

COSTS IN MODULARIZATION APPROACHES: A CO-CITATION ANALYSIS

S. Ripperda and D. Krause

Keywords: modularization, cost, early design phase, research method, integrated approach

1. Introduction

Modularization is now a common method in product development used to meet the challenges faced by companies in offering customers individual and affordable products. One property of modular product structures is the commonality of components, which describes the reuse of components in a product family [Salvador 2007]. Commonality of components leads to higher quantities and less complex logistics, resulting in perceivable cost reduction [Ehrlenspiel et al. 2007]. Current literature provides several modularization methods with different approaches and focuses. However, they all provide little support in assessing the cost impact of their proposed product structures [Krause and Ripperda 2013] although companies need an initial cost estimation for the selection of modular concepts in early design phases. Solely considering production costs is not convenient, as complexity reducing effects of modular product families are not reflected.

The purpose of this systematic literature review, based on a co-citation analysis, is to clarify the consideration of costs in modularization approaches. It gives an overview of current research trends and possible gaps. Costs in modular product development and previous works in this research field are introduced, followed by a description of the method of co-citation analysis, the gathering and preparation of data and the identification and interpretation of clusters. Finally a summary of the identified research trends, the outlook for further research and a conclusion is given.

2. Costs in modular product development

Product development determines 70 percent of the total costs of a product, but only about five percent emerges there. The biggest part of the total costs of a product occurs during its production [Ehrlenspiel et al. 2007]. Consequently, product development has a high impact on total costs and reliable costs prognoses are needed in early design phases.

In a classic costs model prime costs are the total costs of a product for a company. It can be divided into direct costs that can be directly assigned to a costs object (e.g. material and labour costs in manufacturing) and overhead costs that cannot be directly assigned to a costs object (e.g. costs for management, sales, development) [Ehrlenspiel et al. 2007]. In the context of modular product development total costs can be divided into production costs, as direct costs, complexity costs, as overhead costs and product specific costs (e.g. certification costs). Complexity costs are costs for indirect activities that may not be directly assigned to the product, which arise by variety of components or variants in the product program (e.g. additional effort in logistics) [Thonemann and Brandeau 2000].

Mechanical engineering companies often use traditional cost accounting methods, like the differentiated overhead calculation [Ehrlenspiel et al. 2007]. Here, overhead costs are assigned by

overhead absorption rates to direct costs. These methods were developed with a focus on cost accounting for controlling, not supporting, product development. Since the variety in product programs led to costs distortion in traditional cost accounting methods (activities that were previously unique to a large number of similar products or components now must be carried out for almost every product sold [Ehrlenspiel and Meerkamm 2013]), new approaches, like activity-based costing (ABC), were introduced to show overhead cost transparently [Cooper 1988]. Other approaches based on ABC, such as the resource method [Schuh 1989] or the variety accounting method [Pfeiffer et al. 1992], followed with different focuses. However, these methods are of limited applicability in early phases of product development due to lack of information and big effort required.

Companies who are concerned by the effects of high product variety still use traditional cost accounting methods and focus only on production costs for product decisions [Krause et al. 2013]. One way to reduce the complexity costs introduced by the effects of variety [Ripperda and Krause 2013] is by using modular product structures. These can be introduced with the integrated PKT-approach for developing modular product families [Krause et al. 2011]. The approach was developed at the Institute of Product Development and Mechanical Engineering Design (PKT) at the Hamburg University of Technology with the purpose of reducing internal variety for the company and offering optimised external variety for the customer. Depending on the objective specified, method units can be used (Figure 1).

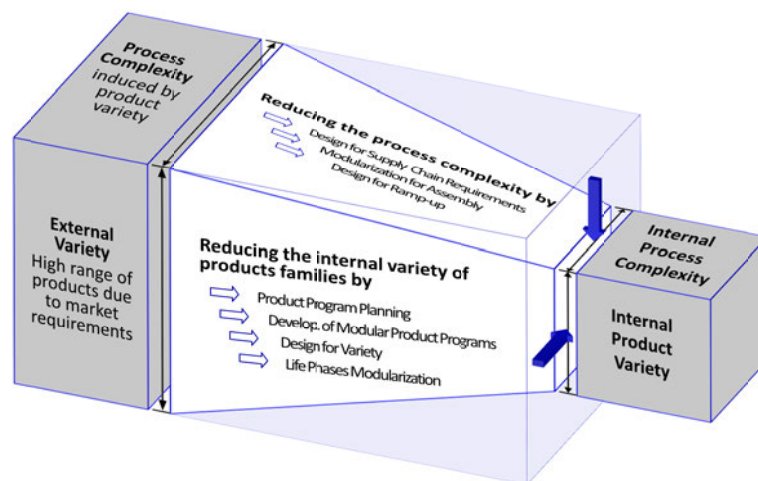


Figure 1. Research motivation and goals of the integrated PKT-approach [Krause et al. 2014]

An evaluation of ten case studies shows the applicability and usability, as well as the limitations, of the integrated PKT-approach [Eilmus et al. 2012]. Costs were not considered in this evaluation, nor are they included in the integrated PKT-approach yet. Ongoing modularization research projects and industry workshops show that companies have a demand for costs data to see the economic benefits and to justify modularization decisions [Krause et al. 2013]. This is also observed in literature [Guo and Gershenson 2007], [Park and Simpson 2008]. Current literature often provides only qualitative information about the cost effects of using modular structures (e.g. economies of scale) [Ehrlenspiel 2007].

In a modularization project for wiring harnesses in forklift trucks, quantitative cost information was included in the integrated PKT-approach by using the average cost practice. This approach includes complexity costs as code number costs to estimate the total costs (including production costs and complexity costs) of modular concepts. In the project the total costs of four different module concepts with varying grades of commonality, created with the integrated PKT-approach, were estimated [Eilmus et al. 2013]. Results show how the consideration of complexity costs, in terms of code number costs, can support companies in selecting modular concepts and how it can lead to different solutions to traditional cost accounting. The results also show the limitations of the average cost practice and the need for further development [Ripperda and Krause 2013]. To compare this action research with current research, this paper presents a systematic literature review for research trends in the fields of modularization and costs in the next section.

3. Exploring the consideration of cost in modular product development research

The literature review in this section is based on a co-citation analysis. A co-citation analysis is a common tool used to explore a lot of literature and generate clustered maps to visualize affinity of publications. This systematic approach is used to identify the main research trends that focus on modularization with respect to costs.

3.1 Co-citation method

A co-citation analysis is a commonly accepted bibliometric method for analysing the structures of scientific research areas and trends [Gmür 2003], [Meyer et al. 2009]. The co-citation method analyses the relationship that exists between several cited publications [Meyer et al. 2009]. It investigates the affinity of the publications and their research method. If two papers or authors appear on the same list of references of a given paper, they are co-cited. The level of affinity of these two papers increases with a rising number of co-citations.

There are currently two approaches: the document co-citation approach and the author co-citation approach. Which is used depends on the object studied. A document co-citation reveals the research trends based on the co-cited papers. An author co-citation investigates the social structures of authors who are cited together [Gmür 2003]. The document co-citation method leads to clearer trends of research compared to the author co-citation method. For this analysis of the consideration of costs in modularization approaches, the document-based approach is the most applicable.

The state of science provides several methods to determine the co-citation clusters [Gmür 2003]. In this paper the method CoCit-Score is used. It generates distinctive and clearly defined areas of research. The method of absolute citation values is not useable to define clearly separated clusters, because widely distributed papers tend to be cited more often. The CoCit-Score relativizes this by putting the absolute citation value in relation to the frequency of citation [Meyer et al. 2009]. The approach used is divided into three main steps (collection of data, preparation of data, and cluster identification and interpretation) [Meyer et al. 2009], which will be shown in the following three subsections.

3.2 Collection of data

Four databases (ScienceDirect, IEEE Xplore, EBSCO Business Source Premier and ISI Web of Knowledge) were used for the collection of data. The search for relevant papers was done by using keywords (“modular*”, “product” and “cost*”), which link modularized products or modularization approaches with economic aspects. Only journal articles were selected for the co-citation analysis because these contributions have gone through a review process with high scientific quality and so represent accepted knowledge within the research community [Gmür 2003]. Additionally, the results were filtered to exclude duplicates, working papers, conference articles and incorrect search results. The search of publications was started with EBSCO Business Source Premier, followed by ISI Web of Knowledge, IEEE Xplore and finally ScienceDirect. A database containing 178 papers was created for the preparation of data.

3.3 Preparation of data

The construction of the co-citation matrix is done in the next step. An initial matrix (178 x 178) was built with all publications found in the previous step. The references of all 178 publications were then cross-checked with the references in the matrix to indicate which publications were cited. This was done manually by going through the references of all papers found in the four databases. Papers which were not cited at all were excluded from the matrix. This results in a set of 67 publications for the co-citation analysis. The level of affinity of publications was determined with the CoCit-Score. It can be calculated using the formula:

$$CoCit_{AB} = \frac{(co-citation_{AB})^2}{\text{minimun}(citation_A; citation_B) \times \text{mean}(citation_A; citation_B)} \quad (1)$$

resulting in values between zero and one [Gmür 2003]. The preparation of data concludes with a symmetrical matrix with 67 papers and their calculated CoCit-Scores.

3.4 Cluster identification and interpretation

A tool named ORA (organisational risk analyser), developed at Carnegie Mellon University, is helpful for visualising the co-citation network. The visualised network contains different types of clusters which may appear as isolated nodes, pairs, chains, stars and groups with different sizes [Meyer et al. 2009]. In this analysis all kinds of clusters which consist of at least two linked nodes are examined. Clusters were only selected for interpretation if they are reasonable and interpretable.

To visually identify clusters, a minimum value for the CoCit-Score has to be chosen, below which no links between nodes are displayed. This link threshold has to be increased until clusters appear which can be interpreted. Starting with one cluster at a threshold of zero, seven reasonable and interpretable clusters emerge at a link threshold of 0.35 (Figure 2). These clusters present different trends of research in the field of modularization with respect to costs. The following subsections will describe the core topic of the clusters and the essential content of the publications.

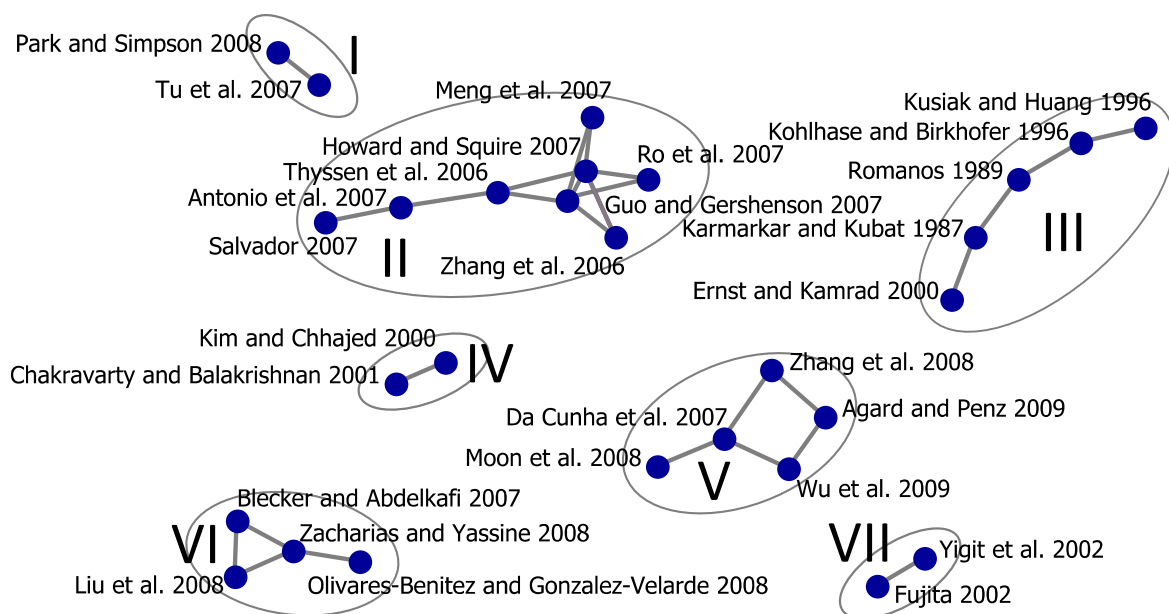


Figure 2. The seven resulting clusters of the co-citation analysis (link threshold 0.35)

3.4.1 Cluster I – cost estimation approaches in early design phases

The first cluster introduces cost estimation approaches in early design phases to support design selection. Companies used to focus on production costs and quantity-driven allocation of overhead costs; nowadays they are interested in indirect costs. Most companies still do not use any cost estimation and control systems, which would consider the real costs in modular product families with high variety. In this cluster, one approach estimates the costs for all variant activities [Park and Simpson 2008], while the other focuses on the estimation of costs for variant processes during product development [Tu et al. 2007].

Park and Simpson present an activity-based costing approach for cost estimation of product families in early stages of development. The approach estimates production costs (direct and indirect production costs) and non-production costs. These costs are linked to the individual components of a product family to give designers relevant information for product family design decisions [Park and Simpson 2008]. Tu et al. introduce an approach for product development cost estimation in mass customization. They differentiate between product definition, design and production costs (e.g. costs for test, rework, manufacturing resources and logistics). Their variant cost estimation method enables the calculation of variant process costs by searching for and comparing similar processes with existing data. The approach provides a cost estimation and optimisation to support decision making [Tu et al. 2007].

This cluster shows that only a few cost estimation methods for modular product structures are presented in the current literature. The available approaches focus on analysing activities for complexity costs allocation.

3.4.2 Cluster II – cost effects of modularization

The second cluster includes eight publications which reveal the cost effects of modularization. Due to the need for over-dimensioning, modules become more expensive than product-specific components. These expenses have to be compensated with occurring cost effects of modularization, e.g. purchase discounts, lower set-up costs or learning curve effects. The effects of modularity in general [Thyssen et al. 2006], [Salvador 2007], on manufacturing, assembly and retirement [Guo and Gershenson 2007], on competitive capabilities and performance [Antonio et al. 2007] and on supply chains [Howard and Squire 2007], [Ro et al. 2007] are discussed.

Salvador gives a definition of modularity and relates it to literature definitions. He qualitatively shows the impact of modular properties on costs [2007]. Thyssen et al. use an activity-based costing method for assessing the economics of modularization, which should support decision-making in product modularity. They state three general characteristics of cost efficient modularity. The results of their case study show that most profitable effects appear where commonality between modules is high [Thyssen et al. 2006].

Guo and Gershenson define the relationship between product modularity and product costs. They develop relationship graphs which quantitatively relate different modular redesigns (manufacturing, assembly and retirement) and their costs for four product examples. The results of their relationship analysis did not show a general relationship between modularity and costs. They conclude that current cost models need to be improved to reflect real cost savings and to show the relationship between modularity and costs [Guo and Gershenson 2007].

Antonio et al. show the effects of product modularity on competitive capabilities and performance in an empirical study of Hong Kong's manufacturing industry. Their results indicate the positive influence of product modularity on the capabilities of delivery, flexibility and customer service and, in turn, demonstrate better product performance. However, product modularity cannot improve every capability simultaneously. In terms of costs, they have to reject their hypothesis that product modularity has a positive relationship with low price (total manufacturing and development costs), which is based on major assumptions in literature [Antonio et al. 2007].

Howard and Squire explain the impact of modularization on supply relationships. They qualitatively discuss different cost effects when suppliers are more or less integrated into the product development process [Howard and Squire 2007]. Ro et al. use the example of the U.S. auto industry to describe modularity impacts on outsourcing, product development, and supply chain coordination. They identify that most modularity activities in their examples are for primarily strategic cost reduction reasons, leaving the potential of modularity largely untapped. They also notice that in their case studies the shift in industry reorganisation has not been accompanied by changes in the supply chain infrastructure to encourage long-term partnerships [Ro et al. 2007].

Other studies research mathematical modelling approaches for module identification in product families on basic effects of modularization [Zhang et al. 2006], [Meng et al. 2007].

The findings of the cluster show that, in general, the qualitatively stated positive effects of modularization could not be proven quantitatively. The potential of modularity is often not used. Nevertheless, the cluster shows that the modular property commonality seems to generate the most positive cost effects.

3.4.3 Cluster III – evaluation of modular products

This cluster contains publications that evaluate modular products for various aspects, taking account of costs. In particular, supply chain structures [Ernst and Kamrad 2000], modular design as a support strategy [Karmarkar and Kubat 1987], overall rating and the flexibility of modular systems [Kohlhase and Birkhofer 1996], modules under market performance requirements [Kusiak and Huang 1996] and sales data for module forecasts [Romanos 1989] are evaluated.

Ernst and Kamrad introduce an approach to evaluate different supply chain structures in the context of modularization and postponement. They quantify the total costs of four types of supply chain structures and compare them. Results show that modularization and postponement decisions are not independent and should be considered in combination to obtain operational advantages [Ernst and Kamrad 2000].

Karmarkar and Kubat present cost models for the evaluation of modular designs. Additionally, they discuss the issue of modular design as a support strategy [Karmarkar and Kubat 1987].

Kohlhase and Birkhofer describe a system for the computer-aided development of modular product structures. The system supports the development, configuration, calculation and evaluation of modular products. The evaluation is performed to gain an overall rating and the flexibility of modular systems [Kohlhase and Birkhofer 1996].

Kusiak and Huang suggest a method to determine modular product structures by evaluating market performance requirements and costs. They use a visual and heuristic approach to identify the modules of a product. For the defined module components, a fuzzy neural network approach is applied to analyse the trade-off between performance and costs of modules [Kusiak and Huang 1996].

Romanos gives a heuristic method for forecasting the demand of modules used in a modular product family of searchlight projectors by evaluating the sales data. The total costs are included [Romanos 1989].

The cluster is heterogeneous due to its chain shape and considers several aspects of evaluation. Initial stages of a general evaluation of modularity are shown.

3.4.4 Cluster IV – optimal product modularity for different market segments

The cluster describes how profit maximisation can be obtained by optimal product modularity for different market segments. Scenarios are formed to show the costs trade-off for modular concepts.

Kim and Chhajed develop a model to examine when modular products should be introduced and how much modularity is to be offered. The model considers a market consisting of a high segment and a low segment, develops different scenario concepts for both segments and analyses them to gain the highest margin [Kim and Chhajed 2000]. Chakravarty and Balakrishnan introduce an algorithm to achieve product variety through an optimal choice of module variety. Different scenarios show how the choice of modules affects product variety, total sales, product development costs and company profit [Chakravarty and Balakrishnan 2001].

This cluster uses cost data in combination with market development for strategic product structure decisions.

3.4.5 Cluster V – mathematical optimisation models

Cluster V consists of five publications deploying mathematical optimisation models to support modular design decisions considering costs. Models for composition and choice of modules [Da Cunha et al. 2007], [Agard and Penz 2009] for configuring platform-based product variants and their supply chain [Zhang et al. 2008], for a market-based negotiation mechanism to design a product family [Moon et al. 2008] and for supporting decisions to update modular products [Wu et al. 2009] are shown.

Da Cunha et al. present a simulated annealing method combined with a heuristic approach to determine the optimal mix of modules and their stock. Their outcomes show that savings can be realised by optimising the composition of modules in the supply chain [2007]. This approach is further developed as a simulated annealing method based on a clustering approach for the efficient choice of modules [Agard and Penz 2009].

Zhang et al. discuss decision variables for simultaneously configuring platform-based product variants and their supply chain by considering supplier capabilities and production costs. They developed a model to integrate platform product design and material purchase design decisions based on commonality and modularity. Results show that the model can be used as a support tool for product decisions on development, production and supply chain [Zhang et al. 2008].

Moon et al. present a mathematical model of a market-based negotiation mechanism for designing a product family in a conceptual design phase. In the proposed dynamic multi-agent system, specific

design tasks are assigned to agents by decomposing tasks for product family design, and an optimal platform is determined by negotiations between agents [Moon et al. 2008].

Wu et al. introduce a non-linear model to support decisions for updating modular products. In particular, they examine reuse, redesign, quality, speed-to-market, and marketing decisions for a modular product. Their results show that when the fixed development costs are negligible, it is profitable to upgrade every component, otherwise the existing components should be reused without making any design improvements to save development costs [Wu et al. 2009].

The cluster shows that the mathematical optimisation of different aspects of modularity is a complex task. Authors use heuristics and simplifications to solve their models.

3.4.6 Cluster VI – degree of commonality and optimal platform selection

The sixth cluster describes the optimal degree of commonality [Blecker and Abdelkafi 2007], [Liu et al. 2008] and optimal platform selection [Olivares-Benitez and Gonzalez-Velarde 2008] when considering costs. Both aspects are integrated in the model for the development of platform-based product families of Zacharias and Yassine [2008].

Blecker and Abdelkafi assess literature commonality indices by evaluating component commonality for mass customisation. They introduce the total commonality index, which enables the evaluation of the overall commonality of a product family. Their index does not use cost data, due to the effort of estimation. However, they discuss the cost impact of commonality qualitatively [Blecker and Abdelkafi 2007]. Liu et al. present an approach to modularizing product family architecture at early design phases. They show a variety index method to estimate effects of customisation on conceptual modules. The method compares the degree of variety with nonrecurring engineering costs to decide the optimal degree of commonality [Liu et al. 2008].

Olivares-Benitez and Gonzalez-Velarde propose a meta-heuristic approach to select the optimal platform based on product performance and manufacturing costs [Olivares-Benitez and Gonzalez-Velarde 2008].

Zacharias and Yassine describe a model for the development of platform-based product families that simultaneously considers concepts from engineering and marketing. Starting with a conceptual design of the product family, the model suggests the optimal initial investment in the platform, the commonality of components, and the number of variants to be produced to maximise market coverage [Zacharias and Yassine 2008].

Commonality, as also shown in cluster II, is an important modular property to reduce costs. Consequently, optimal commonality, and its associated optimal platform selection of cluster VI, is an interesting research topic.

3.4.7 Cluster VII – mathematical optimisation models

The last cluster is closely linked with cluster V. It also consists of mathematical optimisation models with different focuses for costs.

Fujita sees product variety as an optimisation problem. He divides the three optimisation problems into attribute assignment, module combination and simultaneous design of both. These problems are solved mathematically [Fujita 2002].

Yigit et al. focus on optimising modular products in a reconfigurable manufacturing system. The problem is formulated as a trade-off function between losing quality due to modularization and costs of reconfiguration and is solved as an integer nonlinear programming problem [Yigit et al. 2002].

4. Towards a consideration of costs in modularization approaches

The main research trends in modularity and costs were revealed using the co-citation analysis. The analysis is restricted by being limited to the journal articles of the databases and does not claim to be exhaustive. The selection of the keywords also has a major impact on the analysis; new publications are excluded due to the method used. The co-citation method helps understanding of the directions of research. Six relevant research trends were extracted by analysing the 67 papers in the database. Cluster I provides cost estimation approaches in the early design phases to support design selection. Cluster II includes the cost effects of modularization. Cluster III evaluates aspects of modular

products. Cluster IV maximises profit through optimal product modularity for different market segments. Cluster V and VII show mathematical optimisation models of modular designs under different aspects and, finally, Cluster VI estimates the optimal degree of commonality and optimal platform selection. An overview of the clusters is given in Figure 3.

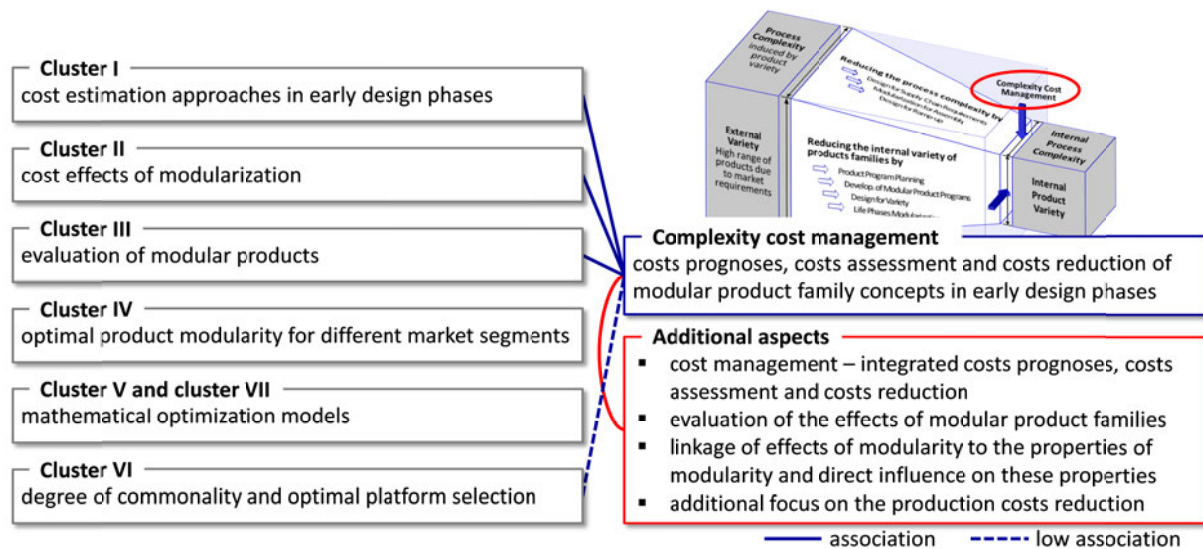


Figure 3. Identified clusters and their association with the complexity cost management within the integrated PKT-approach

The results show the need to understand the economic benefits of modularization. Traditional cost accounting systems are not sufficient to acquire the effects of modularity. Even though six research trends were identified, there are still additional aspects to investigate. First, an integrated approach of costs prognoses, costs assessment and costs reduction is missing. Next, many publications only consider individual products when trying to evaluate the effects of modularity and are not able to show a positive relationship. It is necessary to consider and evaluate modularization of the whole product family to get positive effects. Additionally, it is necessary to link the effects to the properties of modularity and to know how to directly influence these properties. In this way, product costs could be directly reduced by optimal modularity in the company. It might also aid acceptance by industry to focus on reduction of production costs, because it is still the focus of several companies.

Further research will support the integrated PKT-approach with a complexity cost management approach, consisting of (1) costs prognoses, (2) costs assessment and (3) costs reduction of modular product family concepts in early design phases. Results of the publications of the clusters I, II and III will be helpful. Publications of cluster VI will also support these goals. Additionally, the named gaps will be addressed. This complexity cost management will be another method unit of the integrated PKT-approach (cf. Figure 1), which can be optionally used in modularization projects, depending on the planned effort and available data.

5. Conclusion

Economic aspects of modular product structures can be considered under several aspects and is becoming a research trend of increasing interest. The co-citation analysis performed in this paper provides a systematic method for literature review in the field of modular product structures regarding costs. Four different databases were used to create a data set of 67 publications. With the help of the calculated CoCit-Scores, a co-citation network was visualised. Seven different clusters with six different research trends have been identified, mainly concentrating on the estimation of costs in early design phases, cost effects, evaluation of modular products, optimal product modularity under market aspects, mathematical optimisation models and the optimal degree of modularity and optimal platform selection. Further research could integrate costs prognoses, costs assessment and costs reduction into

one complexity cost management approach. Additionally, effects of modularity should be shown that consider product families instead of individual products. For the costs reduction the effects of modularity should be linked to the properties of modularity. Finally, the planned addition to the integrated PKT-approach was shown. In summary, the integration of costs prognoses, costs assessment and costs reduction could be an interesting challenge for further research.

References

- Agard, B., Penz, B., "A Simulated Annealing Method Based on a Clustering Approach to Determine Bills of Materials for a Large Product Family", *International Journal Production Economics*, Vol. 117, 2009, pp. 389-401.
- Antonio, K. W. L., Yam, R. C. M., Tang, E., "The Impacts of Product Modularity on Competitive Capabilities and Performance: An Empirical Study", *International Journal Production Economics*, Vol. 105, 2007, pp. 1-20.
- Blecker, T., Abdelkafi, N., "The Development of a Component Commonality Metric for Mass Customization", *IEEE Transactions on Engineering Management*, Vol. 54, No. 1, 2007, pp. 70-85.
- Chakravarty, A. K., Balakrishnan, N., "Achieving Product Variety through Optimal Choice of Module Variations", *IIE Transactions*, Vol. 33, No. 7, 2001, pp. 587-598.
- Cooper, R., "Predevelopment Activities Determine New Product Success", *Industrial Marketing Management*, Vol. 17, 1988, pp. 237-247.
- Da Cunha, C., Agard, B., Kusiak, A., "Design for Cost: Module-Based Mass Customization", *IEEE Transactions on Automation Science and Engineering*, Vol. 4, No. 3, 2007, pp. 350-359.
- Ehrlenspiel, K., Kiewert, A., Lindemann, U., "Kostengünstig Entwickeln und Konstruieren – Kostenmanagement bei der integrierten Produktentwicklung", 6. Auflage, Springer, Heidelberg, 2007.
- Ehrlenspiel, K., Meerkamm, H., "Integrierte Produktentwicklung", 5. Auflage, Hanser, München, 2013.
- Eilmus, S., Gebhardt, N., Rettberg, R., Krause, D., "Evaluating a methodical approach for developing modular product families in industrial case studies", *12th International Design Conference - Design 2012, Dubrovnik, 2012*, pp. 837-846.
- Eilmus, S., Ripperda, S., Krause, D., "Towards the development of commonal product programs", *19th International Conference on Engineering Design (ICED13)*, Seoul, 2013.
- Ernst, R., Kamrad, B., "Evaluation of Supply Chain Structures Through Modularization and Postponement", *European Journal of Operational Research*, Vol. 124, 2000, pp. 459-510.
- Fujita, K., "Product Variety Optimization under Modular Architecture", *Computer Aided Design*, Vol. 34, 2002, pp. 953-965.
- Gmür, M., "Co-citation analysis and the search for invisible colleges: A methodological evaluation", *SCIENTOMETRICS*, Vol. 57, No. 1, 2003, pp. 27-57.
- Guo, F., Gershenson, J. K., "Discovering Relationships Between Modularity and Cost", *Journal Intelligent Manufacturing*, Vol. 18, 2007, pp. 143-157.
- Howard, M., Squire, B., "Modularization and the Impact on Supply Relationships", *International Journal of Operations & Production Management*, Vol. 27, No. 11, 2007, pp. 1192-1212.
- Karmarkar, U. S., Kubat, P., "Modular Product Design and Product Support", *European Journal of Operational Research*, Vol. 29, 1987, pp. 74-82.
- Kim, K., Chhajed, D., "Commonality in Product Design: Cost Savings, Valuation Change and Cannibalization", *European Journal of Operational Research*, Vol. 125, 2000, pp. 602-621.
- Kohlhase, N., Birkhofer, H., "Development of Modular Structures: The Prerequisite for Successful Modular Products", *Journal of Engineering Design*, Vol. 7, No. 3, 1996, pp. 279-291.
- Krause, D., Beckmann, G., Eilmus, S., Gebhardt, N., Jonas, H., Rettberg, R., "Integrated Development of Modular Product Families: A Methods Toolkit", in Simpson, T.W., Jiao, J.R., Siddique, Z. and Hölttä-Otto, K., "Advances in Product Family and Product Platform Design", Springer, New York, 2014, pp. 245-270.
- Krause, D., Eilmus, S., "A Methodical Approach for Developing Modular Product Families", *International Conference on Engineering Design, Copenhagen*, Vol. 4, 2011, pp. 299-308.
- Krause, D., Ripperda, S., "An assessment of methodical approaches to support the development of modular product families", *19th International Conference on Engineering Design (ICED13)*, Seoul, 2013.
- Krause, D., Ripperda, S., Gebhardt, N., Eilmus, S., Hackl, J., Beckmann G., "Workshop on Modularization Methods", *Research training for engineers, 5th and 6th of November 2013, TUHH, Hamburg*, 2013.
- Kusiak, A., Huang, C., "Development of Modular Products", *IEEE Transactions on Components, Packaging and Manufacturing Technology*, Vol. 19, No. 4, 1996, pp. 523-538.

- Liu, Z., Wong, Y. S., Lee, K. S., "Integrated Approach to Modularize the Conceptual Product Family Architecture", *International Journal Advanced Manufacturing Technology*, Vol. 36, 2008, pp. 83-96.
- Meng, X., Jiang, Z., Huang, G. Q., "On the Module Identification for Product Family Development", *International Journal Advanced Manufacturing Technology*, Vol. 35, 2007, pp. 26-40.
- Meyer, M., Lorscheid, I., Troitzsch, K. G., "The Development of Social Simulation as Reflected in the First Ten Years of JASSS: a Citation and Co-Citation Analysis", *JASSS The Journal of Artificial Societies and Social Simulation*, Vol. 12, No. 4, 2009, pp. 224-243.
- Moon, S. K., Park, J., Simpson, T. W., Kumara, S. R. T., "A Dynamic Multiagent System Based on a Negotiation Mechanism for Product Family Design", *IEEE Transactions on Automation Science and Engineering*, Vol. 5, No. 2, 2008, pp. 234-244.
- Olivares-Benitez, E., Gonzalez-Velarde, J. L., "A Metaheuristic Approach for Selecting a Common Platform for Modular Products Based on Product Performance and Manufacturing Cost", *Journal Intelligent Manufacturing*, Vol. 19, 2008, pp. 599-610.
- Park, J., Simpson, T. W., "Towards an Activity-based Costing System for Product Families and Product Platform in the Early Stages of Development", *International Journal of Production Research*, Vol. 46, No. 1, 2008, pp. 99-130.
- Pfeiffer, W., Dörrie, U., Gerharz, A., Goetze, S. v., "Variantenkostenrechnung", *Handbuch Kostenrechnung*, Hrsg. v. W. Mannel, Wiesbaden, 1992.
- Ripperda, S., Krause, D., "Komplexitätskosteneffekte modularer Produktfamilien", *Design for X, Beiträge zum 24. DfX-Symposium, Hamburg, 2013*, pp. 13-24.
- Ro, K. Y., Liker, J. K., Fixson, S. K., "Modularity as a Strategy for Supply Chain Coordination: The Case of U.S. Auto", *IEEE Transactions on Engineering Management*, Vol. 54, No. 1, 2007, pp. 172-189.
- Romanos, M. S., "Demand Forecasting for Parts Used in Modular Products: A Case Study", *Engineering Costs and Production Economics*, Vol. 17, 1989, pp. 231-244.
- Salvador, F., "Towards a Product System Modularity Construct: Literature Review and Reconceptualization", *IEEE Transactions on Engineering Management*, Vol. 54, No. 2, 2007, pp. 219-240.
- Schuh, G., "Gestaltung und Bewertung von Produktvarianten – Ein Beitrag zur systematischen Planung von Serienprodukten", *Dissertation, Fortschritts-Berichte VDI, Reihe 2, VDI-Verlag, Düsseldorf, 1989*.
- Thonemann, U. W., Brandeau, M. L., "Optimal Commonality in Component Design", *Operations Research*, Vol. 48, No. 1, 2000, pp. 1-19.
- Thyssen, J., Israelsen, P., Jorgensen, B., "Activity-based Costing as a Method for Assessing the Economics of Modularization – A Case Study and Beyond", *International Journal Production Economics*, Vol. 103, 2006, pp. 252-270.
- Tu, Y. L., Xie, S. Q., Fung, R. Y. K., "Product Development Cost Estimation in Mass Customization", *IEEE Transactions on Engineering Management*, Vol. 54, No. 1, 2007, pp. 29-40.
- Wu, L., De Matta, R., Lowe, T. J., "Updating a Modular Product: How to Set Time to Market and Component Quality", *IEEE Transactions on Engineering Management*, Vol. 56, No. 2, 2009, pp. 298-311.
- Yigit, A. S., Ulsoy, A. G., Allahverdi, A., "Optimizing Modular Product Design for Reconfigurable Manufacturing", *Journal of Intelligent Manufacturing*, Vol. 13, 2002, pp. 309-316.
- Zacharias, N. A., Yassine, A. A., "Optimal Platform Investment for Product Family Design", *Journal Intelligent Manufacturing*, Vol. 19, 2008, pp. 131-148.
- Zhang, W. Y., Tor, S. Y., Britton, G. A., "Managing Modularity in Product Family Design with Functional Modeling", *International Journal Advanced Manufacturing Technology*, Vol. 30, 2006, pp. 579-588.
- Zhang, X., Huang, G. Q., Rungtusanatham, M. J., "Simultaneous Configuration of Platform Products and Manufacturing Supply Chains", *International Journal of Production Research*, Vol. 46, No. 21, 2008, pp. 6137-6162.

Dipl.-Ing. Sebastian Ripperda, Scientific Assistant
Hamburg University of Technology / Institute of Product Development and Mechanical Engineering Design
Denickestraße 17 (L), 21073 Hamburg, Germany
Telephone: +49 (0)40 42878-4306
Telefax: +49 (0)40 42878-2296
Email: sebastian.ripperda@tuhh.de
URL: <http://www.tuhh.de/pkt>