Decisive Economies and Opportunity Cost of Modular Product Structure Alternatives: An Empirical Case Study

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Abstract – Versatile, global markets as well as the increasing demand for more individualized products has increased the pressure on companies to offer a broad variety of products. Developing modular product families is an established approach to provide a suitable variety under economic conditions. However, balancing the demands for more external variety and less internal variety is a complex task for product development, affecting multiple domains in companies. In this paper, we conduct an empirical case study and investigate the correlating effects of external and internal variety on respective performance indicators (PI). Within two companies, we identify recurring chain reactions across ten decision scenarios and derive a subset of PIs affected by modular product structure alternatives (MPSA). In addition, the results highlight the major trade-offs between different target dimensions that occur while choosing dissimilar product structure alternatives.

Keywords – Modular product families, modularization, decision making

I. INTRODUCTION

Since global markets increase cost pressure and the time to market is cut to a minimum, companies are facing vast challenges in product development. Modular product families are powerful approaches to maximize the success of a company’s product program in saturated markets by providing high external variety while keeping internal variety as low as possible. Product development plays an important role, because it comprises the definition of modular characteristics of products, product families and product programs and therefore determines the internal and external variety in a company. Internal variety is defined as the variety of modules, components and processes, whereas external variety represents the variety and diversification of products offered to markets [1]. However, changing the external variety of a company influences internal variety and vice versa. The resulting conflicting effects of modular product structure alternatives may support the goals of the companies and departments (e.g., lowering efforts, costs or complexities) and at the same time, act adverse (e.g., by leading to less differentiated solutions). These trade-offs play an important role in decision-making. Furthermore, stakeholders associated to certain functions pursue individual objectives and, thus, cause related conflicts. Hence, decision-making problems in the context of modularization are a major challenge for product development units, involving multiple product families, stakeholders and their different objectives.

To understand how modular product structures are defined and how decision-making problems for MPSAs can be solved, we empirically investigate decision situations within ten case studies. We identify recurring, decisive effects of modular properties in two companies. The results demonstrate that decision-making procedures and methods to assess MPSAs differ significantly across decision situations. Furthermore, we give an outlook on the needs for a decision support system to enhance the balance between external and internal variety.

II. REVIEW OF THE LITERATURE

A. Development of modular product structures

In the last decades, researchers have provided numerous approaches to support the systematic development of modular product structures. Some influential methodologies in this area are: Modular Function Deployment [2] by Erixon, Structural Complexity Management [3] by Lindemann et al., Theory of Modular Design [4] by Stone, Integration Analysis Methodology [5] by Pimmler and Eppinger or the Integrated PKT-Approach [6] by Krause et al.. Characterizing modularity is best done by determining its descriptive attributes. In his literature review, Salvador [7] derives five modular characteristics - decoupling, commonality, combinability, interface standardization and functional binding. All of these properties are gradual parameters and specify, in their entirety, the overall degree of the product structure modularity.

B. Decision-making in the context of modular product structures

A suitable product variety under economic conditions can be attained by using different product architecture strategies. The systematic development and design of product architectures has significant benefits for product development and beyond: Reduction of complexities and product development expenses, shorter time to market or economies of scale [2] are just a few advantages modularity and platform approaches have to offer [8] [9] [10] [11]. By choosing a certain modularization approach for a product family, different product structures arise, as well.
A dominant aspect of increasing product variety is that customers are more likely to find exactly what they want [12]. Broader product lines also have a positive impact on the company’s profitability, which empirical research demonstrates [13]. In contrast, variety offered to markets should meet the needs of customers and therefore has to be assessed carefully. The results of [14] highlight the fact that product variety and profit do not always correlate positively - a certain product variant has to meet customers’ demands first. The downside of increasing variety, however, can have a significant influence on the company’s performance. Studies show that increasing variety lowers lead times, reliability or product innovativeness [15]. By trying to reduce the downsides of variety, distinct modularity in product programs can lead to decreased customer satisfaction due to insufficient product differentiation [16]. Internal variety in companies additionally implies cost effects that are widely known e.g., impacts on unit costs [17] [18], development time [19] and expenditures, and on complexity costs in an organization [20]. Comprehensive overviews of various effects are given by [11], [10] and [21], and [22] compare the research on impact models.

To find the most suitable variety for a company, the literature offers methods and strategies to assess product architectures. These evaluation methods are crucial decision-making tools for developers when choosing or rejecting a product structure alternative, which follows two different principles: The first approach focuses on rejecting a product structure alternative, which follows decision-making tools for developers when choosing or architectures. These evaluation methods are crucial decision-making tools for developers when choosing or rejecting a product architecture alternative. The second approach to evaluate product structures is to observe the metrics measuring the outcome of the product architecture design [2] [17] [25]. Hereby, PIs are rather related to business and management perspectives.

During the assessment process, various stakeholders of several departments include their individual perspectives. Thus, conflicting requirements regarding the desired effects of modularity emerge and lead to trade-offs, e.g., between commonality and differentiation [26]. These trade-offs are a major challenge in the context of decision-making for modular product structure alternatives.

III. RESEARCH DESIGN

Product development is a non-deterministic task with an infinite number of valid solutions. The design process includes testing the implications for internal and external variety in different product structure alternatives and their respective profits (Fig. 1).

The relevant literature and empirical findings strongly suggest that the quality of decision-making is a major factor in balancing internal and external variety. However, companies still struggle in making decisions with mutually exclusive MPSAs [27]. Therefore, we hypothesize that the assessment of MPSAs does not follow a systematic approach in real-life situations. The effects of modularity are recurring. However, the way in which these effects are assessed is not standardized. To meet these challenges, we test the following hypotheses:

H1: Different situations entail different methods and procedures to solve decision-making problems in modular product structure alternatives.
H2: The same effects of modular product structure alternatives occur in different decision situations of the same product development unit.
H3: Different modular product structure alternatives affect external and internal variety simultaneously.

Since behavioral decision-making plays an important role in decision situations – in the end, there are people deciding – we opted for a case study research design [28]. We analyzed relevant product development projects regarding crucial decision situations in two different companies whose products already show distinct modular product structures. Data were collected within ten exploratory case studies [29]. The first company, Hilti Corporation, delivers solutions for construction site applications. Their products show distinctive modular product structures [30]. The second company, Robert Seuffer GmbH & Co. KG, develops and manufactures electronic modules for e.g., automobiles, utility vehicles, power tools or electronics modules for homewares. In this case, data were collected by
We analyzed decision situations in past and current product development projects that adhere to modular characteristics according to [7]. In a next step, we analyzed the use of performance indicators in the decision situations. In addition, we linked the deciding opportunity cost to the cases. We identified distinct modular characteristics according to [7], which differed between the product structure alternatives. Characteristics that occurred in the case studies (CS) most often were commonality and interface standardization (seven out of ten), followed by combinability and functional binding (five out of ten) and decoupling (three out of ten). The scope of affected modular product families ranged from two products in case study 1 and case study 6 (CS1 and CS6) to the entire product program of the companies (CS8, CS9 and CS10). The characteristics were assigned to one case as they were discussed explicitly or there was an evident connection between them.

We found and categorized several different indicators important to decision-making. Key performance indicators for the cases were: profit, turnover and cost. PIs used in external variety cases were: meeting customer requirements, product differentiation and sales. Meeting customer requirements describes the degree to which certain requirements were satisfied. Product differentiation is the distinction between the characteristics of the products considered. Categories customer requirements and product differentiation were further divided into product-specific properties: performance of the product, features, compactness, weight, ease of use, ergonomics or lifetime robustness. PIs affected by internal variety were: cost of goods sold, production investments, operational expenditures, engineering lead-time, resource allocation and flexibility. We further investigated the frequency of decisive PIs. In addition, we analyzed the opportunity cost as it resulted in a trade-off conflict (see Fig. 2).

A. Impact on indicators related to external variety

External variety dimensions were affected and considered in decision-making in nine out of ten cases. Meeting customer requirements was important in nine cases, followed by product differentiation, which was relevant in seven cases. Surprisingly, the impact on sales was only considered in CS1, although there was a definite impact on external variety in nine out of ten cases. We assume that the connections between affected customer requirements and sales numbers are too fuzzy and time-consuming to be determined in our decision situations. This correlation is important but difficult to assess. Therefore, experts were asked to give their opinion on possible impacts on sales. However, no systematic approach was used, neither were all affected products across the product program considered. In eight decision situations, a trade-off in meeting the customers’ requirements had to be made. The alternatives lead to more or less differentiated solutions and, thus, to less market coverage and sales.

B. Impact on indicators related to internal variety

The most frequent indicator (eight out of ten cases) related to internal variety was cost of goods sold, which includes the production costs of the later product. We assume that this is due to the control system of companies today that focus on product costs rather than on recent
research findings, e.g., approaches considering complexity cost [31]. In six cases, the flexibility of the solution was assessed, meaning that modules could be used as carry over parts or combined with other modules. The allocation of resources was decisive in six cases, whereas engineering lead-time, operational expenditures and production investments were important in five cases. In five of the cases, opportunity cost for cost of goods sold occurred.

In nine cases, the MPSAs simultaneously influenced internal and external variety. This interconnection led to conflicting objectives between indicators measuring the results of internal and the results of external variety. Thus, affected dimensions were assessed comparatively. Since it is difficult and time-consuming to determine absolute values for every solution, the people involved compared the alternatives based on an opportunity cost analysis.

C. Connection between the influences on external and internal variety-related dimensions

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D. Impact on product architecture

Stakeholders at the management level were involved in all cases and had to understand the decision-making problem at the beginning of the meeting first. The respective project manager explained the cases with graphical representations of the product structure containing connections between modules and products. However, no explicit indicators were used to measure the resulting product structure from a technical or functional perspective.

V. DISCUSSION

We conducted the case study within two different companies. The findings as presented are valid for product programs where the value for customers increases while external variety increases. This requires an increasing satisfaction of customers with increasing external variety. Both companies use a build-to-stock strategy with production volumes of more than 1000 pieces per year and unit. Except for CS8, all cases were simultaneously influenced by internal and external variety. In CS8, only one indicator was used to justify the decision made. However, this project was at an early stage compared to the other projects. We assume that the impact on external variety plays an important role and will be considered at a later stage of CS8.

VI. CONCLUSION

The results of the case studies demonstrate that the same performance indicators were used to assess the effects of modularity (hypothesis 2) across different projects. Moreover, we found recurring indicators across two companies, notably product differentiation, meeting customer requirements, cost of goods sold, engineering lead-time, flexibility and resource allocation. However, on average only 4.9 out of 9 PIs were used across the observed decision situations (hypothesis 1). In nine cases, indicators that measure external and internal variety simultaneously supported the decision-making process. From this behavior, we derive that modular product alternatives influence external and internal variety simultaneously (hypothesis 3). This connection plays an important role in decision-making since it induces the decisive opportunity cost and, thus, needs to be considered for decision-making. In five cases, the opportunity cost had to be accepted between choosing either meeting customer requirements or cost of goods sold. The process on how these decisions were made also differed significantly among all cases with regard to participating stakeholders, assessed PIs, the decision procedure and the method to illustrate product structure alternatives.

Building on these findings, we propose to systematically consider the mutual influence between internal and external variety in modularity decision-making. Furthermore, the perspectives of managerial stakeholders (performance indicators on management level) should be considered as well as those of designers, product developers and architects (indicators on the product architecture level). In addition, all relevant stakeholders across different product life-phases (e.g., development, production, sales …) shall be considered. A visual approach can support cross-functional and cross-level decision-making, which we will present in subsequent research. We will also expand our research to companies with other business models (e.g., configure-to-
order, engineer-to-order), product family architectures and organizational structures. Our goal is to contribute to the quality of related decision-making processes and to, consequently, achieve a suitable balance between economies and trade-offs of modular product families in collaborative environments.

REFERENCES


