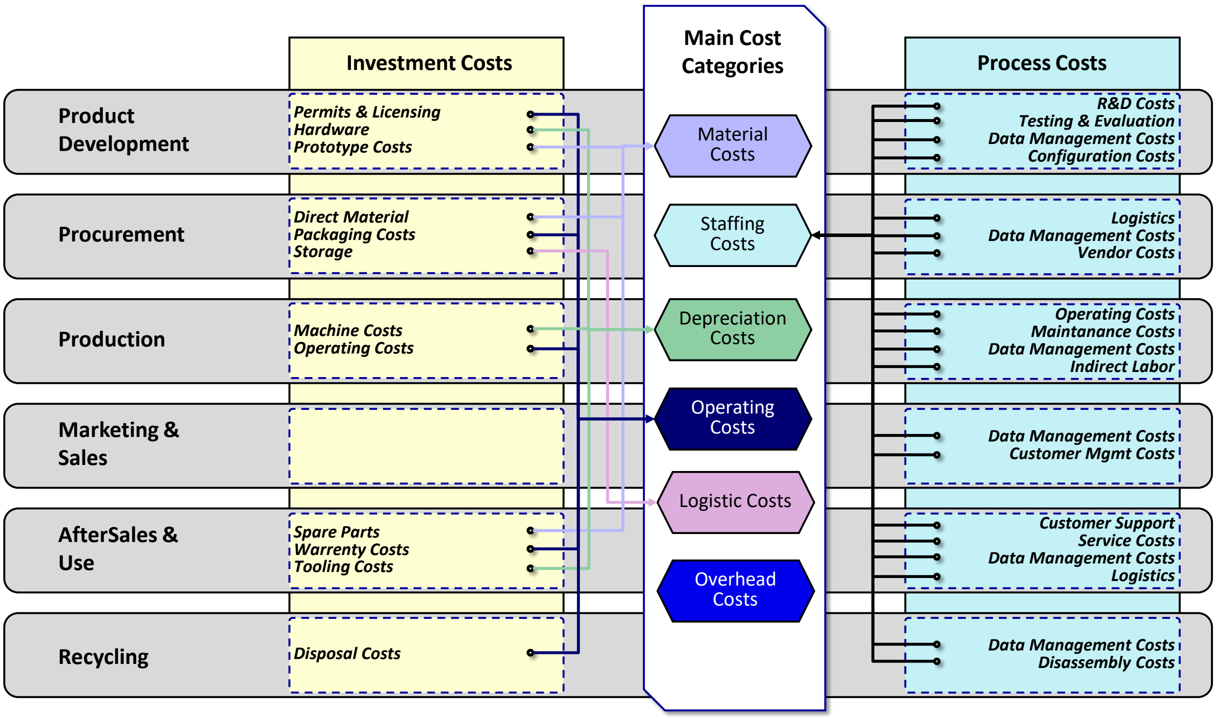


Figure 3: Generic Cost Structure Model

In principle, the cost structure model is structured horizontally into the categories *Investment Costs* and *Process Costs*, and vertically according to the different product lifecycle phases. Across these lifecycle phases, six *Main Cost Categories* have been identified, representing fundamental cost centers within manufacturing companies. These *Main Cost Categories* include *Material Costs*, *Staffing Costs*, *Depreciation Costs*, *Operating Costs*, *Logistic Costs*, and *Overhead Costs*. The lifecycle-specific cost elements are assigned to these categories and collectively represent their total cost contribution.

The objective is to assign existing cost data as precisely as possible to the lifecycle-specific cost elements for each component variant. A highly objective allocation is essential, as the quality of the recorded data directly affects the validity and reliability of the subsequent analysis results. Cost data and activities that companies typically account for under overhead costs can be allocated more accurately to individual cost elements per component variant using supporting methods such as *Activity-Based Costing* (ABC) or *Time-Driven Activity-Based Costing* (TDABC).

In Table 3, exemplary cost data have been assigned to the component variants of the brush module with respect to four cost categories from the generic cost structure model. PC_1 represents the *Data Management Costs* in the *Procurement phase*, such as ordering processes. PC_2 refers to *Operating Costs* in the *Production phase*, such as setup times resulting from the production of different component variants. IC_1 describes *Spare Parts Costs* that must be provisioned in the *After Sales & Use phase*. IC_2 illustrates *Direct Material Costs*, i.e., costs for purchased parts or raw materials in the *Procurement phase*. Based on the number of units sold for each component variant, the total cost per variant can be determined.

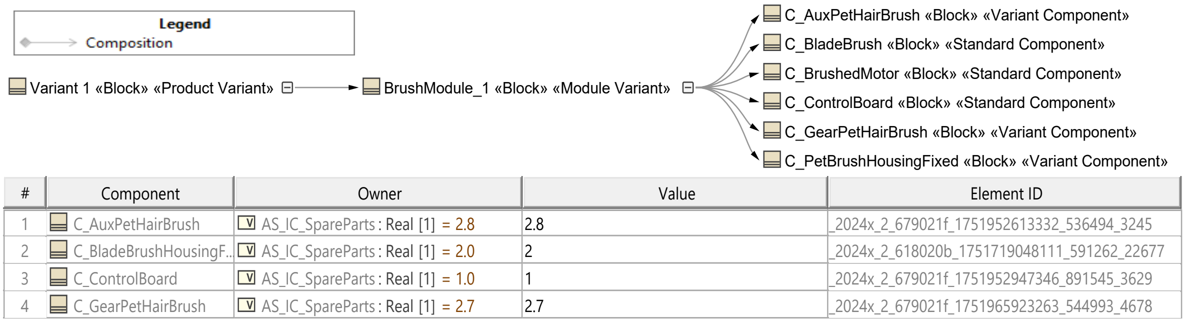
Table 3: Illustrative Cost Data for the Brush Module (in EUR)

Component Variant	Units sold	Purchase	Variance	PC_1	PC_2	IC_1	IC_2
Control board	1.000.000	Purchase	Standard	0,005	0	1	0,5
Brushed motor	1.000.000	Purchase	Standard	0,005	0	2	1
Main brush	1.000.000	Purchase	Standard	0,005	0	1,5	0,8
Blade brush	800.000	Purchase	Variant	0,005	0	2	0,9
Pet hair brush	200.000	Purchase	Variant	0,005	0	2,8	1,3
Gear blade brush	800.000	In house	Variant	0,005	0,03	2,5	0,4
Gear pet hair brush	200.000	In house	Variant	0,005	0,03	2,7	0,4
Blade brush housing fixed	700.000	In house	Variant	0,005	0,03	2	0,5
Blade brush housing flexible	100.000	In house	Variant	0,005	0,03	3	0,8
Pet brush housing fixed	50.000	In house	Variant	0,005	0,03	2	0,5
Pet brush housing flexible	150.000	In house	Variant	0,005	0,03	3	0,8

4.2. Data Transfer & Preparation

The integration of cost data into the system model is carried out based on the *Main Cost Categories* defined in the cost structure model, using an Excel interface. The system model of the vacuum cleaner robot product family includes the complete product structure of all product variants. As illustrated in the upper part of Figure 4, the relevant product variant is linked to the considered module variant of the brush module. The brush module, in turn, consists of component variants such as the Blade Brush or the Control Board.

By applying roll-up patterns to the product variants, all cost categories can be inherited as value properties by the respective component variants and redefined for use in the roll-up patterns [23]. To populate the value properties, a generic table is used in which all component variants are listed alongside their associated cost categories, values, and unique identifiers for unambiguous assignments. This table can be exported from Cameo Systems Modeler in CSV format, then populated with the collected cost values, and subsequently re-imported into the model. As shown in the lower part of Figure 4, the entered values - such as the *Material Costs* in the *After-Sales phase* for spare parts - are automatically assigned to the corresponding value properties.



#	Component	Owner	Value	Element ID
1	C_AuxPetHairBrush	AS_IC_SpareParts : Real [1] = 2.8	2.8	_2024x_2_679021f_1751952613332_536494_3245
2	C_BladeBrushHousingF..	AS_IC_SpareParts : Real [1] = 2.0	2	_2024x_2_618020b_1751719048111_591262_22677
3	C_ControlBoard	AS_IC_SpareParts : Real [1] = 1.0	1	_2024x_2_679021f_1751952947346_891545_3629
4	C_GearPetHairBrush	AS_IC_SpareParts : Real [1] = 2.7	2.7	_2024x_2_679021f_1751965923263_544993_4678

Figure 4: Modeling the Product Structure and Transferring Cost Data via Generic Table in the System Model

4.3. Data Analysis & Export

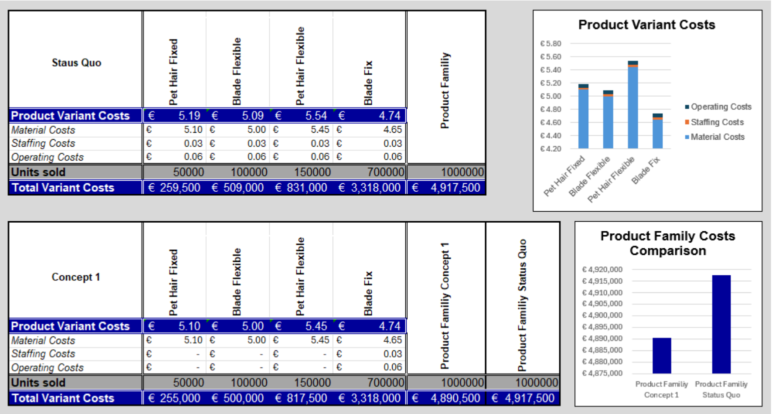
The cost data imported via Excel serves as the basis for further calculations within the Cameo Systems Modeler. By applying the roll-up pattern, the *Main Cost Categories* for all involved component variants can be calculated recursively across the product variants. Furthermore, the individual costs for each lifecycle phase can be aggregated per component, per module, and per variant. The results are visualized in an *Instance Table* and can be exported back to the developer in Excel format for further use and analysis (see Figure 5).

#	Name	totalCost : Real	totalMaterialCosts : Real	totalStaffingCosts : Real	totalDepreciationCosts : Real	totalOperatingCosts : Real	totalLogisticCosts : Real
1	variant 1	5.19	5.1	0.03	0	0.06	0
2	variant 1.brushModule_1	5.19	5.1	0.03	0	0.06	0
3	variant 1.brushModule_1.c_AuxPetHairBrush	1.445	1.44	0.005	0	0	0
4	variant 1.brushModule_1.c_BladeBrush	0.88	0.875	0.005	0	0	0
5	variant 1.brushModule_1.c_BrushedMotor	1.105	1.1	0.005	0	0	0
6	variant 1.brushModule_1.c_ControlBoard	0.555	0.55	0.005	0	0	0
7	variant 1.brushModule_1.c_GearPetHairBrush	0.57	0.535	0.005	0	0.03	0
8	variant 1.brushModule_1.c_PetBrushHousingFixed	0.635	0.6	0.005	0	0.03	0

Figure 5: Results derived from the Analysis of all Main Cost Categories

Since both the calculation and the cost parameters are linked to the roll-up pattern, the analysis can be repeated with minimal effort, even if the product structure changes. Accordingly, the product structure represented in the system model serves as a consistent data foundation.

The export containing the *Main Cost Categories* can be further processed in the Excel tool (see Figure 6) for improved visualization.



Staus Quo	Pet Hair Fixed	Blade Flexible	Pet Hair Flexible	Blade Fix	Product Familiy
Product Variant Costs	€ 5.19	€ 5.09	€ 5.54	€ 4.74	
Material Costs	€ 5.10	€ 5.00	€ 5.45	€ 4.65	
Staffing Costs	€ 0.03	€ 0.03	€ 0.03	€ 0.03	
Operating Costs	€ 0.06	€ 0.06	€ 0.06	€ 0.06	
Units sold	50000	100000	150000	700000	1000000
Total Variant Costs	€ 259,500	€ 509,000	€ 831,000	€ 3,318,000	€ 4,917,500

Concept 1	Pet Hair Fixed	Blade Flexible	Pet Hair Flexible	Blade Fix	Product Familiy Concept 1	Product Familiy Status Quo
Product Variant Costs	€ 5.10	€ 5.00	€ 5.45	€ 4.74		
Material Costs	€ 5.10	€ 5.00	€ 5.45	€ 4.65		
Staffing Costs	€ -	€ -	€ -	€ 0.03		
Operating Costs	€ -	€ -	€ -	€ 0.06		
Units sold	50000	100000	150000	700000	1000000	1000000
Total Variant Costs	€ 255,000	€ 500,000	€ 817,500	€ 3,318,000	€ 4,890,500	€ 4,917,500

Figure 6: Cost of Complexity Dashboard

In the Excel tool, the *Main Cost Categories* of the individual product variants are presented for both the current state and potential future design concepts.

Based on the number of units sold for the respective variants, the total variant costs - and thus the overall cost of the product family - can be determined. Through conceptual measures aimed at variety-oriented product design for individual components and their variants, certain cost categories associated with specific product variants can be reduced. This reduction in costs, reflected in the *Main Cost Categories*, is visualized in the Excel tool.

Moreover, the potential savings are compared to the current state at the product family level. In the present example, the standardization of the *brush gear* and the *brush housing* results in a savings potential of 27.000 Euro. This cost reduction is achieved through a lower number of required ordering processes and reduced setup times, which is the result of the decreased number of component variants within the product family.

5. Summary and Discussion

In this research, an approach for the model-based analysis of variety-induced cost of complexity in modular product families has been developed. Based on a systematic literature review, a generically applicable cost structure model was developed, which supports both the structured recording and the component-variant-specific allocation of cost data.

By integrating the collected cost data into an existing system model of the considered product family, the impact of design for variety on generic cost categories can be systematically calculated and analyzed. The system model serves as a consistent data foundation, which can be further refined through the application of roll-up patterns.

To support decision-making in the early stages of concept development, the cost data embedded in the system model are transferred via an Excel interface into a visual dashboard. This enables transparent representation of potential cost savings and allows for an efficient evaluation of different design alternatives.

The developed model-based cost structure model enables decision-makers to make reliable statements about potential cost savings already in the early phases of product development. The system model functions as a data repository and supports the documentation of development decisions. Due to the virtually unlimited scalability of the models, even large product families can be structured and enriched with the associated cost data.

It should be noted that some of the cost data used are based on subjective expert estimates, and the representation of cost of complexity within the model follows a linear approach.

Since the individual cost data in the system model are assigned to specific component variants, unnecessary variants can be systematically eliminated through the development and implementation of standardization concepts, allowing the associated costs to be avoided. Alternatively, the remaining costs can be proportionally reallocated to the continuing variants. These decisions are continuously incorporated into the system model, ensuring that it reflects the current state of development.

Economies of scale resulting from variant reduction or increased production volumes are not explicitly accounted for in the model. Nevertheless, the proposed approach represents a practical, efficient, and low-barrier method for supporting cost-based concept decisions in the context of variant-rich product families and for providing relevant information already in the early stages of product development.

References

[1] HAUSCHILDT, J.; SALOMO, S.: *Innovationsmanagement*. München: Vahlen Verlag, 2011.

[2] THYSSEN, Jesper; ISRAELSEN, Poul; JØRGENSEN, Brian: *Activity-based costing as a method for assessing the economics of modularization—A case study and beyond*. In: *International Journal of Production Economics* 103 (2006), Nr. 1, S. 252–270.

[3] SKIRDE, Henning; KERSTEN, Wolfgang; SCHRÖDER, Meike: *Measuring the Cost Effects of Modular Product Architectures — A Conceptual Approach*. In: *International Journal of Innovation and Technology Management* 13 (2016), Nr. 04, S. 1650017.

[4] EHRLENSPIEL, K.; MEERKAMM, H.: *Integrierte Produktentwicklung*. München : Carl Hanser Verlag, 2017.

[5] ALT, Oliver: *Modellbasierte Systementwicklung mit SysML*. München : Hanser, 2012.

[6] KRAUSE, Dieter; GEBHARDT, Nicolas: *Methodical Development of Modular Product Families*. Berlin, Heidelberg : Springer Berlin Heidelberg, 2023.

[7] RIPPERDA, Sebastian; KRAUSE, Dieter: *Cost Effects of Modular Product Family Structures: Methods and Quantification of Impacts to Support Decision Making*. In: *Journal of Mechanical Design* 139 (2017), Nr. 2.

[8] THONEMANN, Ulrich W.; BRANDEAU, Margaret L.: *Optimal Commonality in Component Design*. In: *Operations Research* 48 (2000), Nr. 1, S. 1–19.

[9] EILMUS, Sandra et al.: Early Phase Estimation of Variety Induced Complexity Cost Effects: A Study on Industrial Cases in Germany. In: KAHLEN, Franz-Josef; FLUMERFELT, Shannon; ALVES, Anabela (Hrsg.): *Transdisciplinary Perspectives on Complex Systems*. Cham : Springer International Publishing, 2017, S. 271–303.

[10] RIDDER, Maximilian et al.: Development of a dynamic complexity costs assessment approach in aviation development. In: *DS 125: Proceedings of the 34th Symposium Design for X (DFX2023)* : The Design Society, 14 and 2023, S. 125–134.

[11] RIDDER, Maximilian; Wöller, Lea-Nadine; Krause, Dieter: Towards a Framework for the Continuous Decision-Making Concerning Variety-Induced Cost of Complexity in the Product Generation Development Process. In: *Proceedings of the 26th International DSM Conference (DSM 2024), Stuttgart, Germany* : The Design Society, 24th - 26th 2024, S. 21–29.

[12] MERTENS, Kai G. et al.: *Reviewing the intellectual structure of product modularization: Toward a common view and future research agenda*. In: *Journal of Product Innovation Management* 40 (2023), Nr. 1, S. 86–119.

[13] MORTENSEN, Niels Henrik et al.: *Assessing the cost saving potential of shared product architectures*. In: *Concurrent Engineering* 24 (2016), Nr. 2, S. 153–163.

[14] LIBERATI, Alessandro et al.: *The PRISMA statement for reporting systematic reviews and meta-analyses of studies that evaluate healthcare interventions: explanation and elaboration*. In: *BMJ (Clinical research ed.)* 339 (2009), b2700.

[15] RIDDER, Maximilian; TUHH Universitätsbibliothek: *Literature Research Data for Cost Structure Models*. https://doi.org/10.15480/882.15385. 2025.

[16] HEHENBERGER, P. et al.: *Design, modelling, simulation and integration of cyber physical systems: Methods and applications*. In: *Computers in Industry* 82 (2016), S. 273–289.

[17] FRIEDENTHAL, Sanford; MOORE, Alan; STEINER, Rick: *A Practical Guide to SysML* : *The System Modeling Language*. Third Edition. Burlington, MA, United States : Elsevier/MK, 2015.

[18] BERSCHIK, Markus Christian et al.: MBSE within the engineering design community - an exploratory study, Vol. 3. In: *Proceedings of the 24th International Conference on Engineering Design (ICED 2023)*, 2023, S. 2595–2604.

[19] DELLIGATTI, Lenny: *SysML distilled* : *A brief guide to the systems modeling language*. Upper Saddle River, NJ, United States : Addison-Wesley, 2014.

[20] International Standard 26580. 2021. *Software and systems engineering — Methods and tools for the feature-based approach to software and systems product line engineering.*

[21] FORLINGIERI, Marco; WEILKIENS, Tim; CHALÉ-GONGORA, Hugo Guillermo: *Model-Based Product Line Engineering (MBPLE)*: *The Feature-Based Path to Product Lines Success*. 1st ed. Newark : John Wiley & Sons Incorporated, 2025.

[22] BERSCHIK, Markus Christian et al.: *Product Family Engineering along the Life Cycle – Research Aspects to cope with Variability in Advanced Systems*. In: *DesignScience - Special Issue: Advanced Systems Engineering in Research and Education* Vol. 10 (2024), (e27).

[23] BERSCHIK, Markus Christian et al.: Model-based power budget analysis of satellites using SysML Rollup Pattern. In: KOCH, Walter; WILKE, Daria; DREISEITEL, Stefan; KAFFENBERGER, Rüdiger (Hrsg.): *Tag des Systems Engineering 2022 // Tag des Systems Engineering* : *Paderborn, 16.-18. November 2022*. Bremen : GfSE-Verlag, 2022.