Managing Complexity Induced by Product Variety in Manufacturing Companies
Complexity Evaluation and Integration in Decision-Making

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Matthias Götzfried

from

Germany

Approved on the application of

Prof. Dr. Thomas Friedli

and

Prof. Dr. Elgar Fleisch

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Abstract

Managing product variety and its resulting complexity is crucial for the success of manufacturing companies. Variety provided to the market place supports the increase and maintenance of market share, revenue and profit. However, variety induces complexity in the product portfolio, in product architecture and in value-chain processes. Consequently, companies struggle with the trade-off between benefits and efforts of variety-induced complexity. Although a number of concepts to optimize complexity reactively are discussed in research, there is only little insight into how manufacturing companies design and implement their complexity management initiatives successfully.

By conducting a broad survey with 175 participating companies and by investigating companies' approaches in five in-depth case studies, this research contributes to existing cross-discipline theory on complexity management. While the survey analysis provides first insights into the complexity management across multiple industrial sectors, the analyses of carefully selected case studies reveal the success factors of complexity management. A holistic initiative consists of two interdependent categories: Enabling factors and activity areas. The success of a complexity management implementation largely depends on management priority, organizational anchoring and cross-functional involvement. These prerequisites serve as a basis for activity areas designed to optimize complexity in the product portfolio, product architecture and value-chain processes. In addition to providing guidance and exploiting synergies, the creation of transparency on variety-induced complexity and proactive complexity control in early decision-making are identified as crucial to increasing projects' effectiveness and efficiency. High transparency is achieved by non-monetary evaluation of portfolio and product complexity and monetary evaluation of value-chain processes complexity. Proactivity is put into practice by complexity integration in business cases, e.g. by defined complexity-related criteria, and complexity-aligned decision-making processes.

Existing approaches to managing variety-induced complexity are expanded by the research insights. The study suggests a holistic approach to managing complexity rather than only focusing on single and isolated issues. Also, the analyses show that successful complexity management should not only focus on reactive solutions, but drive a proactive approach to control complexity by improved decision-making on products and product variants. These findings, including recommendations and practical applications, provide innovative orientation for managers.

Zusammenfassung

Das Management von Produkt- und Variantenvielfalt stellt eine entscheidende Fähigkeit für den Erfolg von Unternehmen in der produzierenden Industrie dar. Angebotene Produktvielfalt unterstützt den Ausbau und die Verteidigung von Marktanteil, Umsatz und Profitabilität. Produktvielfalt induziert jedoch auch Komplexität im Unternehmen. Obwohl zahlreiche Konzepte zur reaktiven Komplexitätsoptimierung bestehen, gibt es wenige Erkenntnisse darüber wie produzierende Unternehmen Initiativen zum Komplexitätsmanagement erfolgreich gestalten und implementieren.

Durch eine breit angelegte Umfrage mit 175 teilnehmenden Unternehmen und durch die detaillierte Untersuchung der Ansätze bei fünf Fallstudien-Unternehmen, leistet diese Forschung einen Beitrag zur interdisziplinären Theorie des Komplexitätsmanagements. Es zeigt sich durch die Analysen, dass eine ganzheitliche Initiative aus zwei abhängigen Kategorien besteht: Befähigende Faktoren und Aufgabenfelder. Der Implementierungserfolg des Komplexitätsmanagements hängt stark von der Management-Priorität, der organisatorischen Verankerung und der funktionsübergreifenden Einbindung ab. Spezifische Aufgabenfelder zur Optimierung von Komplexität im Produktportfolio, in Produktarchitekturen und in der Wertschöpfungskette werden von diesen Voraussetzungen befähigt. Neben der zielgerichteten Lenkung der Initiative und der Hebung von Synergien, wurden die Bildung von Transparenz über vielfaltsinduzierte Komplexität sowie die proaktive Komplexitätsbeherrschung in der frühen Entscheidungsfindung als entscheidend identifiziert, um die Effektivität und Effizienz von Projekten zu erhöhen. Hohe Transparenz wird durch die nicht-monetäre Bewertung von Portfolio- und Produktkomplexität sowie durch die monetäre Bewertung von Komplexität in der Wertschöpfungskette geschaffen. Proaktivität im Komplexitätsmanagement wird durch die Integration einer Komplexitätsperspektive in frühe Entscheidungsprozesse, z.B. durch komplexitätsbezogene Kriterien, erreicht.

Im Gegensatz zu den isolierten Ansätzen zur Optimierung von einzelnen Problemfeldern, die in der existierenden Literatur zu finden sind, legen die Ergebnisse der Studie einen ganzheitlichen Ansatz des Komplexitätsmanagements nahe. Zudem zeigen die Analysen, dass erfolgreiches Komplexitätsmanagement nicht ausschliesslich auf reaktive Lösungen fokussiert sein sollte, sondern vielmehr einen proaktiven Ansatz zur Komplexitätsbeherrschung durch verbesserte Entscheidungsfindung für Produkte und Varianten verfolgen sollte.

Index

Contents

Figures

Tables

Abbreviations

#	Number
ABC	Activity-based costing
ATO	Assembled-to-order
B2B	Business-To-Business
B2C	Business-To-Customer
B2G	Business-to-Government
BMW	Bayerische Motoren Werke AG
BOM	Bill of material
CA	Complexity Assessment
CAGR	Compounded annual growth rate
CEO	Chief Executive Officer
CI	Complexity Index
CO_2	Carbon dioxide
COGS	Cost of goods sold
cont.	continued
COO	Chief Operations Officer
e.g.	for example, for instance (Latin: *exempli gratia*)
EBIT	Earnings before interests and taxes
ECV	Expected commercial value
ed.	edition
EMEA	European Medicines Agency
et al.	and others (Latin: *et alii/alia*)
ETO	Engineered-to-order
EurOMA	European Operations Management Association
FDA	United States Food and Drug Administration
h	hour(s)

i.e.	that is to say, in other words (Latin: *id est*)
IRR	Internal rate of return
IT	Information Technology
KPI	Key performance indicator
MTO	Manufactured-to-order
n/a	not available
NPV	Net present value
OEM	Original equipment manufacturer
PBP	Payback period
PI	Productivity index
PTS	Produced-to-stock
R&D	Research and development
RBV	Resource-based view
ROI	Return on investment
RPK	Resource-oriented process costing
SKU	Stock-keeping unit
SVP	Senior Vice President
US	United States
USD	United States Dollar(s)
VP	Vice President
vs.	versus
VW	Volkswagen AG

1. Introduction

1.1 Motivation

1.1.1 Practical relevance of research subject

Providing the "right" new products to the market economically is recognized as critical to the success of manufacturing companies. In fact, the ability of companies to create new products and product variants with a low level of company resource consumption is named as one key to sustain a competitive advantage (Chao & Kavadias 2008; Griffin & Page 1996; Cooper et al. 2010). However, standard products and product lines do not necessarily provide the right products to satisfy customer requirements. Times have changed considerably since the era of Ford's Model T[1]. Today's customers are less willing to buy off-the-shelf products and are demanding products to match their specific or unique needs, even at a higher price (Forza & Salvador 2007). As customers are well aware of the available product alternatives on the market, product variety lends a competitive edge to companies that are able to offer tailored products and more choices to their customers (Sanderson & Uzumeri 1997).

Consequently, companies increase the number of different products offered to customers with the objective of responding to heterogeneous customer requirements in the market place (Fisher et al. 1995; Ramdas 2003; Pine II 1993). They are convinced that if they maximize the fit between available products and customer needs it will allow them to defend or even increase market shares (Salvador et al. 2002). New ideas generated company-internal further contribute to this increased product variety. In practice, management in manufacturing companies typically sets ambitious goals for future revenue and profit to be generated from new products,

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[1] Ford (1988) promoted his company slogan "The customer can have any color as long as it is black." to restrict customer individuality for its automobile Model T with the objective of achieving high efficiency in the company's product creation processes.

variants or cost optimizations and quality improvements, which lead to an increase in products and product variants (Kavadias 2008; Ramdas 2003).

A cross-industry study[2] conducted in 2012 by the Institute of Technology Management at the University of St. Gallen (Switzerland) reveals not only an increase in product variants and new products but also in the number of active parts integrated in the products in the last three years (Figure 1). This observation is in line with other empirical studies on product variety and complexity.[3]

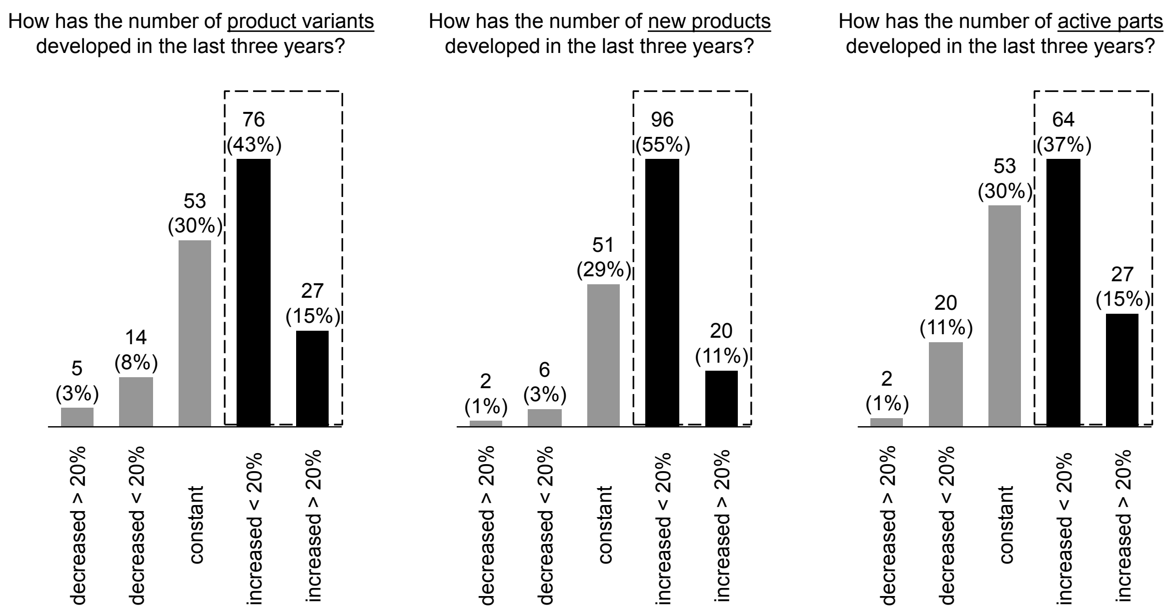

Figure 1: The development of product variety in the last three years

While the decision to extend product variety might allow the company to improve the alignment of supply and demand, such a change leads to a number of challenges with regard to complexity of products, of the portfolio, and of internal processes (Salvador et al. 2002). Complexity within the company spreads through all functional areas and operational processes: Product development, logistics, production, marketing, sales, etc. (Jacobs & Swink 2011). Indeed, as product variety increases, companies often experience internal difficulties which lead to higher direct manufacturing costs, manufacturing overhead, delivery times, inventory levels

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[2] This study was conducted from November 2011 to January 2012 as part of the presented research. It provides results of a survey among 175 responding companies from various industrial sectors such as Mechanical Engineering, Consumer Goods, Automotive, Chemical, Pharmaceuticals, Electronics and others.

[3] Kinkel (2005), for example, observed a remarkable increase in product variety, a decrease in average order quantities and an increase in total amount of required materials in a broad study of 1118 companies from various industrial sectors.

and component prices (Schleich et al. 2007; Child et al. 1991; Krishnan & Gupta 2001).

Introducing new products and adding product variants entails additional costs throughout the company. In fact, companies consider complexity as a major cost driver (Schleich et al. 2007). Costs of increased complexity are often not easily determined. In practice, managers often rely on distorted cost information, ignoring the extra work involved in complexity due to the extreme difficulties involved in conclusively tracing costs back to their respective variants (Cooper & Kaplan 1988a; 1988b). As variety in the product portfolio increases, costs due to complexity do not occur equally for all products and product variants. Schuh & Schwenk (2001) point out that, as they lack economies of scale, non-standard variants generate more costs than standard variants, which are produced in larger amounts. As a result, early cost estimates and ultimately go/no-go decisions for low-volume products are often wrong, leading to overspending the project budget, too low product pricing and effectively cross-financing with standard products (Schuh 1995). Thus, companies have an issue to provide variety cost-effectively due to lack of awareness and understanding of the impact of product variety on complexity (Ramdas et al. 2003; Cargille et al. 2005; Gottfredson & Rigby 2009).

However, the goal is not to reduce complexity as far as possible but to find the optimum level of complexity that takes into account the benefits as well as the extra efforts generated by product variety. As Marti (2007, p. 1) points out: “Complexity is not evil per se. Both the benefits created by product variants and the costs they cause must be weighted against each other in order to find the optimum combination”. This statement is supported by empirical observations as shown in Figure 2. On the one hand, companies acknowledge the value of the differentiation effect in a competitive market environment. A diversified and complex product portfolio is considered an important factor in achieving and sustaining an advantage against competitors. On the other hand, these companies are aware of the importance of managing this complexity to realize their competitive advantage successfully and to deal with the correspondingly broad product portfolio. However, observation shows that complexity management is far from being successfully implemented. Most participants in the study conducted in late 2011 and early 2012 disagree with the statement that complexity management is successfully implemented in their company.

In conclusion, variety-induced complexity and its management is an issue with increasing relevance in manufacturing companies. Companies are required to contribute to trends such as increasing the number of product variants to serve demanding customers by developing and applying innovative approaches to complexity management.

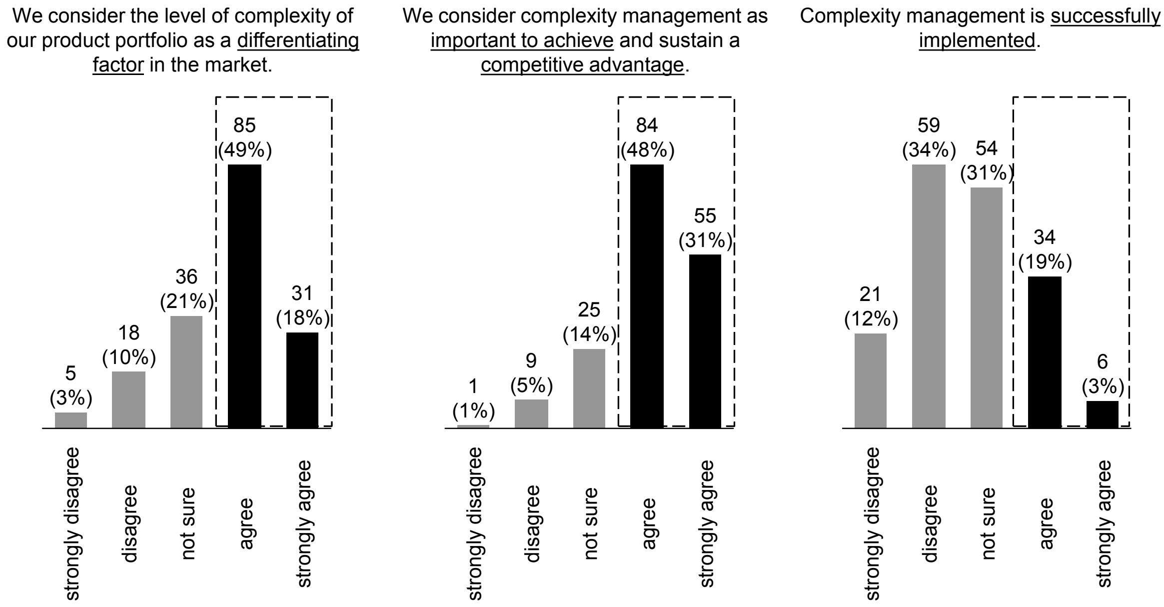

Figure 2: The role of complexity and complexity management

1.1.2 Deficits in existing research

Issues of variety-induced complexity are discussed in a number of management research disciplines such as product design (e.g. Ulrich 1995; Lindemann et al. 2009), operations management (e.g. Fisher & Ittner 1999; Fisher et al. 1999; MacDuffie et al. 1996), supply chain management (e.g. Lechner et al. 2011; Thonemann 2002; Tang 2006) and product portfolio optimization (e.g. Ward et al. 2010; Jacobs & Swink 2011). Existing research particularly provides insights into the definitions of complexity in each of the respective disciplines. Beyond specific definitions, the studies elaborate the influence of variety-induced complexity on companies' efficiency and investigate companies' approaches to handling increased complexity induced by product variety. Although existing research has produced a number of valuable results, it has largely failed to address, how companies can measure complexity induced by variety and how this knowledge can be used in companies' decision-making. In fact, research provides solutions as to how to handle complexity but does not provide practical concepts for making complexity transparent. Furthermore, recent research does not provide ample solutions for managing the "complexity avoidance phase": Early decision-making for products and product variants.

Research on variety-induced complexity management is split into three literature streams across the different disciplines: Management of product variety, complexity management and decision-making. Literature on the management of product variety discusses the perception of variety in companies, the economic benefits and the impact on organizational processes and performance. Complexity management literature describes various types of complexity and provides concepts derived from complexity science or solutions to reduce the impact of variety-induced complexity in companies. Decision-making literature describes different decision types and provides behavioral and procedural determinants of decisions in companies. In the next sections the literature streams are briefly described to show their shortcomings with respect to the management of variety-induced complexity.

Management of product variety

Product variety proliferation is a consequence of a company's strategy to gain market share by offering a high variety of products (Tang 2006). By that, companies across multiple manufacturing industries can contribute to the individuality-seeking behavior of customers in heterogeneous markets (Mendelson & Parlakturk 2008). Many publications report a trend of increasing product variety across various industries: Automobile (Fisher et al. 1995; Scavarda et al. 2009), Mechanical Engineering (Yunes et al. 2007), Information Technology (Ward et al. 2010) and Consumer Goods (Quelch & Kenny 1994).

For years it has been argued that manufacturing company markets are moving from a seller-driven to a buyers-driven business environment, leading to intense price competition in mature markets (Wildemann 1999). Companies are increasing product variety by offering customized products and by targeting new market segments. Ulrich (2006, pp. 6-7) summarizes the trend by adding six economic motives for product variety: "Heterogeneous user preferences, variety in user experience, sole source to customer, price discrimination, niche saturation and avoidance of price competition".

Ramdas & Sawhney (2001) state that the increase in product variety is not necessarily leading to higher profitability. In fact, it can impact the company's profit negatively. Product variety plays a crucial role a company's differentiation strategy[4],

[4] Porter (1980; 1985) identified two main types of competitive advantage: Differentiation and low cost. Based on the dimension of competitive advantage and the strategic target (single or multiple market segments), Porter found that a company can follow three generic strategies: Differentiation, cost leadership and focus.

but the success strongly depends on the management of product variety, e.g. in the product portfolio and the supply chain. Due to the difficulty in resolving issues related to the conversion of external into internal variety, management of product variety has become a source of competitive edge in manufacturing companies (Ramdas 2003; Meyer & Lehnerd 1997). Due to the fact that high internal flexibility and efficiency in processes are key to realize a high variety strategy (Jiao et al. 2008), researchers are concerned with the suitable organization of development, manufacturing and marketing activities to cope with this strategy (Lancaster 1990; Ramdas et al. 2003). However, they have not reached definitive conclusions on product variety's impact on companies' processes and performance (MacDuffie et al. 1996; Fisher & Ittner 1999; Jacobs et al. 2011).

Scientific studies strongly focus on the impact of variety on manufacturing tasks. So far, only little research has been conducted to examine empirically the impact of variety on other processes in manufacturing companies such as development, distribution, sales and marketing or service. These value-chain processes could be very important in practice because they also have to deal with product variety and involve major cost proportions in a manufacturing company (Ramdas 2003). In fact, studies taking a broader perspective on the entire value-chain of manufacturing companies are beneficial to both: Research on product variety and practicing managers.

A central scientific and strategic question in this situation concerns the optimum level of variety. On the one hand, offering variety increases cost; on the other hand, offering product variety can provide differentiation in the marketplace (Lancaster 1990). Researchers have examined theoretical approaches to estimate optimum variety levels (Schuh & Schwenk 2001), but without putting the concepts into operation for practical application.

In the literature stream of product variety, approaches proposed to mitigate the negative effects of product variety are product architecture- and product portfolio-related. Approaches range from modularization of product architecture (Baldwin & Clark 1997) to synergy-concepts such as product platforms and families (Robertson & Ulrich 1998). The concepts developed focus on providing solutions to handle the presupposed tremendous negative effects of product variety.

Although literature on product variety management offers insights into the motives of increasing variety, its impact on manufacturing tasks and product-focused concepts, there are very few indicators as to how managers can evaluate the impact of product variety in a holistic perspective. Similarly, established concepts for product variety management are not designed to create transparency but to use and establish synergies between products.

Complexity management

Maguire, Allen, & McKelvey (2011, p. 1) point out that “complexity is one of the fastest growing topics of research in the natural and social sciences”. Management of complexity in organization is recognized as a crucial managerial challenge (e.g. Morieux 2011; Sargut & McGrath 2011). As a result, complexity management in organizations is under scrutiny from various perspectives and with different scopes. A large body of literature discusses the management of complexity which is induced by the variety of products and product variants. However, complexity in organizations is also discussed in other contexts, such as organizational structures (Child 1972; Schwandt 2011) and the management of corporate networks (Azadegan & Dooley 2011).

Complexity management foundations derived from systems theory build an important frame for this research. Ulrich & Probst (1988) provide an established typology of systems according to their level of complexity. It is based on two dimensions: Multiplicity and variability (Figure 3).

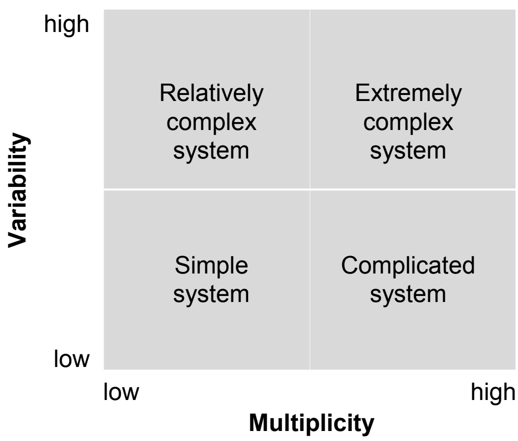

Figure 3: Typology of system complexity (Ulrich & Probst 1988, p. 58)

Multiplicity is determined by the quantity and the level of differentiation between the elements and its relationships. Variability, as the second dimension, is a result of the dynamics of the elements and its relationships over time. This typology has also been adapted by practitioners in manufacturing companies to increase the understanding on the issues of complexity management (e.g. Alders 2006).

Another basic understanding of complexity management is the differentiation between exogenous (external) and endogenous (internal) complexity (Kaiser 1995; Schuh & Schwenk 2001). A typical company finds itself trying to bridge the gap between demanded requirements by customers and product variety provided by the company. The result is the translation of customer requirements into a certain level of complexity in products and processes (Marti 2007; Schuh & Schwenk 2001).

As a result of the introduced theoretical thinking behind complexity management, researchers are concerned with the development of approaches to handle complexity. This follows the economical opinion saying that increased complexity in companies is not for free and generates high costs (MacDuffie et al. 1996). Approaches found in complexity management literature present solutions by aligning corporate processes. A practical concept frequently mentioned and refined is mass customization (Pine II 1993). The key element in this concept is the late differentiation of products realized in product creation. As only few process steps are involved in realizing the differentiation, it enables the company to transfer a high level of external complexity into a lower level of internal complexity.

It is clear that the theoretical concepts of system complexity and the differentiation of internal and external complexity are important in making complexity management more tangible. Nonetheless, the concepts are rather abstract and, to a large extent, not yet developed for practical application. Companies are not able to locate themselves in the typology illustrated in Figure 3 as there are different interpretations of the dimensions multiplicity and variability. As a result of the missing operationalization of internal and external complexity, companies are also not able to estimate their level of internal and external complexity.

Although the concept of mass customization is very popular in research and practice and is providing insights into the impact of complexity on processes, it remains unclear when this concept should be applied and at which stage the differentiation should take place. The concept is a solution-oriented approach which does not create understanding of complexity levels or, more explicitly, enable the quantification of complexity in company processes. It is also solely focused on manufacturing tasks and does cover other company processes only insufficiently.

Decision-making

Decision-making is one of the key tasks and responsibilities of managers in all types of business organizations, large and small, for profit and not-for-profit, private and public (Nutt 1989; Eisenhardt & Zbaracki 1992). Some publications even indicate that management of organizations and decision-making are practically synonymous

(March & Simon 1958). Hence, research on decision-making in companies is central to organizational theory (Nutt & Wilson 2010).

In existing literature the term strategic decision-making is used to emphasize the importance and role of decisions. Examples for strategic decisions in companies are the acquisition or divestment in businesses, entering new market segments, the organization's strategy and the development of new products and product variants. Hickson et al. (1985; 1986) point out that a decision which is considered strategic in one business or industry may be not strategic in other businesses or industries. A common aspect of strategic decisions is that they lead to the allocation of resources (Nutt 1989). Moreover, these decisions have a significant impact on the organization's performance (Nutt 1989; Eisenhardt & Zbaracki 1992). The relevance of decision-making in research is also proven by longitudinal empirical studies showing that half of the decisions made in organizations fail (Nutt 1999). Nutt's (1999) studies also reveal that decisions are more successful when managers emphasize the setting of objectives, allow freedom in the search for alternatives and involve key people to participate in the decision.

Research on decision-making is often divided into content-related research and process-related research (e.g. Elbanna 2006). Content-related research is concerned with the decision issues such as portfolio strategy, mergers and acquisitions or the alignment of the company's capabilities with environmental characteristics. Process-related research, on the other hand, deals with the process by which a decision is made and implemented. It concentrates on the factors influencing the decision process such as the underlying organizational aspects. These two research scopes are complementary and each has an influence on the other (Mintzberg & Waters 1985).

A number of frameworks and approaches for decision-making have been developed. Simon's (1965) intelligence-design-choice trichotomy, which had been adapted by Mintzberg et al. (1976), is probably the most prominent approach. Mintzberg et al. (1976) define three phases in the decision process: Identification, development and selection. Identification includes the recognition of problems and the determination of cause-effect relationships for the situation. The development phase, as the central activity of decision-making, includes the creation of one or multiple solutions for the problem. The decision is made in the selection phase were one decision or multiple sub-decisions are made. Additionally, Mintzberg et al. (1976) found that decision makers use three general procedural methods: Judgment which is strongly intuition-guided without explaining the rationale behind, bargaining which is the finding of a consensus in a team and analysis which involves thorough investigation based on facts. Building on the research by Mintzberg et al. (1976) and others, several types of strategic decision-making processes[5] and decision paradigms[6] have been derived.

Extensive research on decision-making has been published in social sciences. They provide an important basis and sharp the understanding of decisions and corresponding processes. But they are rather abstract and lacking in substance as they typically analyze a number of decisions with completely different contextual factors.[7] Apparently, there has been little applied research investigating the content and procedures of managers' evaluation of alternatives and the success of these approaches in detail.

Intersections of the literature streams

Although there is a sharpening in the focus of research on product variety and complexity in recent publications, the author believes that certain insufficiently treated or wholly unanswered questions with regard to understanding and management of variety-induced complexity could be resolved by conducting focused and empirically-based research.

Of particular research interest are the intersections between the introduced literature streams. They reveal the shortcomings across existing research:

- **Transparency on variety-induced complexity**: The creation of transparency is known as a key task by managers (Child et al. 1991; Amann et al. 2012). It is also critical for complexity management.[8] Managers need to know the complexity levels their company has to handle as well as the impact on processes, products and the product portfolio. Surprisingly, these aspects of

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[5] For example, Nutt (1984) presents five types of decision-making processes which are differentiated by the approach to idea generation and process management rationale.

[6] Eisenhardt & Zbaracki (1992) provide a review of four dominant paradigms in decision-making (rationality, bounded rationality, politics and power, garbage can). They conclude that more concrete and applicable concepts need to be developed by researchers to influence strategic decision-making in "complex organizations".

[7] Nutt (1999), for example, analyzes 356 decisions made in medium and large, public and private, profit and non-for-profit organizations on different issues such as personnel, purchases, product development, pricing, markets, planning, customer service and others.

[8] Kaiser (1995) presents a typology of strategic directions for complexity management: Avoid complexity, reduce complexity, control complexity and its combinations. To decide for the appropriate direction, complexity levels and their impact need to be transparent.

complexity management are not in the focus of existing research. A holistic concept to make variety-induced complexity transparent covering the product, product portfolio and process level, which are all affected, is not existent.

- **Decision-making for products**: Making the right decisions for products is crucial because incorrect choices in early decision-making for products can have a negative impact on the company's competitive position (Vislosky & Fischbeck 2000). Existing research provides several important insights into decision-making processes for products. Mechanisms such as rationality, political behavior and intuition make clear that decisions are not completely rational but are affected by the behavior of stakeholders involved in the decision (Eisenhardt & Zbaracki 1992). Typically, decisions for products are embedded in so-called stage-gate processes which include process phases and milestones (e.g. Cooper et al. 2001; Tzokas et al. 2004). However, milestones and details of decisions in early phases of the product development process are insufficiently investigated in literature (Schmidt et al. 2001; Schmidt & Calantone 1998).

- **Integration of a complexity perspective in decision-making**: Decisions for product and product variants at the milestones in new product development are made periodically by applying simple tools (Olavson & Fry 2008; Amaral & Kuettner 2008). These tools contain a number of monetary and non-monetary criteria showing the benefit and effort associated with the decision (Cooper 2009). Recent research points out that variety is proliferating easily because decisions in practice are not based on a balanced and comprehensive view of costs and benefits. In fact, criteria making the complexity impact in decision-making explicit are only discussed minimally and without empirical evidence.

Conclusion

Several literature streams point out the importance of managing variety-induced complexity. Figure 4 summarizes the relationships between the literature streams introduced and the final research gap to be investigated.

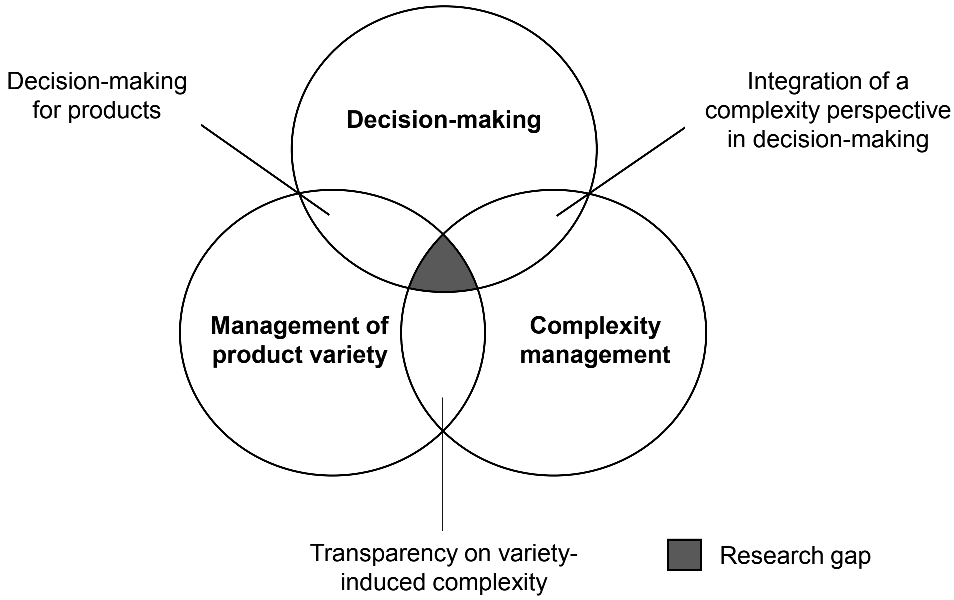

Figure 4: Literature streams related to the management of variety-induced complexity

The streams provide important product- and process-related concepts for handling increased complexity; however the concepts are not applicable for evaluating variety-induced complexity to improve clarity for managers. Evidently, some of the approaches (e.g. the concept of optimal variety) developed by scientists provide important orientation but lack practical applicability. The explanations on the literature intersections lead to another key shortcoming regarding the early avoidance of unnecessary product variety. Literature has neglected the role of complexity in decision-making for products.

In summary, two main deficits are found by considering the issues discussed in the separate literature streams and its intersections:

1. A holistic approach for evaluating variety-induced complexity
2. Explicit integration of complexity aspects in early decision-making for products

1.2 Research objective and questions

Management of variety-induced complexity has emerged as a critical issue for companies today. Research has not been able to sufficiently investigate the challenges associated with variety-induced complexity. In particular, the systematic evaluation of complexity as a result of product variety and its explicit integration in early decision-making for products remain unclear. These two issues have not been addressed empirically in existing research. The dissertation at hand aims to contribute to the closing of these gaps in existing research.

The main objective of this research is to develop a practical model for managing variety-induced complexity. It should support companies in increasing their transparency regarding complexity and in optimizing decisions for products by integrating a complexity perspective. As a sub-objective, implications and applications for practice based on empirical evidence are derived to provide guidance for managers in manufacturing companies. To achieve this research objective, the dissertation aims to answer the following main research question:

How can companies evaluate complexity induced by product variety to improve decision-making for products?

To break down this research question and to provide orientation for the research process, the following sub-questions are raised:

- **What are the main drivers of variety-induced complexity?**
  The first sub-question is posed to investigate the main drivers, externally and internally, of variety-induced complexity in manufacturing companies. Investigating these drivers supports the understanding of the trigger behind companies' complexity management.

- **How can companies evaluate variety-induced complexity?**
  The second research question is posed to investigate the most relevant approaches and indicators used to measure variety-induced complexity. These indicators are investigated on the levels of product architecture, portfolio and value chain processes to understand variety-induced complexity holistically.

- **How can companies integrate a complexity perspective in early decision-making for products?**
  The third research question is posed to investigate approaches towards explicitly integrating a complexity perspective in early decision-making for products and product variants.

1.3 Terms and definitions

Complexity

Definitions of complexity are being discussed and presented in multiple fields of research. In the field of business administration and operations management, researchers use the systems theoretical point of view which is derived from the field of cybernetics (Schwaninger 2000). Since the 1930s, systems theorists, who were inspired by cybernetics, have dominated complexity science in management theory. Basics developed in cybernetics focus on the control and coordination mechanisms in machines and organisms which have shown themselves to be valuable to management theory by explaining the patterns of organization and processes that define systems (Maturana & Varela 1973; Prigogine 1967). In this context, systems are defined as a set of interconnected elements (Bertalanffy 1968; Ulrich 1970). These elements are characterized by certain attributes, which not only have an impact on other system elements but also upon themselves itself due to their interconnections. The interconnections or relationships between the elements define the system's elements. This thinking can be applied to various systems as Bertalanffy (1968, p. 37) concludes: "There appear to exist general system laws which apply to any system of a certain type, irrespective of the particular properties of the system and of the elements involved".[9] The systems theory considers the company as a system in which different entities (e.g. departments or functions) interact with each other in order to transform a certain input into an output.

From a system's point of view, complexity is a given condition of social systems such as industrial companies (Friedli 2006). Key characteristics of complexity are the multiplicity of elements, the relationships between the elements and the combination of multiplicity and relational aspects (Ulrich 1970; Bleicher 1972). These characteristics create difficulties by requiring additional resources to process the item in question (Bleicher 1972). As Table 1 indicates, these complexity characteristics have different specifications across different research fields.

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[9] For a comprehensive review of the historical development of the systems theory and the implications for complexity science please refer to Merali & Allen (2011).

Table 1: Definitions of complexity in different research fields

Research field	Author(s)	Definition
Systems theory	Simon (1962, p. 468)	Complexity is manifested in a system comprised of a large number of parts that interact in a non-simple way.
	Patzak (1982, p. 23)	Complexity is manifested in the variety and connectivity of system elements and the variety and connectivity of relationships.
	Ulrich & Probst (1988, p. 58)	Complexity is a system's attribute which depends on the number of system elements, the relationships between these elements and number of possible system states.
	Senge (1990, p. 71)	Complexity is manifested in the number of variables embedded in a system (detail complexity) in which cause and effect are not obvious (dynamic complexity).
	Klir (1991, p. 115)	Complexity is manifested in the number of entities involved in the system (variables, states, components) and the relationships among the entities.
	Malik (1992, p. 37); Schwaninger (2009, p. 84)	Complexity is defined as a system's property of being able to assume a large diversity of states or modes of behavior.
	Bleicher (1996, p. 31)	Complexity is represented in the characteristics of a system which can pass through a large number of different states in a given time period.
Organizational theory	Child (1972, p. 3)	Complexity is manifested by the heterogeneity and range of an organization's activities.
	Scott (1981, p. 211)	Complexity refers to the number of different items or elements that must be dealt with simultaneously.
	Daft (1998, pp. 17-18)	Complexity refers to the number of activities or subsystems within the organization across hierarchy levels, departments and locations.
Product design	Griffin (1997b, p. 24)	Complexity is represented by the number of functions designed into a product.
	Novak & Eppinger (2001, p. 189)	Complexity is represented in the number of components within a product, extent of interactions, and degree of product novelty.
	Lindemann et al. (2009, p. 29)	Complexity represents an attribute of systems and includes aspects of numerical, relational, variational, disciplinary and organizational complexity.
Operations management	MacDuffie et al. (1996, p. 352)	Complexity is defined as a dimension of manufacturing resulting from the product strategy.
	Fisher et al. (1999, p. 297)	Complexity is manifested in the number of systems and the rate at which products in the portfolio are replaced.
	Bozarth et al. (2009, p. 79)	Complexity is proportional to the number of parts and the degree of unpredictability in supply and demand.
	Jacobs & Swink (2011, p. 679)	Complexity is defined as a design state manifested by the multiplicity, diversity, and interrelatedness of products within the portfolio.

In line with established definitions from systems theory and operations management, complexity in this research is defined as a system's state manifested in the number of system elements, the level of difference across the elements and the relationships between the elements.

Product variety

The definition of product variety is not clear in existing literature (Ulrich 2006; Pil & Holweg 2004). Variety is described in a number of different classifications across business administration and engineering literature. In an example from the business administration literature, Fisher et al. (1999, p. 297) suggest two dimensions to define product variety: "The breadth of products that a firm offers at a given time and the rate at which the firm replaces existing products with new products". When discussing product variety from a complexity standpoint researchers favor a differentiation between product variety and component variety (Blackenfelt 2001), which is also presented as external and internal variety (Kaiser 1995; Schuh & Schwenk 2001).

External variety describes the choice visible to the customers. Internal variety is experienced inside the company when external variety (in form of specific customer requirements) is compiled into tasks to create the product (Pil & Holweg 2004; Kaiser 1995). External variety, meaning the perception from a customer's perspective, is defined by three characteristics: Fit, taste and quality (Ulrich 2006). Fit is achieved when a peak in demand for a certain product attribute is exhibited by the customer. If the product fails to display this attribute, customer satisfaction decreases significantly. In contrast to the case of fit attributes, differences in taste attributes do not necessarily lead to a decrease in satisfaction as customers accept different values. Fit and Taste are dependent on individual customer preferences. Quality attributes are perceived in the same way by all customers. Satisfaction typically increases with higher values of quality attributes as long as the customer is willing to pay the set price.

Internal variety is categorized in three types: Fundamental, peripheral and intermediate (MacDuffie et al. 1996). Fundamental variety means the variation in different base products, platforms and models. Peripheral variety refers to the capacity to offer a large number of options without changing the basic product design (variation in options). Intermediate variety manifests itself in the variation in parts which reflects the impact on the design of products and the supply chain. Figure 5 illustrates the dependencies of these three classifications.

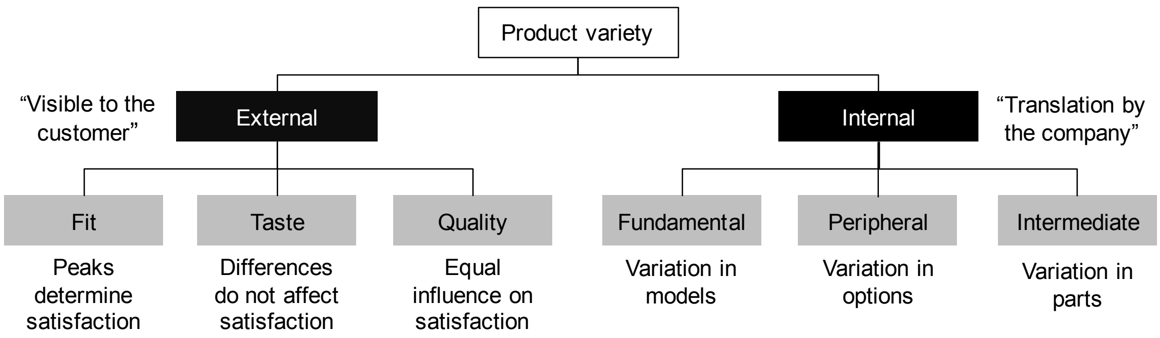

Figure 5: Categorization of product variety (adapted from Pil & Holweg 2004; Ulrich 2006; MacDuffie et al. 1996)

The presented research examines the differentiation between external and internal variety. External variety means the product choice offered to the customer, which can be estimated e.g. by multiplying all possible features offered. Lechner et al. (2011) state that there are German premium automobile manufacturers (e.g. BMW, AUDI, and Mercedes-Benz) whose product variations in automobiles exceeds the number of 10^{20} for several models when multiplying the product options offered. As the company decides to react to the external variety, it translates demands into requirements for their value-chain and creates internal variety (Pil & Holweg 2004). Finding and improving the optimum balance between external variety and the resulting internal variety is named as a core task of variety management. Internally a manufacturing company wants to have as few variants as possible and externally as many variants as needed to fulfill demands of existing and new customers (Riedel et al. 1999; Blackenfelt 2001). There are, however, also internal factors which are not always rational reactions to external business changes. Focus on cost reduction for individual products and quality improvements to products coming from sales field force, quality or development departments are necessary internal changes to stay competitive. But, they are contributing to increased product variety. Additionally, unnecessary product variety is created by individual objectives e.g. by managers who change plans and product strategies too frequently and too suddenly (Ehrenspiel et al. 2007). In conclusion, product variety is a result of multiple external and internal factors.

In the context of this research a definition by Ulrich (1995, p. 428) is adapted which focuses on the capabilities of internal processes to create a variety of products: "…the diversity of products that a production system provides to the marketplace". Hence, product variety in this research proposal is defined as the diversity of products that a company's value-chain provides to the marketplace.

Decision-making

Decision-making is a broad field of research which has been targeted from several perspectives and scientific approaches, e.g. psychology and cognition which deal with the human behavior and cognitive processes, or rational mathematical areas where decision-making always strives for maximized utility. As this research is concerned with the managerial choice between alternatives with the purpose of achieving corporate objectives, best-suited definitions are found in management science.

In line with recognized researchers in management science (e.g. Nutt 1984; Nutt 1989; Eisenhardt & Zbaracki 1992), who follow the work of Henry Mintzberg, a decision is defined as a "specific commitment to action (usually a commitment of resources)" (Mintzberg et al. 1976, p. 246). Decision-making, understood as the decision process, refers to a "set of actions and dynamic factors that begins with the identification of a stimulus for action and ends with the specific commitment to action" (Mintzberg et al. 1976, p. 246).

1.4 Research concept

1.4.1 Research classification

The trigger of this research topic is a practical problem experienced by companies and managers and not a phenomenon exclusively born of scientific discussions. Therefore, the approach used for this research is based on the tradition of applied social sciences following the perspectives of Ulrich (1984) and Bleicher (1996). They argue that, as an applied social science, management research should maintain constant contact with practice throughout the research process with the objective of contributing to the solution of practical problems.

As the management of variety-induced complexity represents a new perspective, an inductive and exploratory research approach has been chosen. The underlying research process is shown in Figure 6.

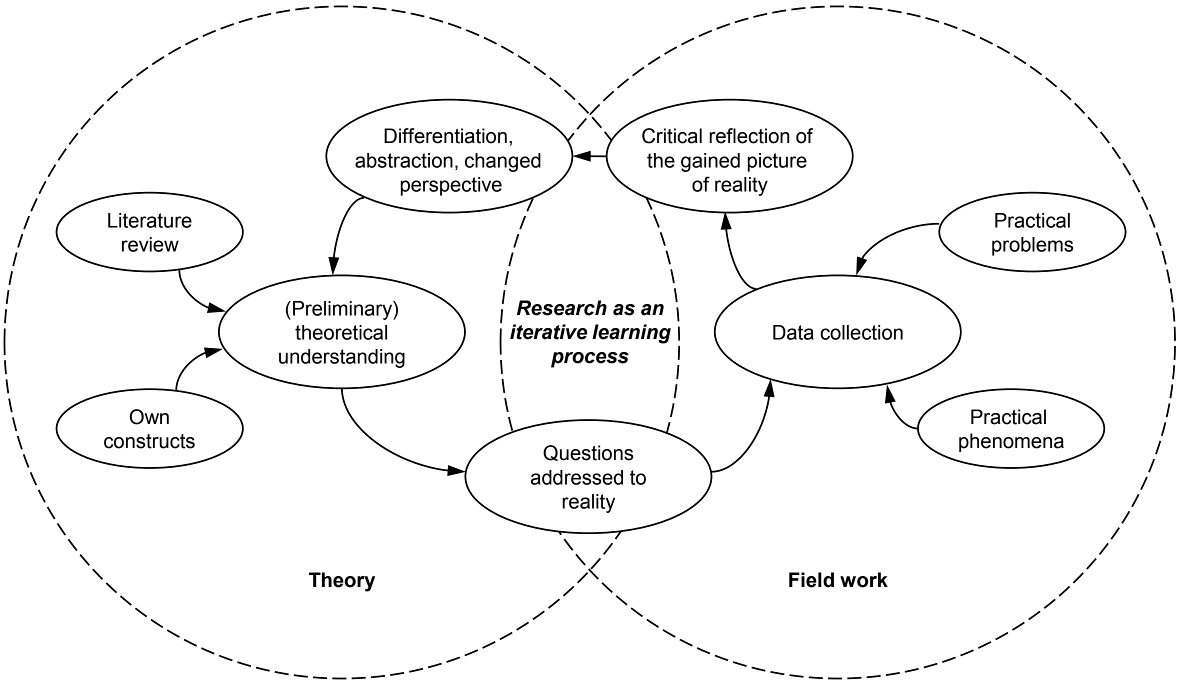

Figure 6: Exploratory research as an iterative learning process (Kubicek 1977, p. 29; Tomczak 1992, p. 84; Gassmann 1999, p. 13)

Based on the identification of problems and possible solutions relevant to business practice, theories relevant to the problem are identified. Then the application context is assessed by the creation of an initial reference framework (Roessl 1990). This framework consists of the researcher's initial understanding of the research problem from a practical and a theoretical perspective (Kubicek 1977). By analyzing survey data and case studies with an explorative, empirical and inductive methodology this initial research framework is tested, refined and developed further. The image of reality is created through the framework and the data collection. Both are reflected critically in order to achieve differentiation, abstraction, and changes in perspective. The result is a new theoretical understanding as a contribution to the existing knowledge base. An aspect which is emphasized is that instead of validating hypotheses created solely upon theory, the targeted new knowledge covers questions on reality, which is based on both: Theory and practice (Kubicek 1977). The described research approach is considered to be a learning process with a number of iterations to reflect findings from the different research phases and combine them with new findings.

This research aims to establish links between the formulated research objectives and the results of the raw data analyses. Results of basic science, following an deductive approach, are usually accepted or rejected hypotheses which are then generalized based on the hypotheses testing (e.g. Eisenhardt 1989). This research, however, follows an inductive approach and leads to a conceptual model and hypotheses that emerge from the raw data. The model and hypotheses extend existing theory or represent new theory on the management of variety-induced complexity.

1.4.2 Research methodology

The research methodology applied here is a combination of quantitative and qualitative research, whereby emphasis is placed on the qualitative part. The reason for this combination lies in exploratory nature of this research and the ambition to achieve internal and external validity in the research process (Voss et al. 2002). In fact, researchers in management science emphasize that qualitative and quantitative approaches are complementary rather than competitive methods (Jick 1979; Wilson 1982). The combination of research methods is also known as triangulation. Denzin (1978, p. 291) defines triangulation as "a combination of methodologies in the study of the same phenomenon". Triangulation represents a multi-method approach investigating the same research object with two or more types of data collection and analysis. A key advantage of using triangulation is that an additional methodology can compensate for another method's shortcomings. For instance, quantitative methods can lack the depth of analysis, which can be balanced by the higher level of detail in the qualitative method.

This research begins by taking a quantitative approach in order to make a broad investigation and provide the basis for an in-depth qualitative study. Main findings of the literature review and the reference framework will be used as the basis of an extensive industry survey. Following Wilson (1982), the goal of quantitative social research is to the meet the key scientific criteria, namely objectivity, reliability, validity and ability to generalize. To meet these criteria quantitative research uses a larger sample (e.g. of companies) compared to qualitative research. It is argued that the main advantage of quantitative research is that data can be compared and systematically analyzed in an objective way by expressing it numerically. However, many social interactions cannot be illustrated numerically. It is further criticized that objectivity and ability to generalize limits the ability to deal with respondents and to fully take them into account (Mayring 2002). Also, given categories in a survey limit the respondents' choices and typically do not offer the option of providing important qualitative detail. Supporting these criticisms, Tomczak (1992, p. 77) states that quantitative "mainstream methods" lack the ability to answer problems from practice. Punch (2005, p. 241) explains: "Quantitative research readily allows the researcher to establish relationships among variables, but is often weak when it comes to exploring the reasons for those relationships". The quantitative investigation is therefore done to provide first insights and to select the companies for in-depth case studies. Companies for the case studies will be selected purposely because a random sampling can lead to a biased selection and can prevent theoretical generalization.

The research requires multiple sources of evidence due to the fact that the boundaries between the phenomenon and the context are not clear (Yin 2009). To overcome the shortcomings in the quantitative stage, the proposed research presents case studies in the qualitative stage. Case study research, as the major empirical part of this research, enables the study of complexity management within its "real" setting (Punch 2005). It leads to valuable insights through observing actual practice in context. Eisenhardt (1989) and Yin (2009) state that qualitative research is especially suitable for research topics about which not much is known or when known results are to be investigated from a new perspective. The aim of the case study approach is to analyze one case or a small number of cases in detail to gain in-depth and comprehensive knowledge (Punch 2005). For the anticipated research, a multiple case study approach with a cross-case analysis is seen as the most suitable method because individual contextual factors are expected to be important when investigating the phenomenon of complexity management (single unit of analysis). The objective is to enhance the ability to generalize the conclusions of the anticipated model by considering multiple cases from different industrial contexts, business models, technology orientations, etc. (Yin 2009). However, as with an experiment, it can be said that case study results can be generalized to the theoretical framework but not to populations or universes (Yin 2009).

Nonetheless, through interviews and workshop sessions, the qualitative case study approach will help to analyze the research framework and its element interrelations. This qualitative research phase is expected to uncover issues not identified in previous research stages. In combination with the quantitative approach, the empirical foundations will be far-reaching, detailed and expected to provide insights to answer the research question.

Sample selection and data collection

The empirical research was conducted in three phases. The first phase was carried out to gain insights into companies' approaches to complexity management on a broad scale. It therefore followed a quantitative research approach based on a survey. This cross-industry survey covered the questions regarding complexity drivers, transparency about complexity on the product, portfolio and process level and the integration of complexity in decision-making for products. In addition to that, data on several structural characteristics, such as the industry, competitive advantages, product types and aspects related to the success of complexity management, were gathered.[10] 175 companies and business units participated in the study and returned the completed questionnaire. Valuable insights were derived from the descriptive analysis and by creating certain clusters to identify elements of successful complexity management. Based on the maturity and success of their complexity management approaches, 17 companies were identified as potential candidates for in-depth case studies.

The second phase follows a qualitative approach to achieve more detailed findings than those revealed in the questionnaire analyses. The phase is divided into case selection and in-depth case studies. For the purpose of case selection (Phase IIa), a structured interview guideline was developed and sent out to the interviewees.[11] 17 companies, which had been identified in Phase I, were interviewed. The interviews were 60 to 120 minutes in length with one to three interview partners from different functions (e.g. Product development, product management, manufacturing, strategy, business development) and hierarchy levels (e.g. CEO, COO, VP, Head of Business Unit). In total 20 interviews were conducted and recorded in Phase IIa.

Phase I and Phase II were part of a contracted benchmarking project[12] financed by six industrial companies allowing for an additional reflection by practitioners of the findings throughout the empirical phases. These six companies also took part in the final selection of the companies for the in-depth case studies among the 17 potential companies. Five companies were finally selected according to the maturity and success of their complexity management as well as the potential of learning.

Phase IIb consists of qualitative, in-depth analyses of the five companies with very advanced approaches to complexity management[13]: Automobile Inc., Mechanical Engineering Inc., Automation Technology Inc., Assembly Systems Inc., and Consumer Goods Inc.[14] The five companies had an established complexity

[10] The questionnaire is added in the appendix.

[11] The interview guideline is added in the appendix.

[12] Camp (1989) introduced benchmarking as a procedure to compare internal processes, approaches, methods or metrics to successful practices within the same branch and in other industries with the objective of learning and adapting these practices.

[13] Eisenhardt (1989) suggests conducting between four to ten case studies to generate a theory with empirical grounding.

[14] The names of the companies have been changed to ensure confidentiality. In this research, the company is referred to under a fictitious company name. The names mentioned replace the actual company names.

management for several years and have interesting, yet very different, approaches to creating transparency of complexity and to integrating complexity in early decision-making. Mechanical Engineering Inc., for example, emphasizes the process-oriented calculation of complexity cost across their value-chain and integrates an estimate of complexity cost based on past project experiences in its business cases. In contrast, Consumer Goods Inc. sets a focus on the profitability of stock-keeping units (SKUs) to evaluate complexity as this is the key indicator. The data gathering for the case studies was done in interviews (each 120 minutes) and on-site workshops (8 hours). Interview and workshop data were augmented by company-internal presentations and documentations. If necessary, follow-up interviews with the companies were conducted to re-confirm interpretations.

The third phase consists of two qualitative, action-research-oriented projects. Each of the projects was conducted in close collaboration with one industrial company to develop practical solutions based on the observations made in the empirical phases I and II. Phase IIIa focused on the creation of transparency of complexity levels and led to a development of a complexity index specifically designed for the complexity evaluation of production plants. Workshops (8 hours each) with key production network representatives and a series of interviews (60 to 120 minutes) with multiple plant managers built the data basis. Another important source was a data set of 158 production plants containing a large number of operational indicators included in the complexity index.

Phase IIIb addresses the problem of integrating complexity in early decision-making for products. It provides a solution to integrate a complexity assessment in early business case evaluations. As a basis a series of workshops (three to six hours each) was conducted with multiple key stakeholders of the company (e.g. Product management, product development, marketing, controlling, supply chain management). The data gathered in the workshops was enhanced by interviews with single or multiple persons. Historical data from past decisions and company-internal documentations (e.g. process descriptions and business case templates) accompanied the analysis and development of the complexity assessment.

The three empirical research phases were accompanied by a constant literature reflection. Emerged issues derived from the data analysis were compared with existing literature. An overview of the empirical data as a basis for this research is shown in Table 2.

Table 2: Overview of the empirical data set in research phases I, II and III

Research phase (data type)		Number of companies	Number of interviews	Number of workshops	Additional data source
Phase I (quantitative)					
I	Cross-industry survey	175	-	-	-
Phase II (qualitative)					
IIa	Case selection and preparation	17	20 (1-2h each)	-	-
IIb	In-depth case studies	5	5 (2h each)	5 (8h each)	Company internal documentations
Phase III (qualitative)					
IIIa	Complexity index	1	12 (1-2h each)	2 (8h each)	Data from 158 production plants
IIIb	Complexity assessment	1	12 (1-3h each)	14 (3-6h each)	Historical data on product decisions
Total number of author's interviews and workshops		**177**[15]	**49 (88h)**	**21 (128h)**	

Data analysis and theory building

Due to the newness of the research issues to be investigated, the study emphasizes empirical research which includes multiple alternations between data collection and data analysis. In this research, data analysis from the survey raises further questions that can only be investigated with additional, in-depth data collections (Strauss & Corbin 1998). These in-depth data collections, as a core element of the research, follow Eisenhardt's (1989) approach to deriving theory from case study investigations.

The starting point of this research is a comprehensive literature review conducted to identify critical issues and elements as components for the initial research framework. This literature review represents an important element to increase the researchers' knowledge of the issues already addressed in complexity management, the gaps in the existing research and insights into established complexity management concepts which are proven to work. On the basis of the initial literature analysis, the research framework is constructed describing the phenomenon under investigation (Miles & Huberman 1994).

[15] The number of companies is adjusted for redundancies.

In the second phase, the reference framework was brought to the field in form of a survey and multiple case studies. The reference framework served as a guide for data collection (Voss et al. 2002). First, a survey was used to gather first insights on successful practices throughout industrial companies, to derive additional questions to be investigated and to provide orientation for the selection of the companies for the case studies. To achieve these objectives the quantitative data was analyzed descriptively and was coded to conduct a cluster analysis. Second, in-depth case studies present in detail the complexity management approaches of five industrial companies with different company profiles and business environments. As new issues are discovered in the empirical parts of the research, additional literature is necessary. This led to a comparison of the research findings with existing literature in a cross-case analysis. The empirical research and additional literature reflection led to specific refinements of the reference framework which is finally represented in the conceptual model for the management of variety-induced complexity.

The results of the survey, the cross-case analysis and the conceptual model were used to create a number of research hypotheses. These new statements extend existing theory on variety-induced complexity management. In summary, the results of the literature analysis, survey and case study analyses lead to three contributions to management theory:

- A reference framework derived from the key issues presented in literature and used to steer quantitative and qualitative data collection
- A conceptual framework built on the findings of the research to provide a science-based, empirically proven and practical concept for the management of variety-induced complexity
- A series of hypotheses based on the iterative analyses of literature and newly gathered empirical data.

1.4.3 Research theory

The ultimate objective in the field of management science is to find an explanation as to why some companies perform better than others (Rumelt et al. 1991). Established strategic approaches developed by Porter (1980; 1985) consider the company from an external perspective and focus on attractiveness and competition in the industry rather than on company-internal capabilities. Internal aspects, on the other hand, are emphasized by the resource-based view (RBV).

Based on Penrose (1959), who provided initial thoughts on a resource-focused perspective of the company, Wernerfelt (1984) articulated the dependencies between internal resources, capabilities, and competitive advantage. RBV advocates that the creation of a competitive advantage is less dependent on the industry setting the company operates in but more on the exploitation and development of internal resources. The use of internal resources, tangible and intangible, such as assets, skills, abilities, processes and knowledge are in the focus of the RBV (Penrose 1959). These resources manifest unique abilities, which can be bundled into capabilities (Wernerfelt 1984; Amit & Schoemaker 1993). By using these resource bundles, a competitive advantage can be attained by a company if the bundles are unique or at least rare and not easily imitable by competitors (Hamel & Prahalad 1994; Barney 1991).

It is argued by researchers that the RBV is basically static, which means that the theory is limited when dynamic environments, surrounding most manufacturing companies, are investigated (Teece 2007; Barney 1991; Eisenhardt & Martin 2000; Wang & Ahmed 2007). More specifically, Griffin (1997a, p. 430) explains: “If the world was stable, there would be no need to change business operations and methods, nor to understand what has changed and what works well. However, firms operate in dynamic environments, not stable ones. Both the competitive and internal environments in which firms operate evolve over time. In response, management processes must also change over time so that firms can remain effective and profitable through the changing situation”. The emergence of dynamic capabilities extends the RBV.

However, definitions in the dynamic capabilities concept, like in the RBV, are not definite. For instance, Teece et al. (1997, p. 516) define dynamic capabilities as “the firm’s ability to integrate, build, and reconfigure internal and external competences to address rapidly changing environments. Dynamic capabilities thus reflect an organization’s ability to achieve new and innovative forms of competitive advantage given path dependencies and market positions”. This does not significantly differ from their definition of capabilities used in the RBV: “The key role of strategic management in appropriately adapting, integrating, and reconfiguring internal and external organizational skills, resources, and functional competences to match the requirements of a changing environment” (Teece et al. 1997, p. 515). Nonetheless, the concept of dynamic capabilities has extended the RBV by providing a basis for explaining the role of environmental changes and its interrelation with resources and capabilities of industrial companies (Wang & Ahmed 2007). However, dynamic capabilities are not directly the source of high organizational performance. They are inevitable but are not ample for creating a competitive advantage (Eisenhardt &

Martin 2000). The competitive advantage is, in fact, created by appropriate resource configurations as an outcome of dynamic capabilities in a company.

The ability to efficiently create a variety of products is a central source of competitive advantage for manufacturing companies and managing complexity is an essential part of this competence. As manufacturers can differentiate themselves from competitors by achieving cost efficiency in their value-chain, it is critical to know the impact of product variety and how a company can cope with this impact. Moreover, decisions for projects for new products and product variants are critical as they are the basis for creating the right resource bundles for each of the categories. Therefore, integrating complexity in these decisions positively influences the ability to create a competitive advantage.

The competitive advantage itself is then generated by controlling complexity to improve effectiveness and efficiency as a result of a decision about the right products to be created. The products to be created and the internal organization (structures and processes) need to be aligned with the environmental changes and dynamics experienced by the company. As explained, the ability to anticipate changes in the environment and achieve internal fit with the environment is a dynamic capability of a manufacturing company. Management of variety-induced complexity contributes to the competitive advantage of a company by enabling the set-up of the most promising resource and capabilities base.

Based on the thinking that the understanding and management of variety-induced complexity leads to improved allocation of resources because of better decisions for products and variants, the basics of the RBV are decisive for this research. Therefore, the RBV including the dynamic capability enhancement will serve as the theoretical perspective for the discussion and interpretation of the empirical findings of this thesis.

1.5 Thesis structure

The remainder of this thesis consists of six chapters (Figure 7):

- Chapter 2 presents the key issues discussed in existing literature relevant to the management of variety-induced complexity. It ends with the conclusions drawn from the literature review.

- Based on a comprehensive literature review, the research framework is designed to provide orientation for the empirical investigation. This reference framework concentrates on the elements of transparency creation in complexity management, the elements of complexity management in decision-making for products and their interrelations.

- Building on the reference framework, Chapter 4 presents the empirical investigation consisting of a quantitative and a qualitative part. At first, descriptive results from 175 completed questionnaires reveal first insights into complexity management. A cluster analysis supports the identification of differences between the companies and the selection of the case study companies. As the quantitative analysis led to additional questions and lacks the necessary level of detail, five in-depth case studies are presented in the second part, each with the same structure to ensure comparability.

- Chapter 5 includes reflections on the findings of the empirical observations. The analysis starts with a comparison of the individual cases to reflect the observation with the operationalized reference framework. In a second stage, the cross-case analysis is conducted to identify commonalities and differences between the case studies and to find reasons for these. This cross-case analysis is accompanied by additional literature reflections. The chapter finishes with a presentation of the conceptual model for managing variety-induced complexity.

- In Chapter 6, the research findings are summarized and the implications for management theory and management practice, which should serve as a guideline for managers, are outlined. The chapter is enriched with two practical applications. The first application is designed for the evaluation of variety-induced complexity on production plant level. The second application presents an approach to integrating complexity perspective in early decision-making.

- Chapter 7 explains the contributions to theory and practice. The dissertation closes with a discussion of the limitations of the research conducted and suggestions for future research.

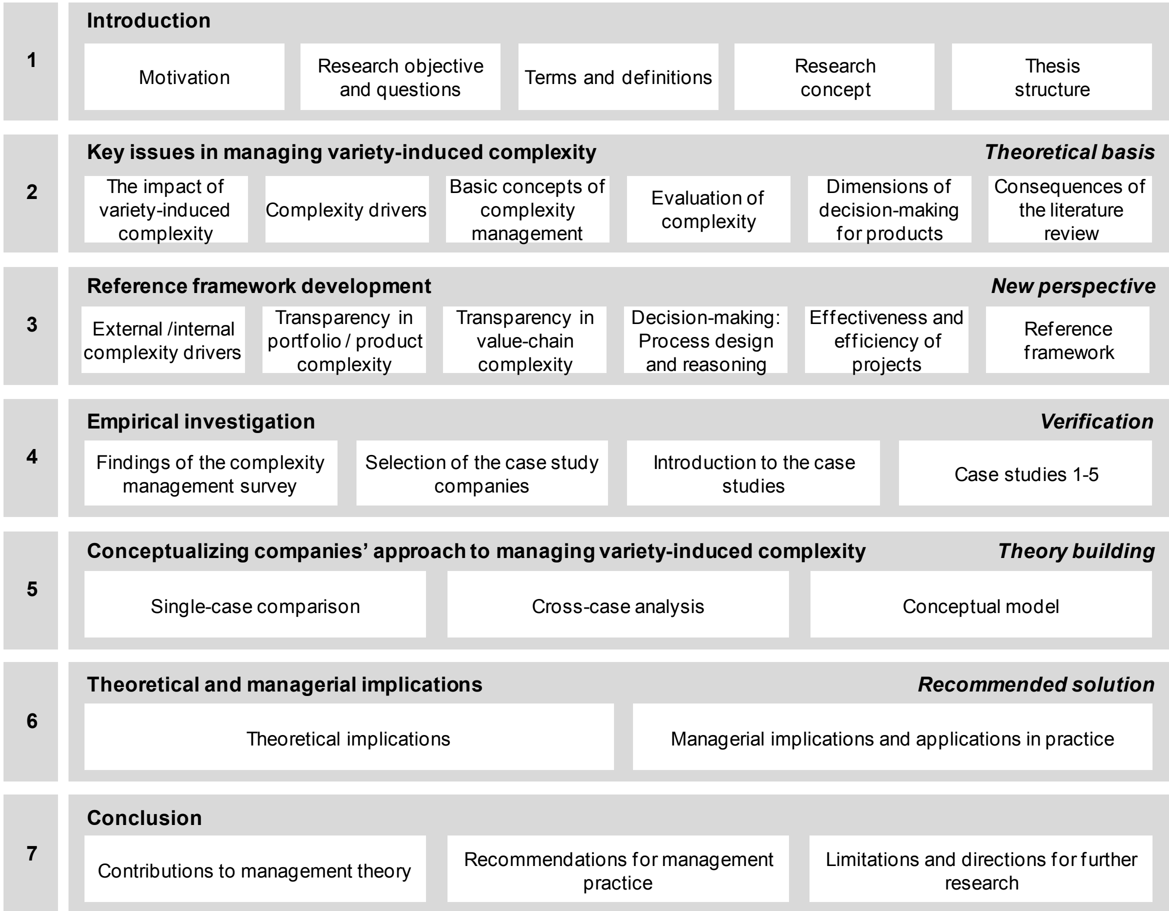

Figure 7: Structure of the thesis

2. Key issues in managing variety-induced complexity

The development of a concept for managing variety-induced complexity necessitates for the review of related research to complexity management and managerial decision-making. This chapter provides an aggregated view on the key issues presented in research to date. The literature on complexity management discusses the role and triggers of variety-induced complexity, solutions to reduce complexity in the product architecture, product portfolio and processes, existing approaches to complexity evaluation, whilst the literature on decision-making emphasizes the decision mechanisms in manufacturing companies. This literature review enables consequences for the research conducted to be drawn and provides input for the elements of the reference framework.

2.1 The impact of variety-induced complexity

Industrial companies strive for high levels of effectiveness for their products and efficiency in product creation to create a competitive edge (Drucker 1973; Day & Wensley 1988). Effectiveness in systems theory is described as the benefits created when fulfilling demands by customers which becomes visible e.g. in revenues or customer satisfaction (Patzak 1982). Efficiency, on the other hand, is achieved when the effort required to realize these benefits is low, e.g. visible in costs (Patzak 1982).

From the systems perspective, the impact of variety-induced complexity can be divided into benefits and efforts. In decisions on product variety, benefits and effort have to be weighted against each other. Schuh (1995) has investigated the effects of product variety and presents a model to describe the transition from standard, high-volume products to individual, low-volume products and the resulting impact on costs and competitive position (Figure 8). Manufacturing companies are moving from standard, high-volume products to more exotic, low-volume products and product variants. As a result the frequency curve of products is changing and is becoming broader. Former economies of scale are no longer achieved (Boutellier et al. 1997b). There is a critical point where the company has too many non-profitable product variants and enters the loss zone when actual costs exceed revenues. The low-volume products are then typically cross-subsidized by the standard products. Consequently, the broadening of the product portfolio and uncontrolled adding of product variants lead to a competitive disadvantage.

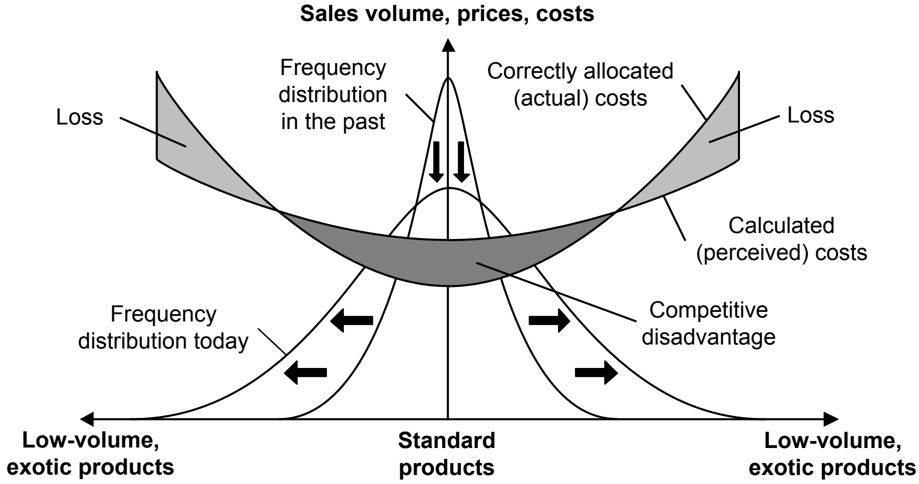

Figure 8: The complexity challenge of manufacturing companies (Schuh 1995, p. 431)

2.1.1 Benefits of variety-induced complexity

Although complexity typically has negative connotations, there are clearly benefits associated with increased complexity which are acknowledged by manufacturing companies. Product proliferation enables customers to find the products which explicitly match their requirements and attracts new customers. The extended choice offered to the customers leads to sales improvements and maintains and expands the customer base (Child et al. 1991; Rathnow 1993). If a company provides a large portfolio that is aligned with the customers' requirements, existing customers do not have to deal with other providers in order to get the desired product. In fact, this can lead to an increase in profits, revenues and market share.

If a company is able to create a specialized yet broad product portfolio, it can position itself as a specialized niche provider and achieve a competitive advantage in the market (Bleicher 1996; Boutellier et al. 1997b). Variety in combination with flexible processes can also lead to operational benefits. For example, Toyota's production system showed that a production plant is able to produce diverse models on flexible production lines which enables the plant to level the demand by shifting orders between the lines (Liker 2004). At a production plant level, capacity under-utilization is avoided and on company level lost sales due to missing capacity are reduced. Table 3 categorizes the benefits resulting from variety-induced complexity.

Table 3: Research findings on the benefits of variety-induced complexity

Benefit	Author(s)	Main findings
Competitive advantage	Lancaster (1990)	Offering customized product variants reduces competitive pressure and avoids price competition.
	Quelch & Kenny (1994)	Customized product variants prevent a direct comparison with competitors.
Gain new market share	Rathnow (1993)	An increase of product variety can expand the company's market share by gaining new customers.
	Kekre & Srinivasan (1990)	A broader product line leads to a significant gain in market share. This is proven for industrial and consumer markets.
Maintain customer base	Menon & Kahn (1995)	Existing customers are more attracted by novel products resulting from an increase in product variety.
	Kahn & Morales (2001)	A broad product portfolio enables a better fulfilling of different customer preferences which leads to larger sales quantities and acceptance of higher product prices.
Increase revenues and profits	Child et al. (1991)	Sales revenue is improved by an extended and more attractive choice offered to the customer.
	Ulrich (2006)	Customers are willing to pay a higher price for higher quality products meeting their preferences.
Improve capacity utilization	Fisher et al. (1995)	A decrease in demand leads to underutilization in plants which are dedicated to certain products. If a plant is flexible and able to co-produce different models, demand fluctuations can be absorbed.

2.1.2 Efforts of variety-induced complexity

Besides the benefits resulting from variety, there are also efforts associated with complexity which are investigated in a number of publications. These efforts are mainly found in company-internal processes, but also at the interfaces to suppliers when realizing product variety. Schleich et al. (2007, p. 1) summarize the negative effects after analyzing the impact of product variety in the automotive industry as follows: "As product variety increases, a firm can also experience a reduced performance in many activities due to reduced economies of scale, with potential negative impact on component prices, lead time, and component inventory levels. Also, direct manufacturing costs, manufacturing overheads, lead time, and inventory levels in the firm's internal operations might increase if batch sizes remain unchanged which in turn leads to longer supply lead times and, consequently, to higher inventory and backorder levels". Table 4 provides a comprehensive review of existing literature discussing negative impacts which are largely consistent across scientific publications.

Table 4: Research findings on the efforts of variety-induced complexity

Effort	Author(s)	Findings
Increase in demand forecast uncertainty	Randall & Ulrich (2001)	Long forecast horizons for product variety, exposed to high demand uncertainty, lead to the difficulty in matching demand and supply.
	Fisher et al. (1995)	Forecasting the demand for a high number of products and variants is difficult, even for a short horizon.
Increase in inventory levels	Fisher & Ittner (1999)	Higher variability in parts as a result of product variety increases inventory requirements and inventory levels.
	Martin & Ishii (1996)	Product variety incurs inventory-related costs, such as raw material costs, work-in-process, finished goods, and post-sales service inventories.
Lengthening of lead times	Thonemann (2002)	Lead times get worse when realizing variety due to a high frequency of machine changeovers.
	Kekre (1987)	The number of products impedes top performance in production (long waiting times) due to the number of items to process.
Increase in product creation costs	Rathnow (1993)	Costs of variety-induced complexity involve a large portion of fixed, irreversible costs and occur in multiple functional departments. This leads to diseconomies of scope.
	Rommel et al. (1993)	A typical product variant leads to an increase in costs of 15-20 % in total (complexity cost). Mainly affected are manufacturing and development processes.
	Schuh (1995)	Exotic, low-volume products are cross-subsidized by standard, high-volume products. Standard products are sold under their real costs.
Increase in overhead costs	Anderson (1995)	More frequent set-ups and diversity in process specifications on a plant level lead to an increase in manufacturing overhead cost.
	Fisher & Ittner (1999)	Variability in product options increases working hours due to overhead functions and rework.
	Hayes & Wheelwright (1984)	Due to the increase in overhead expenses, a broad product line and corresponding low volumes for each variant can lead to higher unit costs.
Increase in quality-related efforts	Fisher et al. (1995)	Product quality suffers with the reduction of volume because statistical process control is difficult to apply with limited historical data.
Difficulties in product design	Salvador et al. (2002)	Higher product variety absorbs developers' hours in activities adding very limited or low value because developers are involved in sales supporting rather than order fulfillment activities.
Influence on suppliers	Naughton (2007)	Variety typically leads to an increase in different components or parts used, triggering more complex or parallel supply processes and requiring a larger supplier base.

2.2 Complexity drivers

In line with the differentiation of external and internal variety, researchers distinguish between external and internal complexity (Wildemann 1998; Schuh & Schwenk 2001; Kaiser 1995). External complexity, also called exogenous, goes beyond the described concept of variety and encloses many business challenges. It is caused by stakeholders in the company's environment who are in a direct relationship with the manufacturing company. Customers, suppliers, distributors and regulatory bodies influence the business landscape and therefore internal assets and processes. External complexity also strongly influences internal organization of processes (Marti 2007). Internal complexity, also called endogenous, is experienced within the company when translating customer requirements into physical products. This type of complexity affects the entire value-chain not only single processes, although with varying intensity. Observations of the automotive industry reveal that the number of variants is very different in the functional departments. For instance, 25 variants of a steering wheel in manufacturing can mean 50 variants for purchasing due to a dual sourcing strategy but only four variants for development due to four different functional product designs (Alders 2006). A complexity driver in the context of this thesis is therefore defined as "a phenomena which prompts a system to increase its complexity" (Piller & Waringer 1999, p. 19). This definition implicates the relationship between external and internal complexity.

2.2.1 External drivers

Companies experience external complexity as a consequence of market demands and requirements which the company intends to fulfill. As homogeneity of external demands is becoming more fragile due to globalism and dynamics of the company's markets, external complexity increases (Wildemann 1998). Market-oriented functions such as sales, marketing and product management are typically the first to know about changes in the market field and manifest such trends in portfolio and product changes. Aligning internal processes for product creation and the product life-cycle is the second step. This change in processes affects all functions and departments in a company.[16] Apparently, external complexity impacts companies on three levels: Product portfolio, product (architecture) and value-chain processes.

[16] Wildemann (2010) and Rathnow (1993) discuss the specific effects of complexity in certain value-chain processes of industrial companies.

This observation is supported by Bliss (1998; 2000) who introduced external complexity as a result of market requirements with the following categories:

- Demand complexity: Complexity is caused by fragmented markets, the number, size, diversity and power of customers served as well as extensive country-specifics and regulations.
- Competitive complexity: Companies increase their complexity as a result of the urge to serve global, unsaturated markets. It is often anticipated by companies that these new markets are not already occupied by powerful competitors and they therefore see an opportunity to serve a large number of new customers.
- Technological complexity: Technology advances result in a higher number of product functions. Higher product performance as another consequence of these advances leads to longer product durability and reliability (life cycles) for the customer necessitating support by the industrial company for a longer time.

In addition to these categories and their associated drivers, Wildemann (1998) mentions supplier variability as a driver. In fact, companies with a low level of vertical integration typically handle a high number of suppliers and frequent changes in their active supplier database. By taking a broader perspective, Marti (2007) emphasizes the role of society complexity for industrial companies. This category includes drivers such as political economical and legal issues as well as ecology and culture surrounding the company.[17]

In summary, external drivers are becoming tangible in the number and variability (change frequency) of products and product variants. They are caused directly by the customer, by competitors and by technology advances. Companies are typically aware of these factors and track them with practices such as market forecasts, business analyses, competitor benchmarks, product portfolio techniques and life cycle management. Nonetheless, external drivers are difficult to control by the company as most of them are not decided by the company but by external stakeholders. The characteristics of and decisions taken by company-external entities define the level of external complexity to a large extent. Nonetheless, it is emphasized in existing research that external complexity is interrelated with internal complexity (e.g. Schuh & Schwenk 2001; Pil & Holweg 2004). However, this interrelation is only described on a very high level by explaining the drivers very

[17] Marti's (2007) presentation of external complexity drivers adapts research by Kirchhof (2002) and Sekolec (2005).

vaguely. Evidently, comprehensive lists of drivers and short explanations are provided (e.g. Closs et al. 2008; Wildemann 2011), but the operational application of “complexity drivers” concepts and the link to complexity management approaches remain unclear.

2.2.2 Internal drivers

Internal complexity is the result of the translation of external complexity and complexity solely created internally without external pressure to do so. External complexity entails a certain level of internal complexity when the company adapts its internal processes in the value-chain (Marti 2007). However, researchers also point out that a high percentage of internal complexity has its origin in structure-, communication- and people-related issues which are not at all directly linked to external demands (Wildemann 1998).

Bliss (1998; 2000) differentiates between two main categories of endogenous drivers of complexity: Correlated company complexity and autonomous company complexity. Four determinants define the level of correlated company complexity:

- Customer structure complexity is the result of a large number of heterogeneous customer groups with low volumes for the products.
- Product portfolio complexity is driven by the breadth of the product portfolio (number of variants and the level of diversification of the variants).
- Product complexity is experienced when the architecture of the product requires a large number of raw materials, parts and components with a high level of differentiation.
- Target complexity manifests itself in the variety of operational targets to be achieved in parallel within the organization.[18]

Endogenous and exogenous drivers are not selective. For example, product portfolio complexity is the logical consequence of demand complexity. In fact, it represents the internal adaption of demand complexity. Similar links can be established for autonomous company complexity which consists of three main categories:

[18] Target complexity is also discussed in literature under the term “task complexity” (e.g. Campbell 1988).

- Production process complexity emerges from a high proportion of internally manufactured variants, modules and components very early in the production process.[19]
- Organizational complexity is a result of strong functional and hierarchical orientation and division of labor along the value-chain. Companies with a high level of organizational complexity are forced to manage a high number of interfaces leading to a high effort for planning and steering.[20]
- Production system complexity is experienced in companies running the same highly integrated processes for all types of products. Such non-differentiating systems are usually steered centrally and deterministically.

While correlated company complexity is directly influenced by external requirements, autonomous company complexity is not necessarily required to satisfy customers and is therefore undesired. Consequently, autonomous company complexity is the first subject of optimization effort in companies. Lean management practices, for example, are used to decrease all three types of autonomous company complexity.[21] However, as changes in the environment affect multiple complexity drivers externally and internally, it is challenging for companies to decrease or maintain complexity levels. Bliss (1998) phrases the interrelations between external and internal drivers as "complexity breeds complexity", i.e. complexity rises exponentially because in most cases multiple drivers are affected.

In addition to the research shortcomings pointed out in the paragraph on external drivers, it remains unclear which drivers are the most important for industrial companies. This thesis aims to investigate the importance of complexity drivers for manufacturing companies in the context of product variety.

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[19] Größler et al. (2006) argue that the process configuration, e.g. number of process types, concentration of process types, process layout and location of the order penetration, is one of the key internal complexity drivers.

[20] Wildemann (1998) lists a number of internal complexity drivers which are strongly focused on organizational complexity such as the number of hierarchical levels, duration of decision processes, concentration of interfaces, information asymmetry and unclear responsibilities.

[21] Liker (2004) investigates the practices of the automobile company Toyota and presents a general concept which has been adopted by many companies across multiple industries. For example, Friedli et al. (2010) provide insights into the application of lean management in the pharmaceutical industry.

2.3 Basic concepts of complexity management

The concepts companies have applied in coping with product variety and complexity challenges can be classified on three levels: Product portfolio, product architecture and processes in the value-chain. Product portfolio-related concepts target the determination of the optimum level of product variety as well as the creation of synergies between products. Product-related strategies have the objective of creating product architecture that allows high variety in the marketplace while presenting a production and distribution system with a relatively low level of component variety and assembly complexity.[22] Process-related strategies seek to imbue operational processes with sufficient efficiency and flexibility to enable them to accommodate a high level of variety at reasonable costs. Figure 9 illustrates the scopes of the basic concepts briefly described in the following sections.

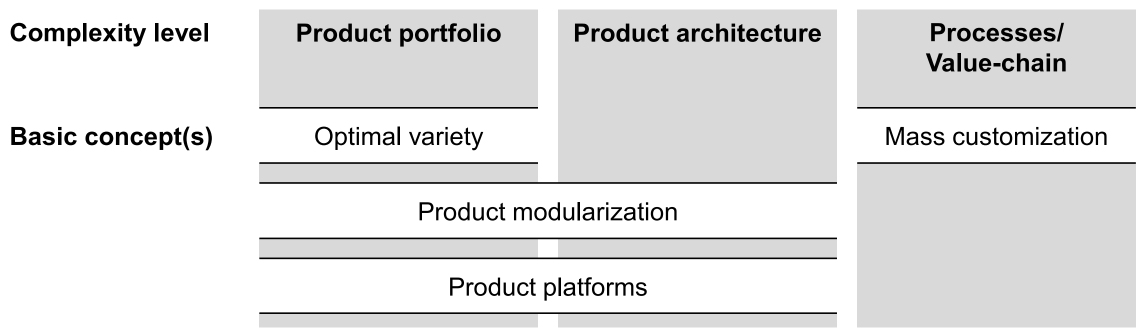

Figure 9: Basic concepts of complexity management

The concepts focus on providing solutions to the presumed problem of product variety and complexity and are geared towards the reduction of the amount of internal effort necessary. They are not explicitly concerned with the problem understanding or creating transparency. Nonetheless, important insights into the management approaches are generated which allow for the derivation of implications for the presented research. In summary, an understanding of the concepts of complexity management is important to those wishing to build on existing research, connect their own research to existing solutions and to carry out their own research.

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[22] For a presentation of tools to align product architecture with product variety such as Quality Function Deployment, Modular Function Deployment, Design for Configuration, Design for Variety, Variant Mode and Effects Analysis see Marti (2007) and Schuh & Schwenk (2001).

2.3.1 Optimal variety

The definition of the optimal level of product variety is a fundamental, as yet unresolved, challenge for most companies. Generally speaking, this challenge stems from the interplay between the profit and revenue from variety and the level of scale economies associated with product creation (Lancaster 1990). If a company does achieve a gain from product variants but does not have any economies of scale with product variants in the value-chain, the optimum is to create the product individual to the specific customer's requirements. However, if a company does not have any gains but achieves significant scale economies, the optimum is to create only one single product or a low variety that is still associated with economies of scale. Between these extremes of no economies of scale and unlimited economies of scale is a continuous range of variety levels within most industrial companies are located. Rathnow (1993) presents a visualization of the companies' need to balance gains (revenues and profits) and costs (influenced by economies of scale) to define the optimal variety (Figure 10).

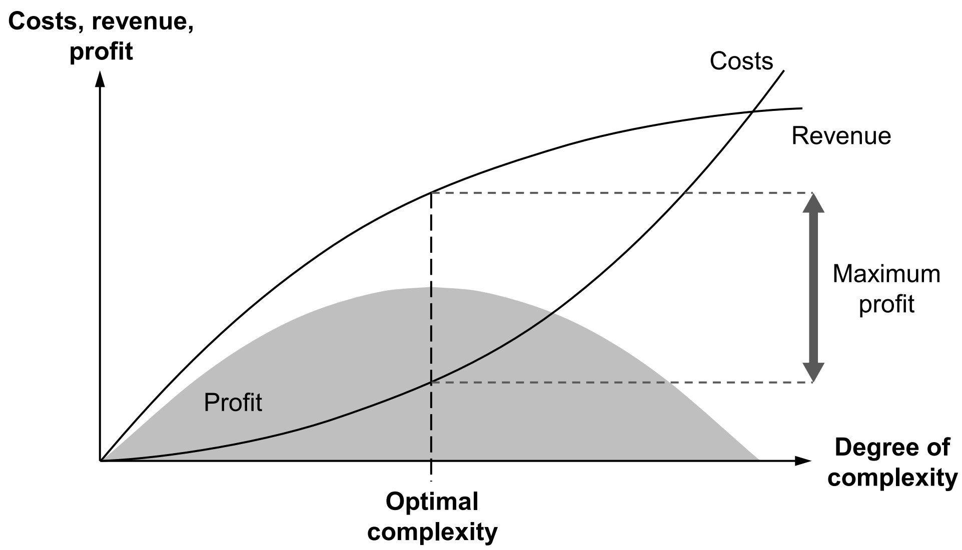

Figure 10: Balance of revenues and costs to define optimal variety (Rathnow 1993, p. 44; Kaiser 1995, p. 111; Danne 2009, p. 16)

There is a specific point on the x-axis after which the impact of cost for product variety becomes more significant than the revenues and profits start declining (Gottfredson & Aspinall 2005). To apply this concept, companies are forced to constantly determine the optimal variety that yields the maximum profit (Danne 2009). Rathnow (1993) adds a three-step process to approximate optimal variety:

- 1st step: By analyzing customer requirements, the appropriate level of product variety is determined with the objective of optimizing the product offering.

- 2nd step: By considering the handling of this appropriate variety level with regard to the inputs needed (materials, supplies, modules etc.), technologies, organizational complexity (processes, interfaces, etc.), competences and outputs (portfolio, variants, functionality, etc.), the structure is optimized.

- 3rd step: By taking into account the interdependencies between optimization of product offering, company-internal structure and environmental constraints, the optimal variety is determined.

The approximation process and the visualization provided by the optimal variety concept support managers' thinking about downsizing, limitation or broadening of their product portfolio. It also represents a starting point for optimization, e.g. by intensifying product differentiation which lifts the revenue curve or by cost reduction which levels the cost curve (Rathnow 1993).[23] Nonetheless, practitioners and researchers argue that the optimal variety is rather a theoretical value and difficult to establish in practice.[24] The simplified view of the trade-off between revenues and costs reveals several shortcomings in practice (Abdelkafi 2008):

- Costs and revenues depend on many other factors and not only on the level of product variety offered.
- The availability of complete and accurate cost and revenues estimates at the time of determination of the optimal variety is typically not the case.
- The concept of optimal variety assumes that the portfolio is inherently static and does not cover the dynamics of portfolio changes over time.
- The model of optimal variety only takes into account the number of variants and not the type of variant. There might be some variants which have higher complexity costs than others.

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[23] Abdelkafi (2008) suggests concentrating on actions such as making costs less sensitive to variety, enhancing the revenues of a specific product range and reducing the number of variants to converge towards the optimal variety level rather than conducting a one-time determination of the optimal variety level.

[24] Alders (2006) states that the determination of the optimal variety is a key task in variants management at VW. However, the company is only able to determine an "area of the optimum". Alders adds that the creation of variety scenarios supports the determination of the optimum in new product projects.

2.3.2 Product modularization

The alignment of product architecture is a key element of product variety management (Fujita et al. 1999).[25] It is not only limited to the optimization of single product architecture but intends to optimize architecture across multiple products in the product portfolio. Ulrich (1995, p. 419) defines product architecture as "the scheme by which the function of a product is allocated to its physical components". These schemes are critical and define key processes and relationships to create this product (Ro et al. 2008).

As product variety grows in most companies, a trend from integral to modular product architecture is observed. Integral product architecture is characterized by parts that perform many functions, are in close proximity or close spatial relationship, and are tightly synchronized (Fine 1998). Modular product architecture, on the other hand, consists of parts that are interchangeable, individually upgradable, and have standardized interfaces (Fine 1998). The final product typically consists of a fixed number of modules. An automobile, for example, has modules for transmission systems, brake systems, fuel systems (Chakravarty & Balakrishnan 2001). Therefore, the "degree to which a system's components can be separated and recombined, referring to both tightness of the coupling between components" and the "degree to which the system architecture enables or prohibits the mixing and matching of components" are key parts of modularity (Schilling 2000, p. 312). Taking these characteristics into account, a module is defined as "a unit whose structural elements are powerfully connected among themselves and relatively weakly connected to elements in other units" (Baldwin & Clark 2000, p. 63).

Ulrich (1995) developed a prominent typology of modular product architecture which distinguishes between slot, bus and sectional architecture (Figure 11).[26] Slot architecture describes a structure in which all component interfaces are different. The various components in the product cannot be interchanged, e.g. a radio in an automobile fulfills exactly one function and is decoupled from the other components in the dashboard of a car. In bus architecture, physical components are connected

[25] Fixson (2007) provides a comprehensive analysis of the literature related to modularization and component commonality based on a review of 160 publications. He finds a significant increase in research publications since the year 2000.

[26] Ulrich (2005) derives his typology on the type of interface between components. Salvador et al. (2002) reviews two other typologies of modularity which are based on the stability of the task or function assigned to the module and on the approach of final product configuration.

via the same interface on a common bus. An example is a card reader as an extension of a personal computer. In a sectional architecture, all components interfaces are the same. Examples for connecting components via identical interfaces are piping systems which are attached via the same type of sockets but are not attached to a common bus. In all types of modularity, a clear definition of the interfaces is critical to integrate the independent designed modules in the end product (Baldwin & Clark 1997).

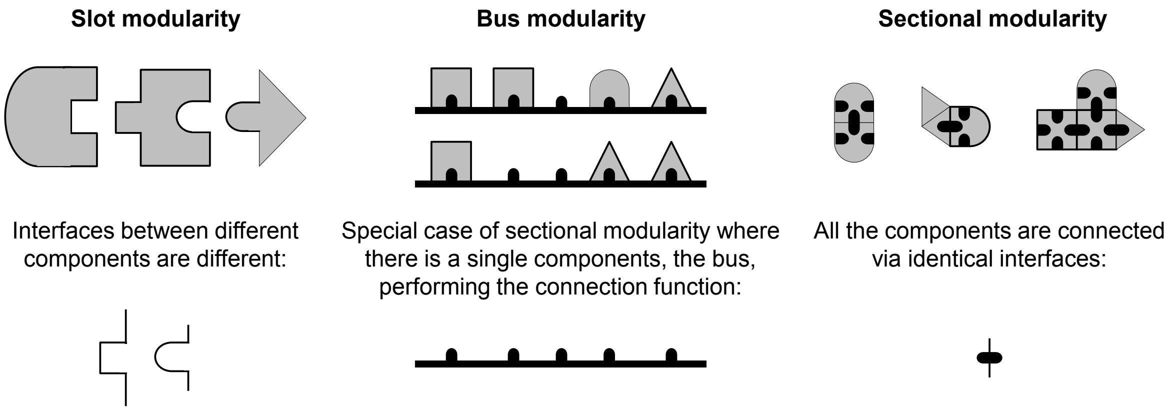

Figure 11: Typology of modularity (Ulrich 1995, pp. 424-425; Salvador et al. 2002, p. 552)

Researchers and practitioners link certain benefits to the use of product modularization.[27] It is argued that it can shorten development time, improve the ability to adapt to changes in a dynamic environment and it can reduce costs by minimizing the interdependencies between the modules of a product (Arnheiter & Harren 2005). In summary, product modularization should enable the company to offer a large variety of products whilst making use of economies of scale (shared parts and components) and economies of scope (using the same modules in different products) (Pine II 1993).

However, there is some criticism with regard to the deployment of modular product architecture. The design of such products is more difficult and effort is needed to design the product architecture with the right degree of modularization (Baldwin & Clark 1997). For single products it can be the case that direct costs for development and design increase (Pine II 1993). Additionally, products with a very high degree

[27] Bartuschat & Krawitz (2006), for example, describe the benefits of product modularization based on a case study of a vehicle company. They point out that modularization leads to a significant increase of external variety (from 81 variants to 43 million variants) compared to a necessary mediocre increase in internal variety (from 4 modules with 3 variants each to 16 modules with 3 variants each).

of modularization run the risk of creating less innovative products due to the re-use of pre-defined standard modules.

2.3.3 Product platforms

Modular product architecture and product platforms are complementary and represent core elements of a new product strategy (Krishnan & Ulrich 2001). In fact, product platforms can be regarded as the next logical step in product modularization (Schuh & Schwenk 2001).[28]

In general, product platforms are built as combinations of a standardized platform and customized modules. A core technology is used as a common technological foundation for the standardized platform leading to a number of derivative products (Meyer 1997). The objective of platforms is a high level of commonality in components, parts, and material but also in processes.[29] Thus, platforms allow for the efficient development of a large number of partially customized product variants (Marti 2007). They are not only beneficial on the product level but also on a module level, especially in highly modularized product portfolios (Boutellier et al. 1997).

An established definition is given by Robertson & Ulrich (1998) who define a product platform as a set of common assets that is shared across products. Assets can be components, processes, knowledge and people. Thus, a platform can include shared components and parts, but also production, distribution or sales processes. Meyer & Lehnerd (1997) illustrate the relationship between internal capabilities (common building blocks), market application and the role of product platforms (Figure 12).

[28] Product platforms also build the technological basis for product families (Meyer et al. 1997). A product family emerges from an increased level of modularity in product architecture and commonality throughout a range of products (Pasche et al. 2011; Jiao & Tseng 2000). Product platforms and families are the result of the deployment of the company's core capabilities (Meyer & Utterback 1992). For the product family's success and quality, the platform design is critical (Meyer et al. 1997).

[29] Commonality is defined as the re-use of components across product families and product generations (Fixson 2005).

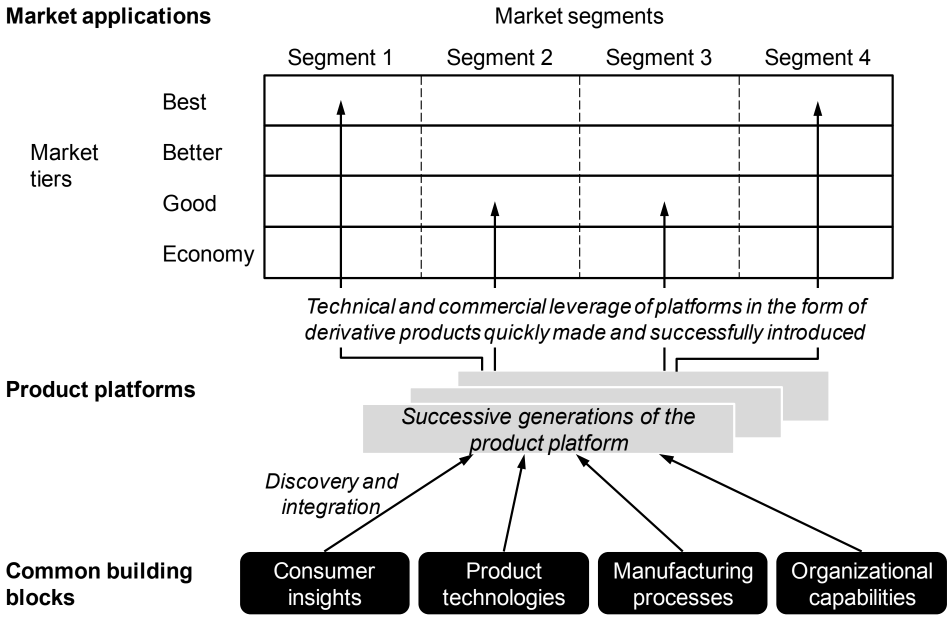

Figure 12: The relationship between common building blocks, product platforms and market applications (Meyer & Lehnerd 1997, p. 38)

This integrative framework emphasizes that product platforms should be capable of accommodating knowledge, technologies, process and organizational capabilities in order to create derivative products at low cost. Meyer (1997) mentions the reduction of manufacturing costs and economies in components and materials procurement due to sharing between products as two key cost advantages of product platforms. Also, risks associated with new product development can be reduced because of a lower investment for the product based on the platform (Robertson & Ulrich 1998). From a market perspective, customers can be served faster by integrating new customized modules into existing product platforms.

Consequently, platform strategies have been widely adopted in manufacturing industries to achieve scale effects in product creation processes (Scavarda et al. 2008). A prominent example for successful product platforms is the automotive industry. Italian manufacturers were already using basic platforms in the 1920s by combining a standardized chassis with multiple bodies (Blackenfelt 2001). Volkswagen AG (VW) further made use of this concept by using beetle systems for the VW bus. It is estimated that more than 60 percent of the value of VW's cars in the 1990s are based on common platforms (Ley & Hofer 1999). In 2011, VW even reinforced the platform concepts across brands and models by introducing the so-called modular transverse matrix (MQB) to reduce unit costs by 20 percent, one-off expenditure by 20 percent and engineering hours per vehicle by 30 percent (Volkswagen AG 2011).

Nonetheless, Boutellier et al. (1997) point out two main problems when making use of product platforms: The time and resources required to develop a platform and the determination of the number of platforms and derivative products. The main challenge is to define the "right" platforms and to preserve them. Customers often break the borders of these pre-defined platforms by demanding additional options or other modules. As described, product platforms should take a holistic perspective and also consider company processes and organizational capabilities. However, it is observed in practice that the focus is clearly set on physical components and modules.

2.3.4 Mass customization

The strategy of mass customization is popular in many industries, ranging from Automobile (e.g. VW) to Information Technology (e.g. Hewlett-Packard or Dell). It can enable a company to differentiate in the marketplace while still creating products at relatively low cost. It is argued, that mass customization overcomes the traditional thinking of Porter (1980) that a company needs to decide on one strategy: Cost leadership, differentiation or focus.[30] Hence, mass customization represents a hybrid strategy of mass production and customization.

The term mass customization was introduced by Davis (1987, p. 169) who explained that "the same large number of customers can be reached as in mass markets of the industrial economy, and simultaneously treated individually as in the customized markets of pre-industrial economies". Pine II's (1993, p. 44) definition focuses on the capabilities of the corporate value-chain when defining mass customization as the "creation of variety and customization through flexibility and quick responsiveness".[31] Over the last two decades, a number of typologies and taxonomies has been developed which describe the different opportunities to apply mass customization.[32] All of these classification typologies have in common that

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[30] By following the cost leadership strategy a company intends to become the leading low cost manufacturer in its industry. With the differentiation strategy a company intends to be unique in its industry, e.g. by providing products which are widely valued by buyers. The focus strategy by the company involves the selection of a specific market segment and exclusion of others. Two alternatives of the focus strategy are differentiated: The cost focus is applied by companies which seek a cost advantage in a specific target segment and the differentiation focus is selected by companies which intend to differentiate themselves in their target segment. Porter (1980) discusses the advantages and disadvantages of these generic competitive strategies.

[31] The key principle behind mass production is also discussed as "postponement" across literature (e.g. Alderson 1957; Feitzinger & Lee 1997; Altfeld et al. 2011).

[32] Abdelkafi (2008) presents a comprehensive review of mass customization typologies and taxonomies.

they are describing various degrees of customization and standardization along a company's value-chain. A prominent classification has been introduced by Lampel & Mintzberg (1996) who differentiate between five strategies by considering a simplified view of the value-chain (Figure 13).

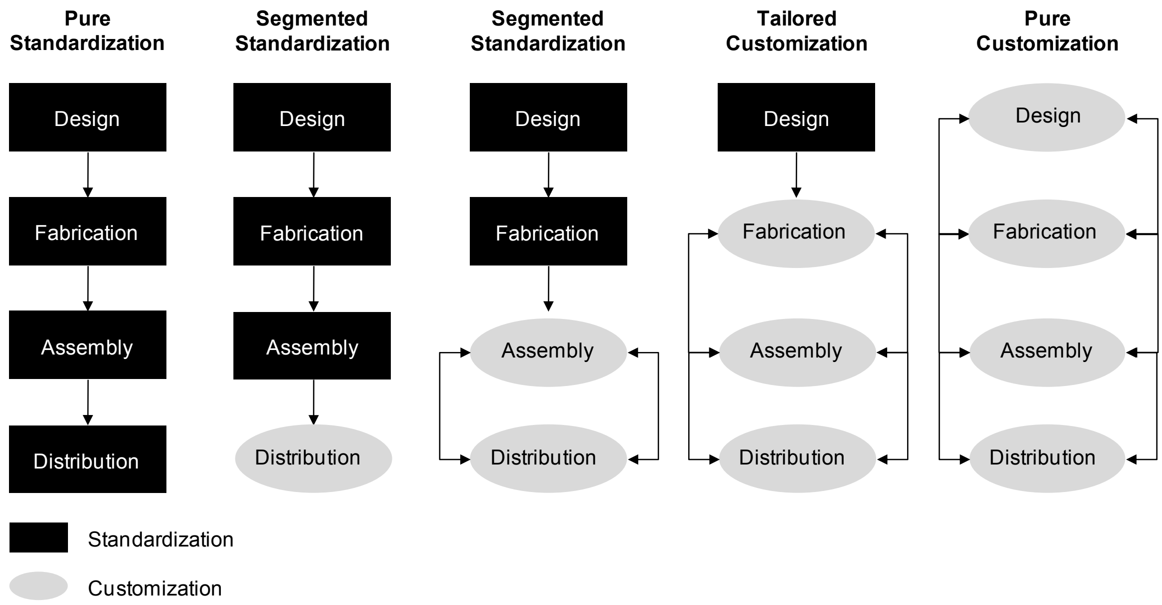

Figure 13: A continuum of mass customization strategies (Lampel & Mintzberg 1996, p. 24)

As this typology shows, mass customization follows the postponement principle which results in a delay of some of the phases or activities in the value-chain until a customer order directly influences the product. The value-chain perspective includes a fundamental question regarding the so-called decoupling or order penetration point (Ramdas 2003).[33] This question about the point in the value-chain, at which the customer "penetrates", divides the value-chain into two parts. In the first part, upstream of the decoupling point, standardized activities take place. In the second part, the downstream activities are specifically customer-driven. If the decoupling point is placed further downstream, more value-adding activities are carried out with a degree of uncertainty and if it is positioned further upstream, activities are based on more definite information from the customer (Blecker & Abdelkafi 2006). Figure 14 illustrates the role of the decoupling point in manufacturing. A push system characterizes the first stages in manufacturing in which raw materials and components are transformed into semi-finished products (Blecker & Abdelkafi

[33] The decoupling point is also discussed in literature under the term "sequencing point" and "push-pull boundary" (Swaminathan & Nitsch 2007).

2006). Up to the decoupling point, achieving economies of scale is the main objective. After passing the decoupling point, the manufacturing stages are performed customer-individual. In fact, the customer "pulls" the order through these stages (Blecker & Abdelkafi 2006).

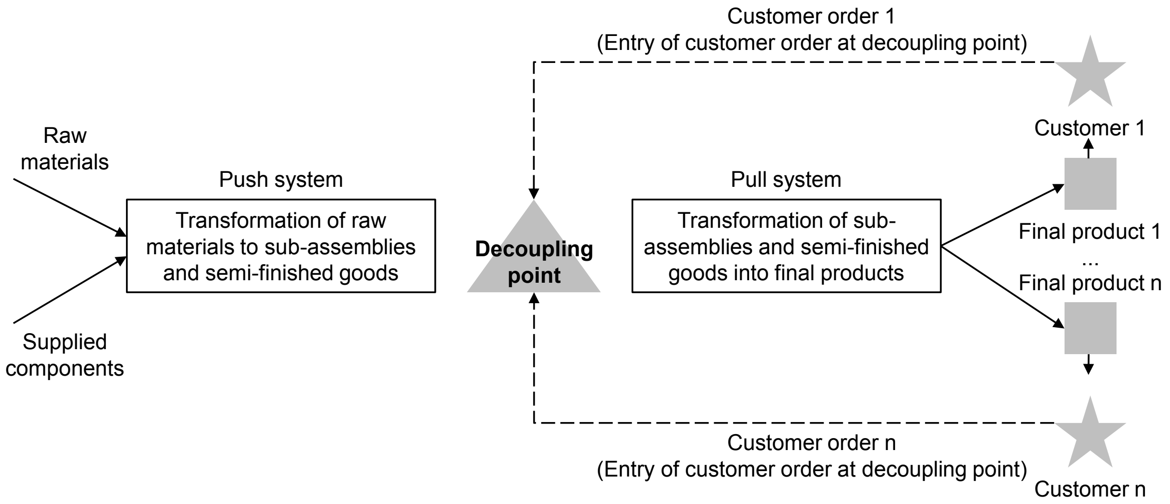

Figure 14: A simplified view of the mass customization production system (Blecker & Abdelkafi 2006, p. 5)

From a complexity standpoint, mass customization provides a framework to align internal and external complexity. It sets a focus on the processes in the value-chain and its ability to cope with process complexity induced by product variety. Advanced approaches in complexity management consider the combination of product modularity and process modularity, which is enabled by mass customization, as the key to an agile supply chain for cost-effectiveness and flexibility in creating customized products (Feitzinger & Lee 1997).

However, it remains unclear which customization strategy is suitable for which business. The concept lacks the consideration of different types of products in the selection of the appropriate strategy. Also, the position of the decoupling point is not easy to define and the adaptation and effects beyond manufacturing have not yet been analyzed in depth.

2.4 Evaluation of complexity

While the previous paragraphs outline established approaches a company can choose in order to control and reduce complexity, none of the concepts explicitly discusses the evaluation of complexity. However, increasing transparency in variety-induced complexity in order to understand its impact on the company represents a crucial element in managing complexity and choosing the appropriate actions (Child et al. 1991; Lechner et al. 2011). Closs et al. (2008, p. 608) emphasize the shortcomings in complexity research by pointing out that "there is a glaring need to develop complexity metrics that measure the relational and combinatorial dimensions of complexity". The lack of comprehensive and precise evaluation concepts impedes the testing of theories in complexity management (e.g. the impact on performance or the success of complexity control and reduction approaches).

Following Rossi et al. (2004, p. 28), an evaluation is defined "as a systematic, rigorous, and meticulous application of scientific methods to assess outcomes of a subject". The subject in this case is variety-induced complexity.

Two types of evaluation are differentiated: Monetary approaches and non-monetary approaches. Both monetary and non-monetary approaches enable the setting and tracking of quantifiable targets in manufacturing companies. Monetary approaches mean cost calculations. Non-monetary approaches mean indicators and indices which are not directly and immediately translated into costs.

2.4.1 Monetary approaches

The cost dimension is the primary in literature when discussing the evaluation of variety-induced complexity (Lancaster 1980). Due to the fact that complexity affects the cost position of a company, researchers and practitioners put effort into developing appropriate approaches to determine complexity costs. A number of publications limit complexity costs solely to the indirect part based on the assumption that a major part of complexity costs occur in indirect corporate functions. For example, Thonemann & Brandeau (2000, p. 1) define complexity cost as "the cost of indirect functions at a company and its suppliers that are caused by component variety". However, in order to cover the costs of complexity comprehensively, multiple researchers argue that complexity costs calculations need to cover direct and indirect costs (e.g. Schuh & Schwenk 2001). Figure 15 illustrates the breakdown of complexity costs including some exemplary cost blocks.

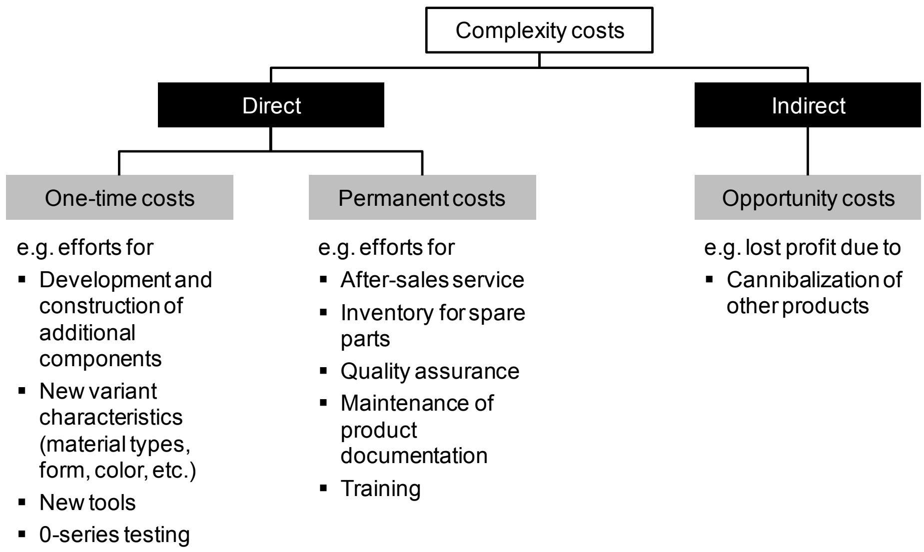

Figure 15: Breakdown of complexity costs (Homburg & Daum 1997, p. 333; Schuh & Schwenk 2001, p. 45)

Ward et al. (2010) differentiate between two cost types: Variable complexity costs which are driven by product volume and fixed complexity costs which are driven by product variety (Table 5). They base the approach on their experiences at the computer company Hewlett-Packard.

Table 5: Types of complexity costs (Ward et al. 2010, p. 20)

Cost type	Nature of relationship	Cost categories
Variable complexity costs	Volume-driven	▪ Material costs: volume discounts ▪ Variability-driven costs: excess costs (financing, storage, depreciation, obsolescence, fire sales) and shortage costs (material price premiums, expediting, lost sales because of shortages)
Fixed complexity costs	Variety-driven	▪ Revenue costs: R&D, testing, product management, etc. ▪ External cash outlays: tooling, costs to contract manufacturer ▪ Indirect impacts of variety: manufacturing switching costs, warranty-program expenses, quality impacts, returns costs

Such breakdowns of complexity cost support the understanding about which cost categories should be considered when creating cost models. In addition to a precise definition, four exceptional effects for the accurate determination of complexity costs need to be taken into consideration:

- Allocation effect (e.g. Heina 1999): The traditional accounting approaches allocate overhead expenses proportionally. Overhead costs are therefore assigned incorrectly, i.e. not according to the actual utilization of resources.
- Degression effect (e.g. Ehrlenspiel et al. 2007): Unit costs decrease with increase in order volume due to the fact that fixed costs in manufacturing and purchasing costs are split across higher volumes. Traditional accounting systems do not cover this effect but charge constant costs per unit.
- Complexity effect (Schuh & Schwenk 2001): Product variety and the resulting complexity lead to an increase in indirect activities. Costs of these activities are not directly traced back to the specific product variants, in fact a proportional increase of costs is assumed. This affects not only cost allocation but also translates into wrong pricing for product variants.
- Cost remanence (Rathnow 1993): Increasing product variety requires changes in structures and processes which leads to a "jump" in fixed costs. It is very difficult to bring down this increased cost level even with a significant variety decrease.

A small number of costing approaches to calculate complexity which take these effects into account have been proposed in literature. This is a consequence of the inability of established cost approaches to determine individual costs of product variants and to illustrate the cost effect of a variety increase. Cooper & Kaplan (1988a; 1988b) found that complexity costs cannot be made transparent by using traditional cost accounting methods. As simple volume-based product cost calculations distort true costs of products by incorrectly allocating costs (Cooper 1988; Mather 1992), the approach of activity-based costing (ABC) is frequently favored by researchers for accurate product costing (Kaiser 1995; Wildemann 1999). ABC is based on the principle of identifying all of a company's major operating activities along the entire value-chain. Then costs are traced for these activities and costs for resources (personnel, material, etc.) are assigned to the activities (Babad & Balachandran 1993). The intent of ABC is to provide managers with more precise and realistic data by assigning costs directly to specific cost objects (Figure 16).

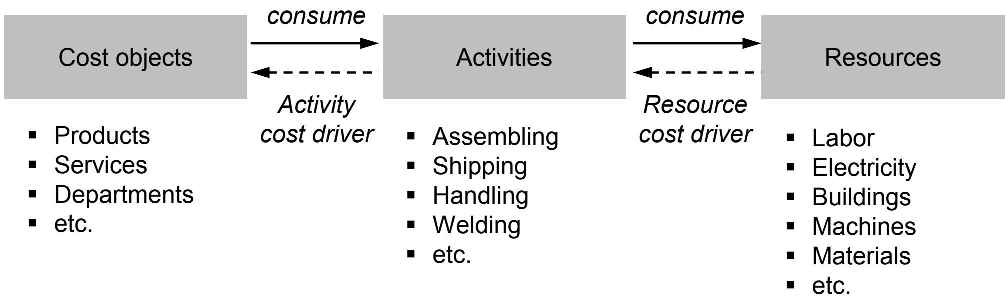

Figure 16: The principle of activity-based costing (Zhang & Tseng 2007, p. 132)

However, there is also some criticism, especially from practitioners, when it comes to the implementation and deployment of ABC (Piper & Walley 1991). On the technical side, systems need to be in place in order to trace the efforts very precisely back to specific product variants (Cokins 1999). In reality, existing systems summarize a lot of effort in costs for overhead, leading to the inability to allocate a huge part of the costs to single products or even product variants. On the "social" side, employees providing the data need to be committed to ABC as the entire approach relies on the quality of data submitted (Cokins 1999). Because this requires sensitive information, e.g. working hours spent for specific product-related activities, it is sometimes hard to get the commitment by employees. In fact, especially in indirect functions the allocation of effort in this detail is not a standard in most companies. Nonetheless, the ABC approach presents the foundations for a number of cost systems developed to make complexity costs transparent.

Horváth & Mayer's (1989) approach of process costing adapts the principle of ABC. Process costing is intended to be complementary to traditional accounting systems because it focuses solely on indirect company areas. For analysis in these indirect areas, the processes are split up into volume-dependent and volume-independent. Volume-dependent processes are explicitly proportional to cost drivers and volume-independent processes are not directly relatable to cost drivers. By splitting processes into sub-processes and then summing several sub-processes up in main cross-sectorial processes, it is possible to allocate costs more precisely (Horváth & Mayer 1989).

Schuh (1988) presents a costing approach to evaluate variants based on their resource consumption called resource-oriented process costing (RPK). Unlike the classical process costing approach, the resource-based approach does not aggregate the resources to main processes but provides the resources per sub-process to maintain a high and reliable level of detail. Three steps are proposed to successfully build up a RPK system (Schuh & Schwenk 2001). First, main processes for product creation are split up into sub-processes to identify resources absorbed by a single cost driver. Second, resources are assigned to value-chain stages (e.g. development, logistics, manufacturing, distribution). Third, the resource consumption function is calculated and visualized in so-called nomograms. These visualizations reveal the process costs, cost drivers and resource consumption and, by that, represent the starting point for cross-functional discussions and optimizations.

As is the case for ABC, process costing and RPK are criticized for their lack of practical application due to the tremendous effort required for system implementation and data gathering (Franke 1998). In fact, Martin & Ishii (1996) argue that a number of different theoretical ABC-based approaches are presented, but successfully implemented ones are hard to find in practice.

Not relying on the ABC principle, Anderson (2004) and Bohne (1998) suggest zero-base costing to calculate complexity costs. By defining the premium variant in the product family with the highest range of options as the baseline product, costs are determined by comparing the current costs position with the ideal situation costs. In an ideal situation operations are set up to manufacture of one single product at the same current volumes. The baseline product costs are normalized to equal 1.0 and the other product variants are calculated with a multiplier (complexity factor) of this baseline product (Anderson 1997). The approach described is reactive rather than proactive, i.e. it is difficult to use in early decisions for products. In fact, the availability of information (e.g. of actual unit costs) is not given before proceeding through the entire value-chain. Additionally, estimates on the complexity factor are often not reliable, especially when no comparable products have been created in the past.

Multiple studies in the manufacturing industries conclude that complexity cost amount to 15-20 percent in addition to the costs for creating the standard product (e.g. Rommel et al. 1993; Wildemann 1994). However these are only rough estimates based on single case studies because, although there are new cost approaches elaborated, complexity costs remain to be difficult to calculate (Scavarda et al. 2009; Rommel et al. 1993). This is caused by a number of problems of complexity cost observed by researchers, which are, at least partially, a result of the exceptional effects of complexity costs. A large part of complexity costs affect and occur in processes and functions which are not the origin of the product variant. Sales and R&D divisions trigger most of these decisions but complexity drastically affects purchasing, production logistics, quality assurance and maintenance (Wildemann 2010). A single decision to create a new product variant may not be harmful to company's competitiveness, but if these decisions are made frequently over time it will significantly impact internal processes in a negative way. A major part of complexity costs also arise with a certain time delay and not immediately (Adam & Johannwille 1998). Furthermore, companies cannot go back to the initial cost position after the decision has been made to provide a certain level of product variety due to the high investment for fixed assets (Abdelkafi 2008).

In summary, the issue of missing transparency is highlighted by the fact that complexity cost emerges to a large extent in overheads which are often hidden to the company (Quelch & Kenny 1994). They arise in indirect areas of companies and can only be traced back to the physical products with a high effort as there is typically no cost position for complexity costs (Abdelkafi 2008). To do reliable calculations of complexity factors, the cost-driving activities along the entire value-chain need to be known in order to estimate e.g. additional working hours or material (Child et al. 1991).[34]

As a consequence of these problems, several companies, having attempted to evaluate complexity monetarily, gave up. As Alders (2006, p. 227) argues when presenting the complexity management approach of AUDI and VW: "There has been a trial attempt to calculate complexity costs to evaluate variety-induced complexity. This calculation was abandoned after a short time due to the shortcomings of the cost allocations". Although there has been extensive research with the objective of making complexity transparent based on monetary information, most of the existing approaches are not or only partially proven to be applicable.

2.4.2 Non-monetary approaches

The deficits of complexity cost calculations have been partially acknowledged by research. A few mathematical indices have been proposed to evaluate complexity non-monetarily. Table 6 presents the indices clustered along three complexity dimensions: Complexity across products and variants (portfolio complexity), architectural and technical complexity in products (product complexity) and complexity in processes (value-chain complexity).

[34] A study by Rathnow (1993) in an automobile company presents an example of a structured assessment of cost-related activities along the value-chain which are affected by complexity induced by product variety. Olavson & Fry (2006), for example, present a checklist based on their work at Hewlett-Packard differentiating between opportunity costs (e.g. lost sales as a result of demand variability), cost of goods sold (e.g. tooling, rework, warranty expenses) and operating expenses (e.g. R&D, supplier qualification, product data management).

Table 6: Selected non-monetary complexity indices discussed in literature

Complexity dimension	Index name	Description and formula	Source
Product complexity	Part level index	A measure for the part-level complexity of a product: $\sum_{n=}^{N}$, e_i = # of elements in main component t BOM_i = BOM level of component i	Orfi et al. (2011, p. 73)
	Commonality index	A measure for the design utilization of standardized parts: $CI= \sum_{j=}$ – u = # of unique part numbers for the product family p_j = # of parts in model j v= final # of varities offered	Martin & Ishii (1997, p. 109)
	Product modularity	A measure for the degree of product modularity: $\Omega = \sum \frac{}{M}$ I_m = total # of options for each function m M = total # of functions	Kumar (2004, p. 298)
Portfolio complexity	Extent of product customization	A measure for the extent of product configurations possible: $\Psi \prod_{m=}$ otal # of options for each function m M = total # of functions	Kumar (2004, p. 298)

Table 6 (cont.): Selected non-monetary complexity indices discussed in literature

Complexity dimension	Index name	Description and formula	Source
Portfolio complexity	Product variety index (product family)	A measure to evaluate the level of product variety across different product families: $PVI(productfamily) = \quad + \quad$ = # of unique design aspects across products w_2 = # of distinct platforms across product families	Orfi et al. (2011, p. 69)
	Customization on customer basis	A measure for the level of customization provided to customers: $\Theta = \frac{\Psi}{\eta}$ tial customer population for this product Ψ mum number of product configuration (extent of customization)	Kumar (2004, p. 299)
Value-chain complexity	Differentiation index	A measure to illustrate where differentiation occurs within the process flow: $DI = \frac{\sum}{n * \quad * \quad * \sum_{i=}}$ $d_\cdot$ = estimated throughput time process i to sale v_i = # of different products exiting process i a_i = value added at process i v = final # of varieties offered n = # of processes d_1 = estimated throughput time from process 1 to sale	Martin & Ishii (1997, pp. 109-110)
	Product variety index (plants)	A measure to evaluate variety-induced complexity among different production plants: $PVI(plants) = \quad + \quad + \quad$ = # of unique design aspects across products w_2 = # of distinct platforms across product families w_3 = # of produced product lines	Orfi et al. (2011, p. 69)

Table 6 (cont.): Selected non-monetary complexity indices discussed in literature

Complexity dimension	Index name	Description and formula	Source
Value-chain complexity	Process commonality index	A measure to determine the usage ratio of different production paths within a plant: $PCI = \sum_{w=} *$ M = Total # of production paths i_w = total # of components i following a specific production path w $\overline{CR}_{pix}$ = ratio of # of variants in the product family	Orfi et al. (2011, p. 72)
	Process difficulty index	A measure for difficulties in processes due to product variety increase: $PROC(t) = \frac{DA(t)}{DA(B)}$ DA(t)= total # of difficulty-adjusted activites for technology t DA(B)= total # of difficulty-adjusted activites for base process B	Cooper et al. (1992, p. 47)
	Setup index	An indirect measure of how setup costs contribute to overall product costs: $I = \frac{\sum}{\sum_{j=}} -$ u = # of different products exiting process i c_i = cost of setup at process i C_j = total cost (material labor and overhead) of product j	Martin & Ishii (1997, p. 110)

The indices related to product, portfolio and value-chain complexity are mainly set up to evaluate the success of basic complexity management approaches. For example, the indices suggested by Kumar (2004) are for measuring the performance of customization strategies such as product modularity and mass customization. Although variety-induced complexity is recognized as a multifaceted and multidimensional concept (Closs et al. 2008; Adam & Johannwille 1998), each of the indices is limited to single aspects such as the use of standard parts in products or the changes necessary in production lines. A more comprehensive concept for non-monetary evaluation taking into consideration multiple aspects or dimensions is not found. Additionally, available indices are not linked to the established differentiations such as external and internal complexity. The indices are therefore not suitable to making a fundamental evaluation of the complexity level but can, however, verify the effectiveness of complexity reduction initiatives.

Besides these mathematical indices, a few indicators (absolute numbers or simple ratios) are discussed in research as critical to observe when evaluating variety-induced complexity (Table 7).

Table 7: Simple non-monetary indicators discussed in literature (based on Bozarth et al. 2009; Jacobs & Swink 2011; Orfi et al. 2011; Closs et al. 2008)

Complexity dimension	**Indicator name**	**Indicator description**
Portfolio complexity	Portfolio size	# of SKUs
	Size of customer base	# of customers
	Breadth of portfolio	# of products
	Products per function	# of products / # of functions
	Newness of product range	# of new products / total # of products
	Parts complexity	# of parts per product platform
	Variant profitability	# of model variants / total model sales
Product complexity	Number of parts	Total # of parts in product
	Product newness	# of new parts / # of total parts
	Product functionality	# of functions in product
	Re-use percentage	# of re-used parts from existing models / total number of parts
	Revenue of features	Additional revenue per additional feature
Value-chain processes complexity	Number of processes	Total # of processes to create the product
	One-of-a-kind production	Percentage of one-of-a-kind production
	Size of supplier base	Total # of suppliers

Most of the indicators are related to the complexity of portfolio and product complexity. Although there are complexity drivers discussed in literature (e.g. Bozarth et al. 2009) such as heterogeneity of customer needs, manufacturing schedule instability, demand variability, globalization of supply base and unreliability of suppliers, these potential indicators for value-chain complexity have not been put into use in form of indicators.

Closs et al. (2008) add that absolute indicators (e.g. the number of products in the portfolio) should be supplemented by ratios (e.g. the number of new products in relation to the total number of products in the portfolio). However, it has not been investigated how such a combination could be tailored for practical application. In conclusion, a holistic concept (following a systems perspective) for complexity evaluation across multiple complexity dimensions has not been developed by researchers.

2.5 Dimensions of decision-making for products

Managers view each project for products as an investment and attempt to apply the appropriate decision-making to choose the right investments (Cooper et al. 2004). The process of decision-making for products is recognized as one of the most critical tasks of senior management as it is characterized by uncertain and changing information, dynamic opportunities, multiple goals and strategic considerations, interdependence among projects and multiple decision-makers involved. Garvin & Roberto (2001, p. 108) comment that "decision-making is arguably the most important job of the senior executive and one of the easiest to get wrong".

Decisions on products in manufacturing companies, in terms of evaluation of individual projects on an ongoing basis (Cooper et al. 2010), result in allocations of resources to achieve certain objectives (e.g. Mintzberg 2009). Thus, a high quality of decision-making can contribute to better use of an organization's resources. It is criticized in literature that most decision-making approaches over-simplify the issue of decision-making. The evident shortcomings of existing approaches have contributed to the development of prescriptive theories of decision-making (e.g. Bourgeois & Eisenhardt 1988; Eisenhardt & Zbaracki 1992; Elbanna 2006). Five main mechanisms have been recognized by researchers which are described briefly in the next sections: Process standardization, cross-functionality, rationality, political behavior and intuition.

Process standardization

Definitions of product creation processes as a standard procedure for the company represent an established approach in manufacturing companies (Figure 17). Typically, so-called stage-gate processes start with an input derived from corporate strategy or customer needs. The gates in the process serve as quality-control points at which a go or stop of the project is decided (Cooper 2009). Griffin (1997a) states that these gates as review and decision points are implemented in most product development standardizations in place at manufacturing companies.

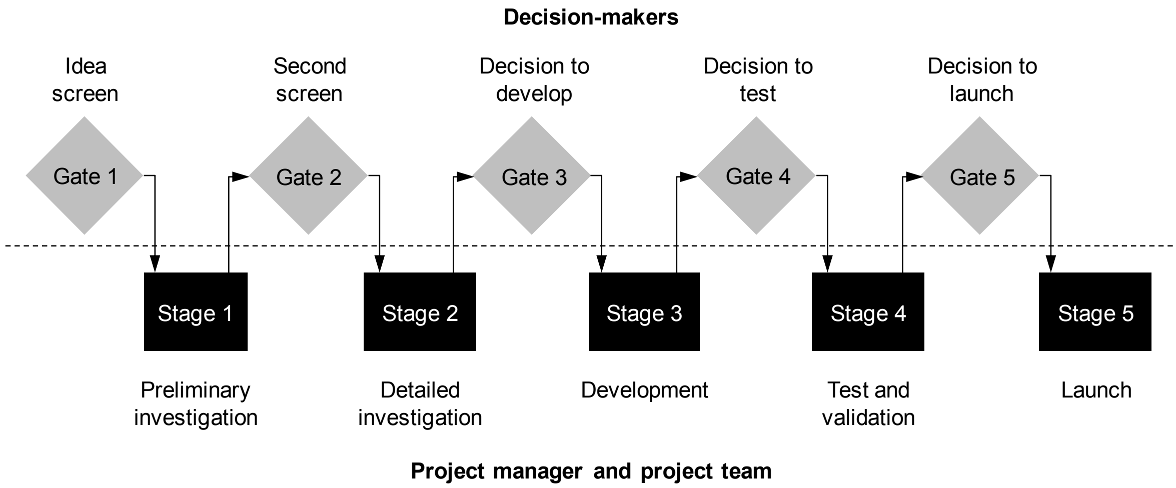

Figure 17: Stage-gate process for products (Christiansen & Varnes 2006, p. 4)

In these process standards multiple decision situations take place in which there is not a single individual decision maker but numerous individuals who interact over a period of time. In fact, a stage-gate process for products includes a series of decisions and interactions between project teams and decision-makers. The decision to go ahead with development is probably the most critical one due to the fact that it results in a major allocation of resources to proceed through the development stage.

Decision-making for products and variants occurs frequently requiring routines manifested in standardized processes. Therefore, typical phases of decision-making such as problem identification, development and selection (Eisenhardt & Zbaracki 1992; Mintzberg et al. 1976) are operationalized in these process standardizations. It is concluded by researchers that such formalized processes including stages and quality gates to frame decisions are implemented in most successful companies (e.g. National Research Council 1999).

Cross-functionality

Stage-gate processes are typically staffed by a number of stakeholders from multiple departments. In fact, research supports proceeding through the process in cross-functional teams as there are certain benefits associated with this, such as the reduction of product creation costs and shortening of lead times, in comparison to using individuals (Brown & Eisenhardt 1997). In line with a high level of cross-functionality in the stage-gate process, researchers recommend also conducting project evaluations in teams. In practice, these cross-functional teams and decision committees are implemented at successful companies (Griffin 1997a). Schmidt et al. (2001) showed that decision-making with cross-functional teams in face-to-face meetings leads to more effective decisions in the gate meetings compared to decisions made by individuals.

However, when working in teams with participants from multiple departments, having different backgrounds, experiences and objectives, additional challenges may arise. A stronger effort (e.g. longer discussions and more information to consider) is necessary to achieve a consensus, firstly in the project team preparing the decision and secondly in the gate meeting of decision-makers (Ullman 2010). More specifically, this represents a problem for urgent product decisions. As pointed out, in early project phases, information as a basis for the decision is often insufficient which hinders the finding of a consensus.

Rationality

The rationality model, a central dimension in decision-making theory, considers the decision as a situation with known objectives. Consequently, decision-makers determine the success of actions by evaluating the achievement of these objectives. For this evaluation, the stakeholders in decision-making gather required information, elaborate a set of alternatives and finally select the optimal alternative (Eisenhardt & Zbaracki 1992). Decision-makers and complementary project teams are asked to run a thorough analysis of environmental aspects and of internal expertise (Elbanna 2006). It is concluded by researchers that companies seek to increase the level of rationality in their decision processes (Eisenhardt & Zbaracki 1992). In practice, this is realized by using more information (e.g. by applying a comprehensive set of criteria) and by integrating multiple perspectives (e.g. by involving functions from multiple departments) in the decision.

At the gates (review points) specific criteria are employed for evaluating new product projects and making go/no-go decisions. Both, researchers and practitioners, agree on the significance of having well-defined decision criteria (Carbonell-Foulquie et al. 2004). Hart et al. (2003) point out that limited knowledge exists as to which go/no-go criteria are essential due to lack of research on the topic. Figure 18 shows a typical scorecard which contains some of the most frequently mentioned criteria when evaluating projects for products in manufacturing companies.

Factor 1: Strategic Fit and Importance

- Alignment of project with our business strategy
- Importance of project to the strategy
- Impact on the business

Factor 2: Product and Competitive Advantage

- Product delivers unique customer or user benefits
- Product offers customer/user excellent value for money (compelling value proposition)
- Differentiated product in eyes of customer/user
- Positive customer/user feedback on product concept

Factor 3: Market Attractiveness

- Market size
- Market growth and future potential
- Margins earned by players in this market
- Competitiveness – how tough and intense competition is (negative)

Factor 4: Core Competencies Leverage

- Project leverages our core competencies and strengths in technology, production/operations, marketing, distribution/sales force

Factor 5: Technical Feasibility

- Size of technical gap (straightforward to do)
- Technical complexity (few barriers, solution envisioned)
- Familiarity of technology to our business
- Technical results to date (proof of concept)

Factor 6: Financial Reward versus Risk

- Site of financial opportunity
- Financial return (NPV, ECV, IRR)
- Productivity Index (PI)
- Certainty of financial estimates
- Level of risk and ability to address risks

Figure 18: Typical scorecard for the decision to go to development (Cooper 2009, p. 51)

Researchers found that the appropriateness of different criteria varies for different types of projects. It is argued by researchers that evaluative criteria should be aligned to the different objectives and therefore to the different requirements of each type (Hart et al. 2003). Also, the quality and reliability of information used for evaluation and decisions are crucial factors, which depend on the stage in the value-chain. Initial evaluations are often not very sophisticated, as early stages are concerned with identifying ideas and understanding customer needs. When the new product project proceeds, the information collected regarding both technical feasibility and commercial opportunity becomes more reliable.

Godener & Soderquist (2004) argue that the combination of a comprehensive set of criteria, a stage-gate process with regular checkpoints and evaluation in a competent team lead to purposeful decisions. Furthermore, criteria with clear connections to processes can increase rationality by enabling knowledge building and learning in opposite to relying solely on financial figures.

Political behavior

Decisions involve multiple internal stakeholders and are the result of a process in which decision makers and project team members have multiple individual or department-driven goals. Political behavior manifests itself in bargaining routines, alliances between individuals or departments and promotion of their own objectives to achieve goals (Mintzberg et al. 1976). It is argued that the most powerful stakeholders and their preferences prevail in decision-making (Eisenhardt & Zbaracki 1992; Elbanna 2006).

Politics as a key concept of strategic decision-making can also be found in decision-making for products. Power imbalances between departments are the trigger of political behavior (Bourgeois & Eisenhardt 1988). The decision for a new product or a product variant is typically triggered by market-oriented functions such as sales and marketing (sometimes even by incentives for sales people), but powerful stakeholders in the value-chain such as R&D (especially in technology-driven companies), manufacturing or logistics are affected by the decision. Other departments such as product management, which are typically not as powerful as technical departments or departments in close contact with the customer, take it upon themselves to negotiate and to balance interests (Eisenhardt & Zbaracki 1992; Bourgeois & Eisenhardt 1988). If the interests of the powerful departments are not entirely integrated in the decision, managers adapt political behavior to influence or hinder the decision-making process.[35] Mintzberg et al. (1976) conclude that high importance of a decision for an organization fosters the occurrence of political behavior. Further, it is argued that there is empirical evidence that political behavior influences organizational effectiveness negatively (Elbanna 2006).

Intuition

In decision-making for products, stakeholders use qualitative and quantitative information which is sometimes incomplete or imprecise. Due to the fact that decisions in practice contain a certain degree of uncertainty (Ullman 2001), decision-makers turn to their past experiences, entrepreneurial judgment and gut feeling for the commitment of resources (Elbanna 2006). These irrational elements are referred to as intuition in decision-making. Studies of decisions in gate meetings reveal that only few are pure rational decisions. Instead, these official meetings are

[35] Eisenhardt & Zbaracki (1992) give an overview on the empirical research on political behavior, which supports the correlation between politics and decision outcomes.

often a place for justifications of decisions already made and the gate system is leveraged as a symbol for rational and objective foundation of the decision (Christiansen & Varnes 2006).

It has been argued by authors (e.g. Elbanna 2006) that the use of intuition is at least partially seen positively in an entrepreneurial situation (unknown technology, new market, dynamic environment) but negatively in a traditional situation of manufacturing companies (known technologies, existing markets, predictable environment). Generally speaking, when managers rely solely on intuition for decision-making on products and variants they may become unaware of process-related routines and may ignore rational details in order to make their decisions very quickly.

2.6 Conclusions drawn from the literature review

The literature review presented in the previous paragraphs provides important insights into research on complexity management. Table 8 provides a summary of the literature discussion by stating the most important implications derived. The implications are clustered along four mechanisms leading to the core elements of the reference framework:

- Transparency on product portfolio and product complexity
- Transparency on value-chain processes complexity
- Process design of decision-making for products
- Reasoning in decision-making for products

Table 8: Overview of key implications and resulting mechanisms

Issue	Key implications	Mechanisms*
The impact of variety-induced complexity	Companies need to take into consideration (with balanced weighting) benefits and efforts resulting from variety-induced complexity.	R
Complexity drivers	The reaction of manufacturing companies to external complexity drivers causes internal complexity when these drivers are translated into actions.	TPP & TVC
	There are internal complexity drivers which are of internal origin and are not necessary to contribute to external drivers.	TPP & TVC
Basic concepts of complexity management	Complexity management needs to be managed on three levels: Product portfolio, product architecture and value-chain processes.	TPP & TVC
	Basic concepts of complexity management provide solutions to reduce complexity rather than proactively avoiding complexity in early decision phases.	R & PD
Evaluation of complexity	Two types of complexity evaluation are differentiated: Monetary and non-monetary evaluation.	TPP & TVC
	Researchers and practitioners place emphasis on the allocation of complexity costs to products although this remains very difficult.	TPP & TVC
	Non-monetary indices are available but are very narrowly focused on the evaluation of the success of basic complexity management concepts.	TPP & TVC
	A few simple non-monetary indicators are discussed but not combined to form a comprehensive evaluation concept covering product, portfolio and value-chain complexity.	TPP & TVC
Dimensions of decision-making	Standardized stage-gate processes provide the frame for a series of decisions for products in which the decision to go to development is the most important.	PD
	Cross-functionality in decision-making leads to better decisions.	PD
	A comprehensive set of rational, reliable and high quality criteria is important to make the right decisions.	R
	Political behavior and intuition by decision-makers influences decision-making for products.	PD
*	PD: Process design of decision-making for products	
	R: Reasoning in decision-making for products	
	TPP: Transparency on product portfolio and product complexity	
	TVC: Transparency on value-chain processes complexity	

Although frameworks such as the differentiation between external and internal complexity are established, many companies have not fully recognized the potential implications of offering a huge variety of products and product variants due to a lack of transparency (Closs et al. 2008). When taking a look at the basic concepts of complexity management, it becomes clear that three main areas are affected by variety-induced complexity and its management: The product portfolio, the product and the value-chain processes. Transparency is then created by monetary or non-monetary evaluation of complexity (Figure 19).

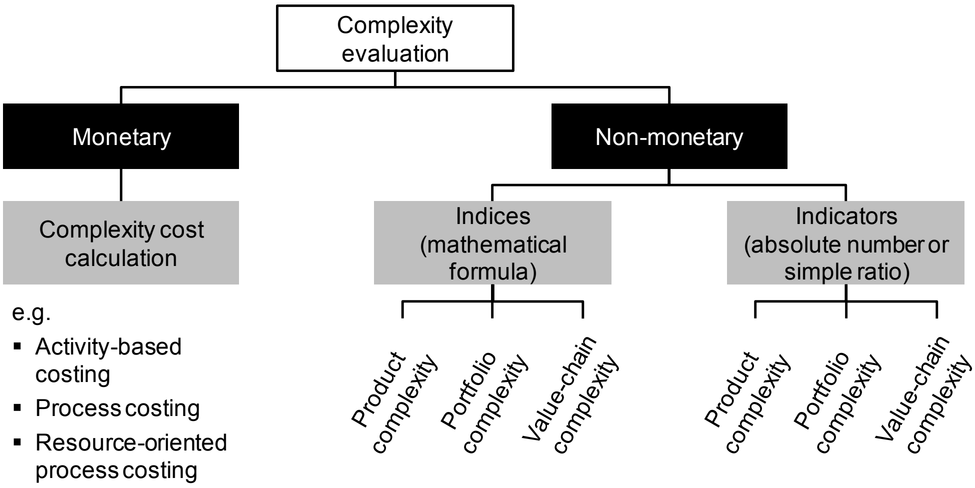

Figure 19: Classification of complexity evaluation approaches

Research and practitioners mainly focus on the monetary calculation of complexity costs but constantly experience severe difficulties in deployment of these approaches. Non-monetary evaluation presents an alternative approach but mathematical indices proposed by researchers are not suitable for a comprehensive complexity evaluation covering the three levels. Likewise, absolute indicators and simple ratios are not combined in a systematic approach and are yet to be investigated as a valuable approach for complexity evaluation.

To avoid unnecessary variety-induced complexity as early as possible, the integration of complexity in decision-making represents a key managerial task. As decision-making on products and variety follows the same patterns as other managerial decisions, the aspects of process standardization, cross-functionality, rationality, political behavior and intuition need to be considered. These aspects are covered in the two mechanisms of process design and reasoning.

In summary, the following research provides a framework for the evaluation of variety-induced complexity and complexity integration in early decision-making. It thus builds on the research done on solution-oriented complexity management concepts.

3. Reference framework development

This research has the objective of contributing to complexity management literature. To guide data collection and subsequent analyses, a reference framework has been developed. The following paragraphs describe the elements of this framework which are derived from the literature review presented in Chapter 2.

3.1 External and internal complexity drivers

Complexity in manufacturing companies is a result of external and internal drivers. Companies are exposed to these drivers and are required to react to these in order to stay competitive and become successful. If a company does not react or reacts too late to changes in external and internal drivers, it risks losing customers, market share and revenues. Both external and internal drivers induce complexity in a company's product portfolio, in product architecture and in value-chain processes. In addition, these drivers trigger decisions for products and product variants in the company.

Dynamics in the environment surrounding the companies are reflected in external drivers. Evidently, the predominant external drivers of variety-induced complexity are related to customers and markets; such as:

- The size of the company's customer base (i.e. the amount of customers served)
- The globalization of the company's customer base (i.e. the global spread of the customers or markets served)
- The product requirements of the company's customers (i.e. the degree of individualization demanded by customers)
- The variability in customer demand (i.e. the fluctuation in orders and order volumes).

As final products consist of multiple components which are not produced internally, manufacturing companies rely on innovative suppliers. However, suppliers are another source of complexity because interfaces between the companies need to be managed. Supplier-related drivers include:

- The size of the supplier base (i.e. the amount of suppliers delivering to the company)
- The globalization of the supplier base (i.e. the global spread of the suppliers)
- The unreliability of the suppliers (i.e. the incapability of the suppliers to deliver their components, material, products in the right quantity and quality and on time).

The environment of manufacturing companies is also characterized by actions of competitors, who can, for example, introduce new products or expand to serve new regional markets. These actions drive complexity in other companies due to the fact that they need to adjust established procedures, e.g. by defining more efficient processes to be able to lower product prices. Another matter driving complexity is the rising power of regulatory bodies, which leads to standards and (global and region-/country-specific) regulations to be fulfilled by manufacturing companies. The effort to become certified by these regulatory bodies drives complexity in internal processes.

Changes experienced by the company in processes, in the organizational structure and in products are reflected in internal drivers. External and internal drivers are to some extent interconnected, e.g. internal product-related drivers are a result of external market- and customer-related drivers. Product-related drivers include:

- The mix of different products offered to the market place (different products could mean the number of different product lines, products with different core technologies or multiple degrees of product customization)
- The length of the product life cycle (i.e. the lifespan of the product from market introduction to the end of customer use)
- The architecture of products (i.e. the technical structure of products provided to the market place).

Another category of complexity drivers is related to organizational and individual behavior within the company. These internal drivers are:

- The level of vertical integration (i.e. the extent to which the company covers the value-adding processes internally)
- The organizational structure (i.e. the amount of hierarchy levels and the resulting lengthiness of decision-making)
- The production structure (i.e. the organization of the production network and of the individual plants)
- The company culture (i.e. the behavior of individuals in the organization).

3.2 Transparency on product portfolio and product complexity

Complexity drivers induce changes in the product portfolio and product architecture in manufacturing companies. At product portfolio level, the broadening of the portfolio is a typical company reaction. The company decides to provide an additional product and initiates a project which requires resources to carry it through. With this comes an increase in complexity of the product portfolio. In line with the change in product portfolio complexity, complexity of product architecture is affected. Complexity drivers lead to a more complex technical product structure due to the adding of individual options and features. This requires a higher number of components and parts which have additional interfaces to existing components. Product portfolio complexity and product architecture complexity are highly interdependent. In most cases, an increase in product portfolio complexity is associated with a change in product architecture complexity. In fact, customer demand for additional product options leads to a new product variant in the portfolio as well as a changed technical product structure.

Understanding the increase as well as the decrease of complexity in the company portfolio and in product architecture is critical. With a high level of transparency on complexity, the company is able to steer complexity. On the portfolio side, this means that the company is able to detect a level of complexity which is probably too high to handle efficiently. A company can then decrease its portfolio complexity by phasing out products and by deleting "zero-seller" products. On the product architecture side, knowledge of an increase in parts, components and interfaces can lead to emphasis on same part rates between products or modularity and platform concepts. To create the necessary transparency for both product portfolio and product architecture complexity as a basis for specific complexity management actions, manufacturing companies can apply monetary and non-monetary evaluation approaches.

3.3 Transparency on value-chain processes complexity

The decision to provide a product or product variant not only leads to an increase in product portfolio complexity but also to complexity in the company's value-chain. This increase in complexity becomes tangible in additional effort (e.g. personnel resources, materials, space) during the processes in the value chain. For instance,

Figure 20 illustrates the complexity increase in terms of the number of parts added along the automotive manufacturing process.

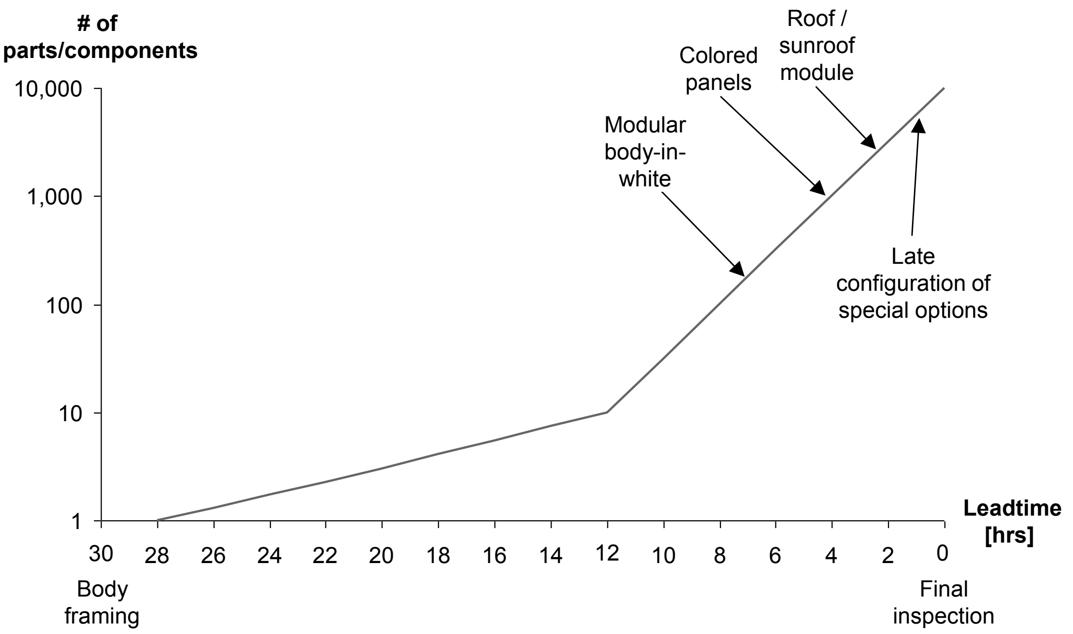

Figure 20: Complexity increase during the manufacturing process of an automobile (adapted from Howard et al. 2001)

However, the decision to create a product or a product variant does not only affect the manufacturing process. Such decisions do, for instance, also require additional testing and prototyping in R&D, launch and set-up effort in manufacturing, adjusted sales tools in marketing and additional documentation and manuals in after-sales. Figure 21 shows a schematic complexity increase during value-chain processes. Similar to portfolio and product complexity, complexity occurring in value-chain processes due to a larger variety of products can be evaluated by applying monetary (complexity cost calculation) or non-monetary (indices and indicators) approaches.

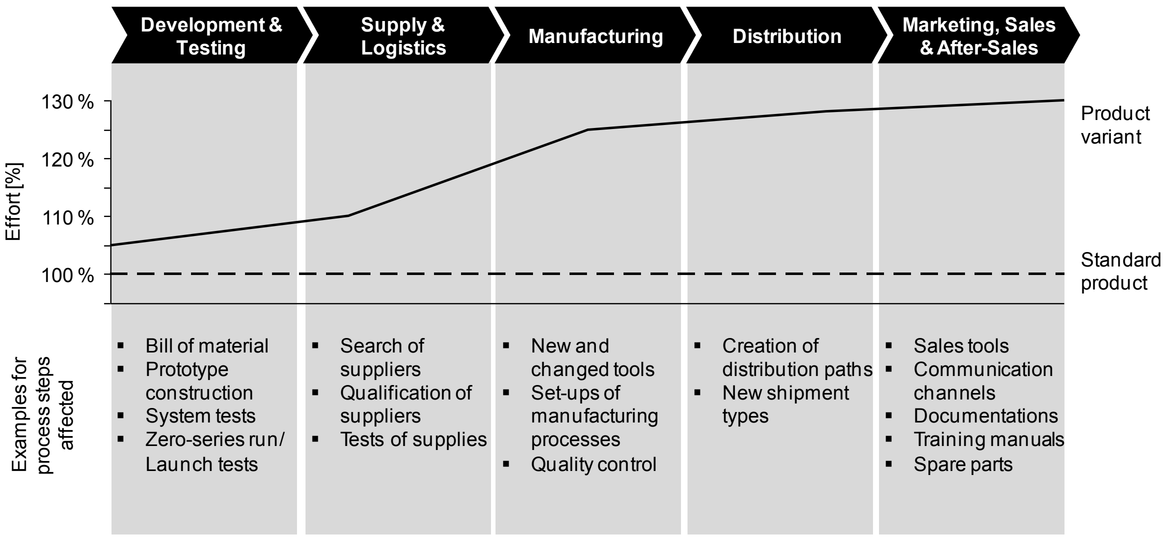

Figure 21: Effort increase along the value-chain of manufacturing companies

3.4 Process design of decision-making for products

Transparency on portfolio, product and value-chain processes complexity represents an important element in understanding changes in complexity. In fact, it is a prerequisite for well-directed actions by the company and successful complexity management. Of course, a high level of transparency is not the only, but certainly the first step in successful complexity management. Creating transparency on variety-induced complexity can enable a company to steer complexity by applying concepts such as product platforms, product modularization and mass customization as well as by thinking up new approaches to controlling complexity in early decision-making. To be able to work proactively rather than reactively it is critical to pull forward complexity management actions in the early phases of projects on products and product variants (Alders 2006). The objective of companies is the right selection of promising projects on products and product variants in early decision-making to avoid unnecessary projects (e.g. for low-volume product variants) and to use internal resources as efficiently as possible. Figure 22 illustrates the direction for complexity management.[36]

[36] The thinking behind this illustration is derived from product development literature which argues that 70 to 80 percent of the overall product costs are defined in development and construction but that these costs do not occur until manufacturing and assembly (e.g. Ehrlenspiel 1985). However, they need to be considered in early development phases to avoid costly "surprises" in subsequent product creation processes.

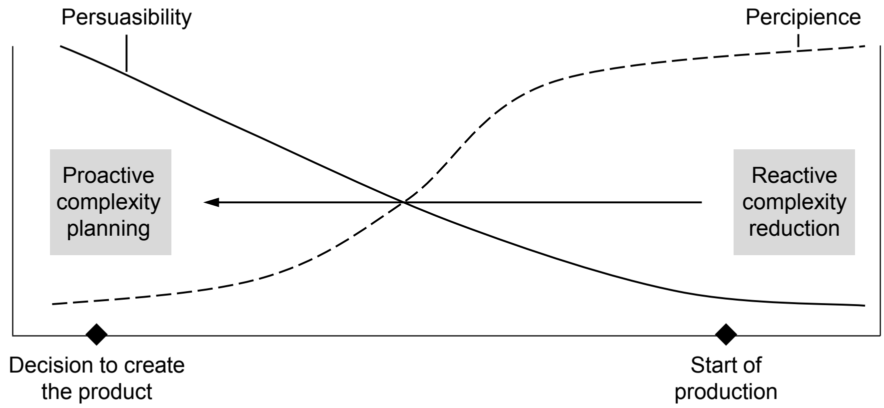

Figure 22: From reactive complexity reduction to proactive complexity planning (adapted from Alders 2006)

Moving in this direction involves adjustments in two areas of early decision-making: Process design of decision-making and reasoning (i.e. criteria) prevailing in decisions on product and product variants. Both areas are keys to successful adjustment when integrating a complexity perspective in decision-making. The isolated addition of complexity criteria in decision-making to improve reasoning without considering the processes involved can lead to biased information due to unsuitable information gathering procedures.

Process design of decision-making is characterized by several aspects related to the process definition, the mechanisms applied and people involved. Defining the phases, activities and milestones of the decision process provides guidance. It standardizes the process in a similar way to existing product development processes. In fact, the decision process is partially covered by product development processes as they involve activities for the preparation of the actual decision and the decision as a milestone in the process. As different projects involve different characteristics in terms of urgency, technical difficulty, strategic importance or customer preferences, flexibility of development processes (and the corresponding decision-making) is recognized as a quality aspect for processes. A high level of process flexibility can be realized by defining adaptive processes according to these characteristics[37] and by improving processes based on past project experiences[38].

[37] Cooper (2006) presents the so-called scalable stage-gate process which includes an early switch point (first gate) after the idea stage ending in one of three development processes according to the project's urgency.

[38] Dooley et al. (2005) explain that companies often fail to implement a continuous learning cycle to improve processes based on past project success and failure.

Defined processes are further characterized by the involvement of multiple stakeholders because such processes require several competencies. A process is typically staffed with people from different departments, hierarchy levels and personal backgrounds who provide information, fill in the templates (e.g. the business case), prepare decision memos and make the go/no-go decision. In addition to the involvement of different stakeholders, a decision is determined by the responsible person or persons (e.g. who are signing the business case) because it initiates the allocation of resources for the duration of the value-adding process phases. The level of cross-functionality in decision-making and the department person bearing the responsibility of the decision influence the process and the outcome.

Within this decision process, interactions between those involved in the process take place. These interactions can be formal in defined meetings or informal conversations which are not defined in the process. Both types of interaction, as well as the degree of standardization, determine the outcome of the decision-making process. Furthermore, as there are a number of personal objectives and opinions involved, processes for new products and variants are affected by typical decision mechanisms such as political behavior, intuition and rationality.

3.5 Reasoning in decision-making for products

Another key aspect of successful decision-making for products is the reasoning applied at the process milestones. It has been observed that company's decisions lack high quality in project evaluations due to unreliable and biased criteria. Decision points are ranked one of the weakest areas in the product development process.[39] Indeed, in most manufacturing companies, running projects for products are rarely stopped at the defined decision points. Most process definitions are not very robust at the decision points. This problem is related to the sets of criteria applied, which are not very accurate, objective and reliable. In an effective process, underperforming projects are identified very early and immediately stopped or sent to rework.

[39] This observation has not only been made for decisions on products but also on other strategic decisions. Nutt (1999) revealed in an analysis of 356 decisions in organizations that half of the decisions in these organizations failed due to certain interventions by managers (e.g. search limits, use of power, wrong objectives, lack of people involvement).

This problem also becomes visible in Figure 23, which shows the calculations of the NPV (containing sales volume und projects costs) for one single product variant at three evaluation points.[40] Evaluation #1 represents the initial estimation of the NPV and evaluations #2 and #3 are calculated after three years project runtime each. The NPV represents one key criterion in the business cases for products in most manufacturing companies. The illustration shows that early estimations were wrong for both inputs to the NPV calculation: Sales revenues and project costs.

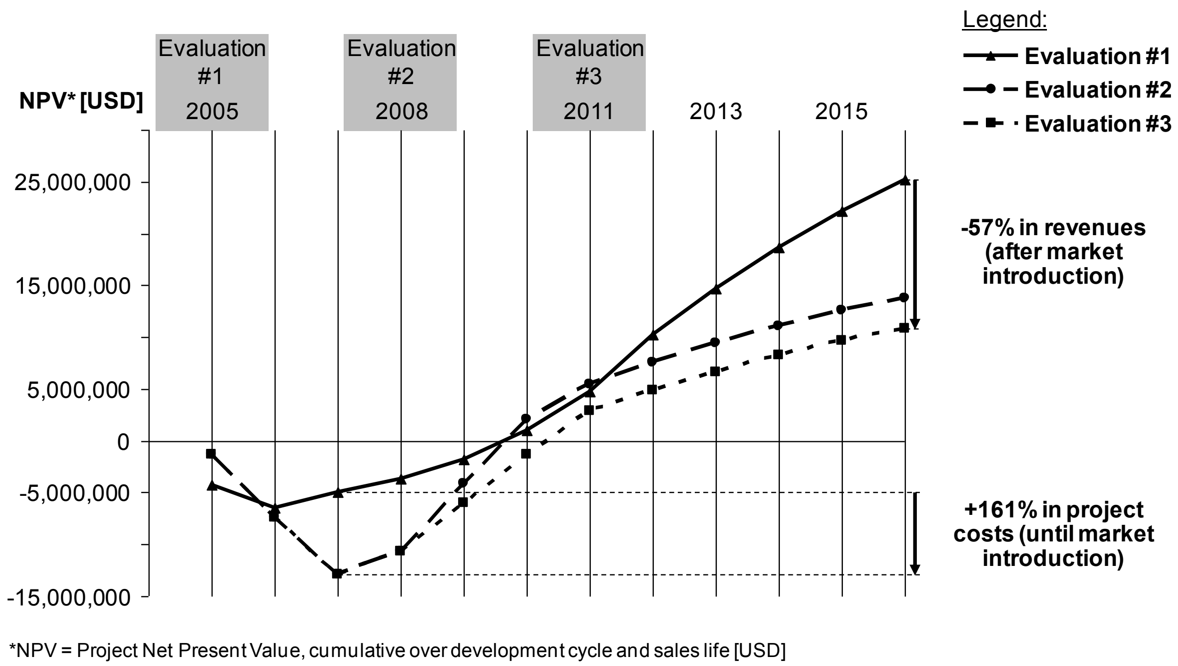

Figure 23: Example for NPV estimates at different product evaluation points

As seen in this exemplary visualization, NPV calculations were not reliable at this European mechanical engineering company. Sales volume estimates were off by 57 percent from the initial estimation by the sales department. Project cost estimations were significantly off by 161 percent due to the difficulty in establishing the link between costs, especially indirect costs, and single products. Complexity effects induced in the company's value-chain were not covered in NPV or other criteria in the business case.

Comprehensive reasoning in early decisions as a basis for proactive complexity planning (Figure 22) requires a complexity perspective which covers both aspects: The benefits associated (in terms of sales/revenue) and the effort resulting. This

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40 The data was gathered in an applied research project, which was conducted from October 2010 to March 2011, at a company in the mechanical engineering industry.

perspective can be implemented by defining reliable criteria for use in early decisions.[41]

3.6 Effectiveness and efficiency of projects

Projects for products and product variants have the objective of achieving a high level of effectiveness and efficiency. Effectiveness targets can be broken down into four central aspects which are of critical importance when assessing project success. These are based on the output created by internal processes and related to customers and markets:

1. Product quality: Products and variants created should meet or exceed the product quality requirements of its customers.
2. Customer satisfaction: Beyond the physical product quality, the company should satisfy the customer with the overall offer (e.g. on-time delivery or after-sales service).
3. Sales volume: The anticipated sales volume for products and product variants should be realized.
4. Competitive advantage: Products and variants should enable the company to create or maintain a competitive advantage in the market.

In addition to performance indicators related to effectiveness, companies are concerned with resources required to achieve positive customer and market reactions. These indicators reveal the level of internal efficiency when conducting products and variants projects. Two main indicators related to cost and to speed of projects are:

5. Project costs: Costs for the project through product creation (until market introduction) and sales life (e.g. cost for spare parts) should remain within reasonable limits which are set at the time of the early decision to create the product.
6. Time to market/delivery: The date for market introduction or delivery to customer should be met.

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41 Ward et al. (2010) present an example from the company Hewlett-Packard, which implemented the "number of newly added SKUs for this product" as a criterion in the business case for products.

Project success in a company, i.e. the achievement of effectiveness and efficiency targets, can be very different for new products and product variants. For example, a niche company with a high percentage of engineered-to-order products can be very effective and efficient for product variant projects. However, the same company probably struggles with high project effectiveness and efficiency for innovative, brand-new products. Exactly the opposite can be observed for companies producing commodities for mass markets.

In the same way as decision-making for products and variants mainly affects resource allocation, proper decisions affect efficiency by limiting the number of running projects and resources consumed. Furthermore, decision-making can influence effectiveness because assigned personnel resources can focus on a few chosen activities leading to higher quality outputs for these activities. Due to the fact that the integration of complexity supports objectivity in decision-making to understand the impact on products, portfolio and processes, transparency on complexity does affect effectiveness and efficiency of projects. In conclusion, comprehensive decision-making in early phases for products affects the performance of the company positively.

3.7 Reference framework

The reference framework used to structure the empirical investigation carried out during this research is derived from the key issues and shortcomings identified in the literature review and from the interrelations between them. It is structured around three main elements: The drivers triggering decision-making and complexity management actions, the related core elements of complexity transparency and decision-making for products and the performance achievements in projects. The framework presented in Figure 24 shows an illustration of the relationship between complexity transparency and its integration in early decision-making for products.

External and internal complexity drivers represent the central trigger of the framework. These drivers therefore influence decision-making and complexity induced in products, the portfolio and value-chain processes. The center consists of two categories with two elements each. In the same way as complexity induced by product variety is experienced on two main fronts, transparency on complexity has also to be discussed on the product and portfolio side as well as on the process side covering the efforts along the value-chain. Decisions on products, characterized by the design of decision processes and the reasoning applied, induce complexity. Transparency on complexity is required for proper, complexity-steering decision-making. In fact, decision-making determines complexity in products, in the portfolio and in processes. Both core categories of the model are therefore interrelated. Proper and comprehensive decision-making on products in combination with a high level of transparency on complexity results in effectiveness and efficiency of projects for products and product variants.

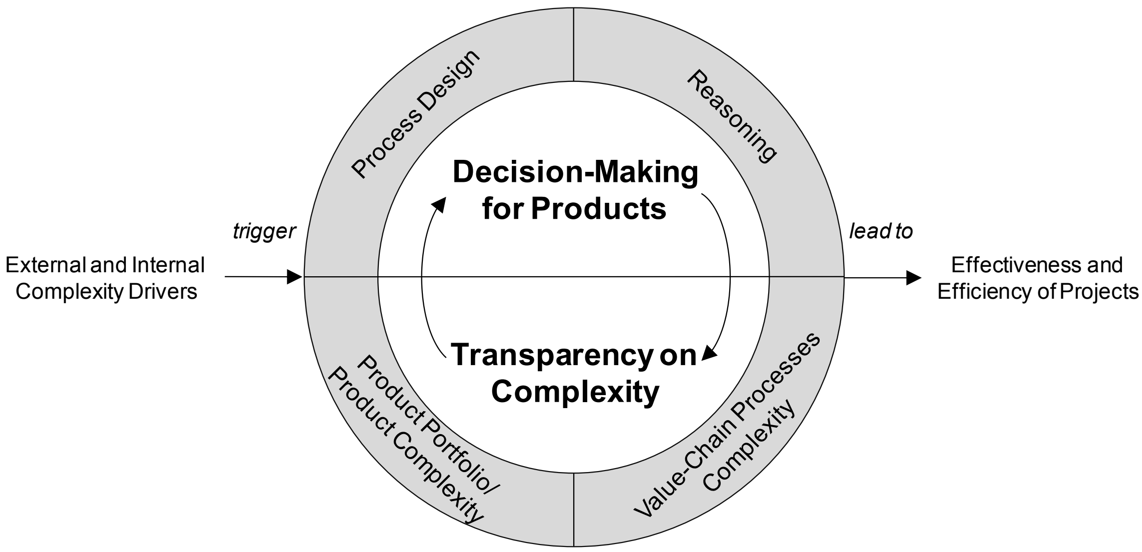

Figure 24: Reference framework

This framework presents a practical model for companies. It reveals key elements and the interrelations to take into consideration when improving the understanding variety-induced complexity and early decision-making for products. The application of this framework as a guideline will enable this research to derive practical results for industrial managers and concrete implications for complexity management literature.

The reference framework is operationalized for the cross-industry survey as the first empirical phase of this research. In the second empirical phase, the in-depth case studies are also structured according to this framework. Insights from these empirical research phases will lead to refinements and adjustments of this initial reference framework. The purpose of these changes is the development of a conceptual framework which reflects the reality in manufacturing companies and their approach to complexity management.

4. Empirical investigation

4.1 Findings of the complexity management survey

4.1.1 Survey design

Questionnaire design

To conduct this quantitative empirical part of the research a questionnaire was developed based on the reference framework which was broken down and treated in detail by specific questions. In order to achieve a high return rate, the sections of the questionnaire were named attractively for managers in industrial companies:

A. Information about your company (division) and markets: This section asks for general information about the company as well as business characteristics and the development of product variety in the company.
B. Managing complexity in your business: This section investigates external and internal drivers of complexity and the overall approach of the company's complexity management.
C. Managing complexity in your product management: This section gathers data about decision-making for products and product variants (stakeholders involved, responsibilities, mechanisms, criteria and the integration of complexity) and the creation of transparency on product architecture and portfolio complexity.
D. Managing complexity in your processes: This section is concerned with complexity transparency and its measurement. In particular, the section asks about complexity indicators in single value-chain process and complexity cost calculation.
E. Performance & competitive advantage: This section asks about the overall financial performance of the company in the last three years. It also covers the development of effectiveness and efficiency indicators in the last three years differentiated for new products and product variants.

These sections include multiple questions, each one generally heading a number of sub-questions with different scales. There is a total of 37 questions which leads, due to the large number of sub-questions, to 238 questionnaire fields (data points in analysis) to be completed by the company representatives. Multiple scales are used to gather the data with respect to the issue to be investigated. Table 9 provides an overview of the scales used in the questionnaire.[42]

Table 9: Questionnaire structure and question scales[43]

Section		Nominal scale	Ordinal & interval scale	Ratio scale	Open questions
A	Information about your company (division) and markets	5	3	3	1
B	Managing complexity in your business	3	2	-	-
C	Managing complexity in your product management	2	4	-	2
D	Managing complexity in your processes	2	4	1	2
E	Performance & competitive advantage	-	2	-	1

Survey procedure and target companies

After finishing the design of the first draft of the questionnaire, the questionnaire was pre-tested by researchers to identify time requirement for completion and practitioners from six companies (from different hierarchical levels and functions such as product management, product development, manufacturing and marketing) to find out about relevance and understandability of the questions. Using the feedback from both pre-test groups, the questionnaire was modified accordingly to create the final version for distribution.

[42] Stevens (1946) presents a classification for the scales of measurements in surveys dividing between four types: Nominal, ordinal, interval and ratio scale. For the overview in Table 9, ordinal scale (for all 5-point Likert scales used in the questionnaire) and interval scale (e.g. for the question concerning the achievement of objectives which uses a scale of percentage ranges) are combined.

[43] The table shows only the main questions of the questionnaire. For the specific scales of the sub-questions please refer to the questionnaire in the appendix.

The questionnaire was sent out by e-mail including a cover letter. This cover letter was individualized for each person and included a project description and the time estimated for completion, the benefits of participation for the company and a statement regarding confidentiality and data security. The main incentives for the companies to participate were the study report created and the opportunity of participating in a personal discussion on complexity management which was organized for the "Top 5" companies in complexity management.

The survey was not limited to a specific industry, but targeted all manufacturing industries. After two weeks an individualized e-mail reminder was sent out. In total, the questionnaire was sent out to 950 contacts from 810 different companies. Approximately 70 of these companies were contacted via telephone. The survey was not limited to a certain geographical area and included companies around the globe. However, approximately 80 percent of the companies in the database are located in the German-speaking area (Switzerland, Austria and Germany). The contact persons were from different hierarchy levels (CEO, VP, Head of Business Unit, Head of Department, Head of Division, etc.) and departments (product development, product management, manufacturing, sales) working on the assumption that complexity management is assigned to different departments depending on the focus. The data was gathered between 14th November 2011 and 14th January 2012.

4.1.2 Characteristics of the respondents

Within the data gathering phase, 177 completed questionnaires were returned which represents a return rate of 18.6 percent. From this overall sample, 175 questionnaires were usable for the analysis. Two questionnaires were excluded due to a large number of answers omitted which could not be completed by the company representatives in the data gathering time frame. Consequently, these two questionnaires were not taken into account due to incompleteness.

Corresponding to the broad range of hierarchy levels and functions in the contact database, the returned questionnaires were submitted by various hierarchy levels such as CEO, COO, VP, Head of Business Unit, Manager of Department or Functional Unit and others as well as by various departments such as product development, product management, manufacturing, strategy, business development, variants management and others. This indicates that complexity management is conducted with varying priorities and levels of commitment in the responding companies. Some of the respondents pointed out via e-mail or phone that they had discussed the answers for the questionnaire with other people and departments in their company. They mentioned that this was necessary due to fact that the questionnaire asks for information concerning topics which are spread across several departments (e.g. portfolio complexity is managed by product management, product complexity is managed by development and process complexity is managed by multiple departments such as manufacturing and logistics).

The geographical focus of the respondents is in Europe, in particular in the German-speaking area, but a few completed questionnaires were returned by companies located outside of Europe:

- German-speaking European countries: 157 returned questionnaires (89.7 percent)[44]
- Other European countries: 7 returned questionnaires (4.0 percent)
- North America: 7 returned questionnaires (4.0 percent)
- Asia: 2 returned questionnaires (1.1 percent)
- Middle East: 1 returned questionnaire (0.6 percent)
- South America: 1 returned questionnaire (0.6 percent)

Participating companies were of different sizes (employee counts) showing that the issue of managing variety-induced complexity is relevant for companies regardless of their size:

- Up to 500 employees: 32 returned questionnaires (18.0 percent)
- 501-2,000: 36 returned questionnaires (21.0 percent)
- 2,001-5,000: 9 returned questionnaires (15.0 percent)
- 5,001-20,000: 42 returned questionnaire (24.0 percent)
- Over 20,000: 50 returned questionnaire (29.0 percent)

53 percent of the participants were large multi-national cooperations with more than 5,000 employees. In some cases these large companies conduct their complexity management and make their decisions autonomously on a business unit level. For this reason, 75 participants completed the questionnaire from a business unit perspective whereas 100 participants completed the questionnaire for the entire company.

The survey was intended to investigate complexity management and specific elements of the reference framework across industries. Figure 25 illustrates the

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[44] Among the participants from Europe were also large subsidiaries whose official corporate headquarters are outside of Europe, namely in the USA or Asia.

range of industries participating in the survey. Industries with the largest populations in the sample are: Machinery and Equipment, Automotive, Chemical, Pharmaceutical, Consumer Goods and Electronics.

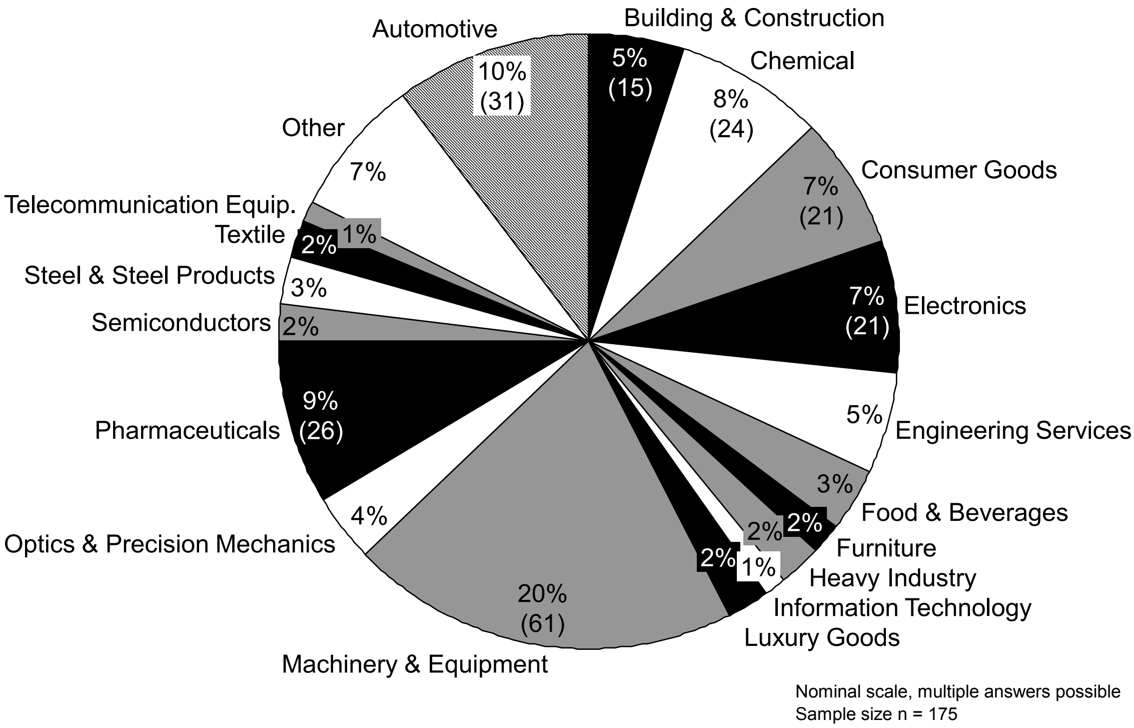

Figure 25: Industries of the survey participants

Among the 175 respondents used for the analysis 45 percent are Original Equipment Manufacturers (OEMs) and 38 percent suppliers (Tier-1, Tier-2 and a combination of both). The remaining 17 percent of the sample are companies which cover both positions in the value-chain: OEM and supplier, depending on the specific product and industry served. Around 80 percent of the companies are covering the entire value-chain in-house: Research, development, logistics, manufacturing, distribution, sales, marketing and after-sales. Some of the remaining 20 percent in the sample have either outsourced after-sales or research activities.

The companies run different business models which leads to a diverse mix of B2C, B2B and B2G companies in the sample[45]:

- B2C: 22 percent
- B2B: 46 percent
- B2G: 1 percent

[45] Multiple answers (B2C, B2B and B2G) were possible for the question regarding the business model.

- B2C & B2B: 15 percent
- B2C & B2G: 4 percent
- B2B & B2G: 5 percent
- B2C & B2B & B2G: 7 percent

Most of the companies who participated in the survey (86 percent) serve a global market. Only smaller companies in the sample have a limited reach with their products, either on a continental market (8 percent) or a regional/national market (6 percent). For the main markets of the participants, multiple maturity levels are stated. Most of the companies state a weak growth with less than five percent (45 percent of participants) or even a strong growth with more than five percent (33 percent of participants) of their main market. 21 percent of the companies consider their main market as mature. At the end of the range are a declining (one percent) and a developing main market (one percent). 64 percent of the participants state an average product life-cycle duration of seven or more years. Among these are 26 percent with a product life cycle of more than 15 years. 29 percent of the participants state a product life cycle of three to seven years, followed by seven percent of participants with one to three years and one percent with less than one year.

Multiple strategic priorities are stated by the participants as crucial to winning customer orders. Figure 26 shows that the reliability of deliveries is at the top of the list, followed by innovativeness of products and lower prices. It is often argued by practitioners that a strict complexity and variants management hinders innovative products; however the list of competitive priorities indicates that companies with a strong focus on innovation are also concerned with complexity management.

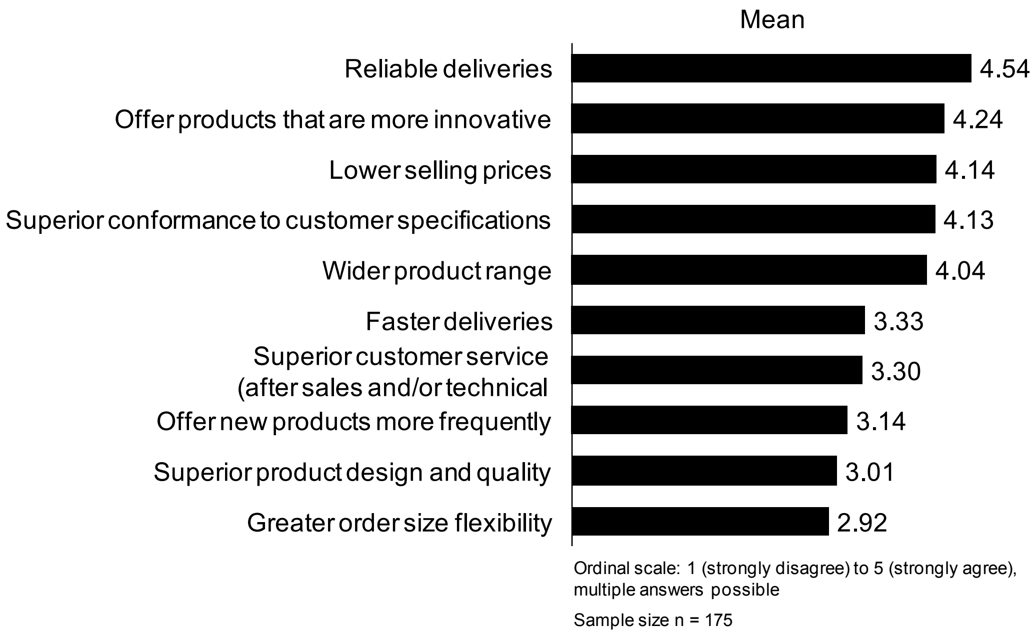

Figure 26: Competitive priorities of the survey participants

4.1.3 Key findings of the descriptive analysis

The following sections present selected results of the descriptive analysis using the entire sample of 175 questionnaires. The objective is to generate first insights into complexity drivers, variant creation, the implementation of complexity management, and, more specifically, into complexity indicators as well as complexity criteria in decision-making by investigating a broad sample of manufacturing companies.

Complexity drivers and their impact

External complexity is driven firstly by demanding and globally scattered customers and secondly by standards and regulations. Companies are exposed to additional country-specific regulations, e.g. when they decide to serve a market or build a manufacturing plant. Although the innovative power of key suppliers is increasing in manufacturing companies leading to more interfaces between the companies, the number and unreliability of suppliers are not considered major drivers of complexity by the survey participants.

Internal complexity is driven by the technical product architecture, which is, at least partially, related to the customers targeted. Apparently, companies consider complexity as a consequence of organizational aspects rather than the result of a diversified product mix to be offered to the marketplace or of a high level of vertical integration. Figure 27 provides the ranking according to the relevance of each complexity driver categorized in external and internal drivers.

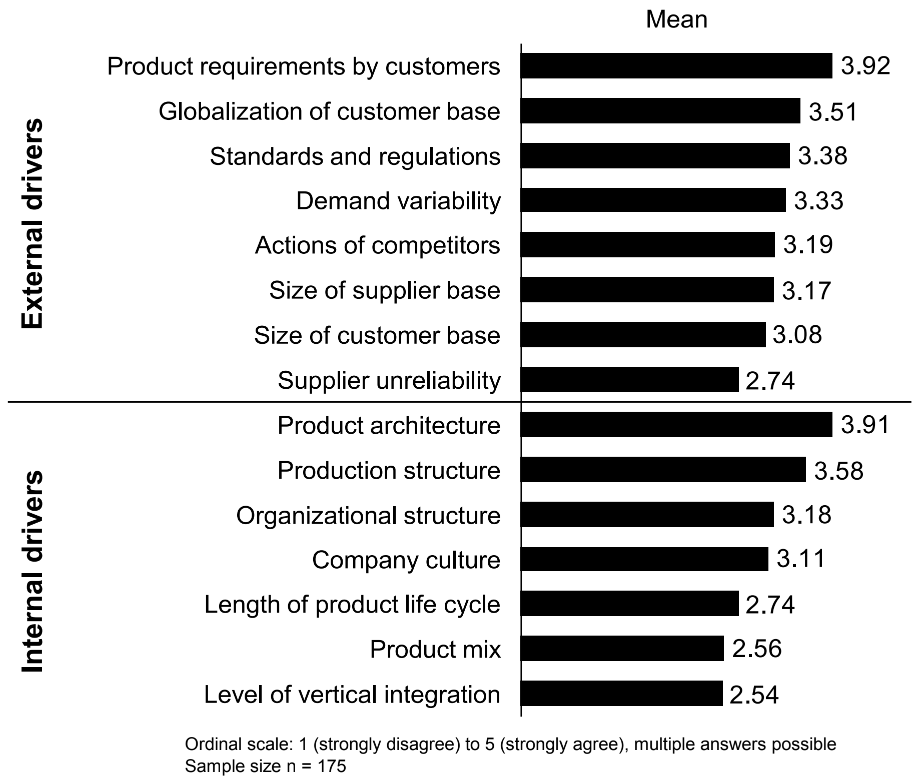

Figure 27: External and internal complexity drivers as given by survey participants

The calculations of the mean scores reveal that external and internal drivers are rated approximately equally in their relevance for creating complexity. In fact, the top-ranking drivers, product requirements by customers (external) and product architecture (internal), have almost an equal score. This supports the observation regarding the origin of product variants. The participants state that 39.8 percent of product variants are triggered by internal push (e.g. by development or quality) and 60.2 percent of product variants are triggered by external pull. It is not the case that all product variants originate from external customers' demands and specifications.

Product variants cause additional costs compared to the "baseline" product from the product line. On average these additional costs account for 29 percent across all industries. As Figure 28 shows, these additional costs (complexity costs) are dependent upon the type of industry. They range from ten percent for the Information Technology industry to 66 percent for the Luxury Goods industry.

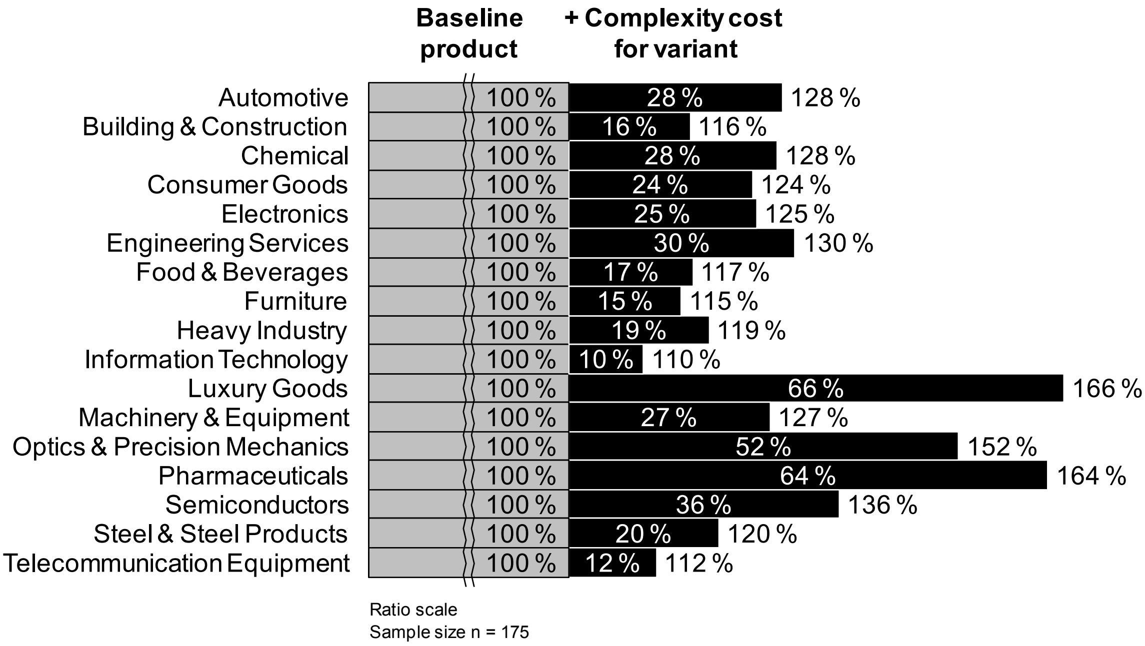

Figure 28: Additional costs for product variants as given by survey participants

Implementation of complexity management

Complexity induced by product variety has two sides: Resulting benefits and effort involved. The majority of companies acknowledge the complexity of their product portfolio as a differentiating factor in the market. 67 percent of the 175 participating companies state that they consider the benefits of complexity as critical to their company's market success. In this context these companies also point out that optimal management of complexity and product variety is important. 79 percent of the participating companies consider complexity management as the key to achieve and sustain a competitive advantage.

Therefore, companies have set up complexity management systems. In line with the balanced consideration of the benefits and efforts of variety-induced complexity, companies focus on complexity control and reduction in their complexity management initiatives. Figure 29 shows the strategic priorities for complexity management stated by the participating companies.

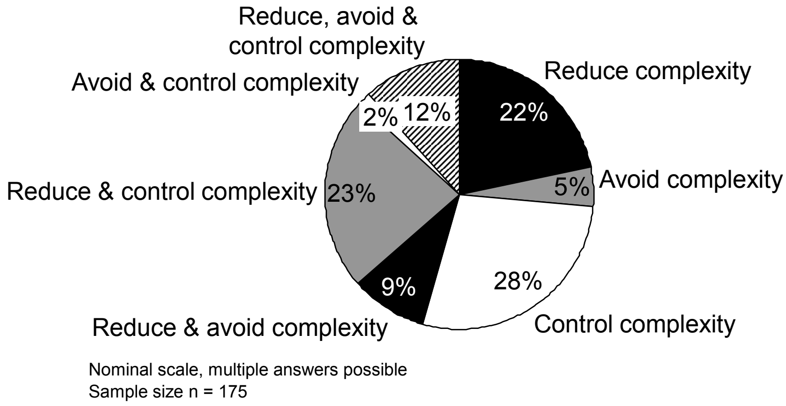

Figure 29: Strategic priorities in companies' complexity management

Due to their effort to set up complexity management initiatives, participating companies have already addressed several facets of complexity. Only one percent of the companies state that they had not yet run any complexity optimization projects. The other companies had targeted at least one area for complexity optimization. Figure 30 indicates that two thirds of the companies have already worked on the complexity of their product portfolio, but only 20 percent have worked on end-to-end optimization across the entire value-chain.

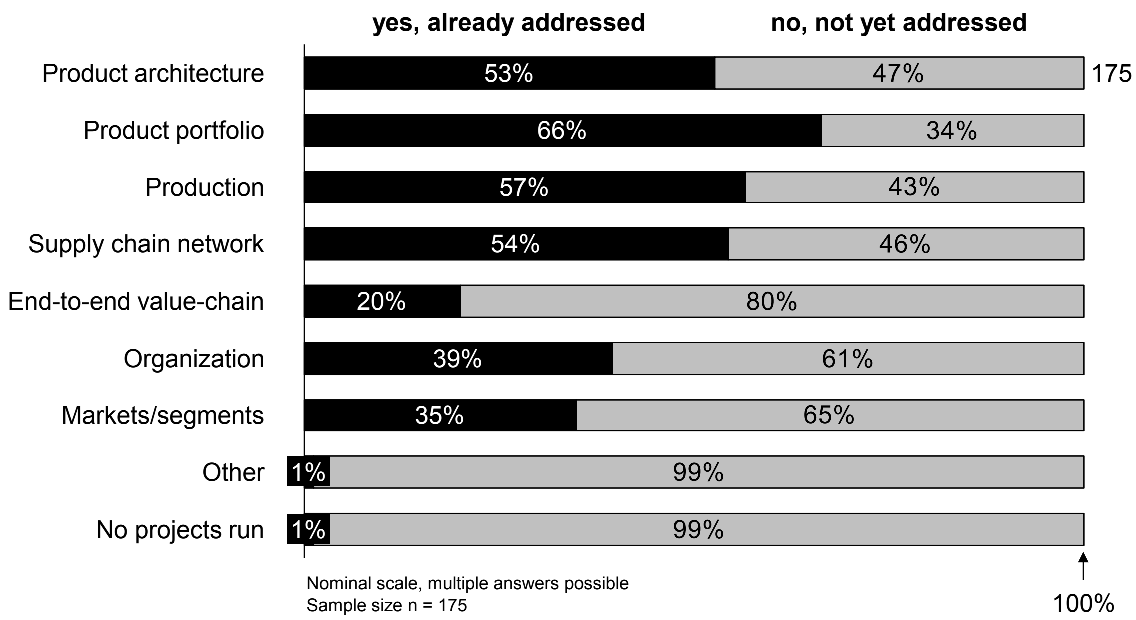

Figure 30: Areas targeted by complexity management

The core areas already targeted by companies' complexity management are also reflected by organizational responsibility for complexity management. Product management tops the list of anchoring the topic within the organization with 32 percent. Nearly 40 percent of the participants have set up cross-functional teams (either permanent or temporary) for complexity optimization efforts. This shows that complexity management is considered a cross-functional approach requiring multiple corporate competencies. In detail, the split of responsibilities for the complexity management initiatives across the participating companies is as follows:

- Product management: 32 percent
- Permanent cross-functional team: 20 percent
- Temporary cross-functional team: 19 percent
- Product development: 17 percent
- Responsibility unclear or non-existent: 6 percent
- Special department in the company: 3 percent
- Special department in the division: 2 percent
- Other: 1 percent

Although companies state a certain strategic priority, specific areas targeted and a typically clear organizational anchoring of complexity management, they are not entirely satisfied with its implementation. Only 22 percent of the participants explain that complexity management is implemented successfully within their company. Even less are satisfied with the performance achievements of their complexity management. 20 percent of the participants state that there has been a substantial improvement in performance since the implementation of complexity management. Apparently, the shortcomings of existing complexity management approaches are confirmed by these two real-life observations in the 175 companies.

Complexity indicators to evaluate product, portfolio and processes complexity

As a reaction to the shortcomings in complexity management, companies try to define complexity indicators to evaluate complexity and track the progress and impact of their initiatives. These indicators can be divided into three main areas of complexity transparency:

1. Product portfolio
2. Product architecture
3. Value-chain processes

To make complexity in the product portfolio transparent, several indicators were mentioned by the participating companies.[46] The most frequently mentioned indicators to measure product portfolio complexity are the following:

- # of products
- # of product variants
- # of customers served
- # of customer segments
- # of stock-keeping units (SKUs)
- # of product lines / product families
- # of modules, systems or compositions
- # of components (e.g. parts, ingredients)
- # of projects in pipeline (new products, product variants)

To measure complexity in product architecture, e.g. in the technical structure of product variants with a certain degree of individuality, the following indicators are stated by participating companies:

- Share of "unknown" components (parts or ingredients) in a product or a product variant
- Level of alignment of a product request to existing science / technology platform
- # of new components (e.g. parts, ingredients) to be developed for a product or a product variant
- Mix of technologies used in a product or a product variant
- # of product platforms affected by a new product or a variant development
- # of products on the product platform which are affected by a new product or variant development

Complexity resulting in the value-chain due to product variety has to be regarded in detail for each process starting with research and development and ending with after-sales. Table 10 provides lists of indicators for each process step of a manufacturing company, which were stated by a number of participating companies as being used to measure complexity in processes. Apparently, multiple process-related indicators in the specific phases are recognized by the companies as necessary for process complexity transparency.

[46] By following an explorative approach, the answers were not limited by the researcher. The data was gathered in open questions to give the participating company a high degree of freedom.

Table 10: Indicators for value-chain processes complexity

Value-Chain Process	**Indicators**
Research & development	▪ # of possible technological solutions ▪ # of related research activities in other projects ▪ # of entities in development bill of material (BOM) ▪ Renewal grade (e.g. # of change requests) compared to the baseline product or product line ▪ Readiness of existing development equipment
Purchasing	▪ # of suppliers ▪ # of supplier countries ▪ # of master agreements (frame contracts) ▪ # of components to purchase ▪ # of new supplier qualifications/certifications for product variants ▪ # of new parts on stock for product variants ▪ Impact on scale effects in procurement (e.g. lot size, cost savings) ▪ Frequency of delivery ▪ Amount of additional testing of components supplied ▪ Supplier reliability
Inbound logistics	▪ # of positions in IT system (SAP) ▪ # of shipments ▪ # of SKUs ▪ # of parts in storage ▪ # of shipping points ▪ Value of additional in-house inventory for product variants ▪ Order size ▪ Geographical distance to suppliers ▪ Turnover rate of components
Manufacturing	▪ # of necessary manufacturing steps ▪ # of components to be manufactured ▪ # of supplier shipments ▪ # of new entities in manufacturing bill of material (BOM) compared to standard product ▪ # of customized components ▪ # of additional sub-assemblies for the product variant ▪ Readiness of existing manufacturing equipment ▪ Additional utilization of production equipment ▪ # of changes to current process stages ▪ # of changeovers in production ▪ Lot size range
Outbound logistics	▪ # of customers ▪ # of stockpiles / distribution centers ▪ # of SKUs ▪ # of carriers ▪ # of shipments ▪ # of items per customer ▪ Amount of additional in-house inventory level for product variant ▪ Carrier reliability ▪ Time of products in storage

Table 10 (cont.): Indicators for value-chain processes complexity

Value-Chain Process	Indicators
Marketing & sales	▪ # of customer countries ▪ # of options provided to the customer ▪ # of active sales items ▪ # of customer countries (languages) ▪ Relatedness of product variant to existing customer segment ▪ Share of standard product sold ▪ # of customer changes per customer order
After-sales	▪ # of customer countries to be served ▪ # of languages ▪ # of spare parts per product or product variant ▪ # of service requests after product sale ▪ # of additional spare parts per product or product variant ▪ # of additional services ▪ Size of additional inventory of spare parts ▪ Relatedness to existing service tasks for products ▪ Duration of spare parts supply

Complexity criteria used in decision-making

The consideration of complexity in early phases is considered an effective strategy for controlling complexity in manufacturing companies. This complexity perspective is typically not covered by criteria found in business cases, which are the basis for the early go/no-go decision for the product. It is assumed that a number of these "standard" criteria are often not reliable in early phases. In fact, it was observed in the survey that 91 percent of the participating companies state that at least one criterion used in decision-making for products and product variants is not reliable in early phases. Several key criteria are investigated in terms of their reliability:

- Project costs: 42 percent of the companies consider this indicator as unreliable
- Market risk: 41 percent of the companies consider this indicator as unreliable
- Project risk: 38 percent of the companies consider this indicator as unreliable
- Market growth: 34 percent of the companies consider this indicator as unreliable
- Financial risk: 33 percent of the companies consider this indicator as unreliable
- Technical risk: 31 percent of the companies consider this indicator as unreliable

Whereas indicators show the impact on the portfolio, the product architecture and processes in the value-chain, criteria for decisions should enable a balanced view of benefits and efforts. They are the basis for objective decisions in the initial phases. Table 11 shows that there are multiple criteria for the integration of a complexity perspective in decision-making which are mentioned by participating companies. They are clustered in resulting benefits and induced effort of complexity.

On the benefits side, it can be seen that criteria used to evaluate complexity are standard criteria included in the typical business case of a manufacturing company. To a large extent, these criteria “implicitly” estimate the benefits associated with variety-induced complexity. On the effort side, however, there are some criteria which make complexity explicit and are often not found in manufacturing companies’ business cases.

Table 11: Complexity criteria in early decision-making

Scope	Category	Criteria
Benefits	Market-related	▪ Future sales potential ▪ Sales expected ▪ Market size ▪ Return-on-investment (ROI) ▪ Intensity of competition ▪ Globalization of markets (regions or countries)
	Customer-related	▪ Value for customer (unmet customer needs vs. nice-to-have) ▪ Innovation degree (technological advancements) ▪ Difference of customer requirements in target markets
	Strategy-related	▪ Alignment with business strategy ▪ Contribution to business objectives ▪ Competitive differentiation ▪ Fit with core business (business model) ▪ Consistency with product platform / family ▪ Dependency on existing products

Table 11 (cont.): Complexity criteria in early decision-making

Scope	Category	Criteria
Effort	Product-related	▪ Degree of modularity in product design ▪ Capacity for delayed product differentiation in the value-chain ▪ Fit with established product components, modules, technologies ▪ Allowance of product configuration for simple variant configuration ▪ Technological feasibility ▪ Level of cannibalization of products in the current portfolio ▪ Existence of in-house technological competence ▪ Impact on the overall component number (creation of new, reduction) ▪ Re-use of variants and technologies in other projects
	Process-related	▪ New process steps required ▪ Number of departments involved ▪ Existence of in-house process capability and experience ▪ Proliferation of SKUs ▪ Synergy with established supplier structure ▪ Distribution of production and sourcing locations ▪ Product-launch scope (regions or countries) ▪ Lead time to market introduction ▪ Duration of product life-cycle ▪ Costs until market introduction ▪ Costs for product maintenance (e.g. inventory of spare parts) ▪ Additional costs due to complexity (e.g. overhead labor hours)

4.1.4 Building the clusters

The descriptive analysis provides first insights into complexity drivers, the implementation of complexity management and details of complexity transparency. However, it does not answer the question regarding the success of these approaches. Therefore, the objective of this next analysis is the identification of differences between specific clusters in the sample of 175 companies.

The basic principle behind the analysis is that the implementation of complexity management capabilities has a positive influence on the company's effectiveness and efficiency. Several items from the questions are summarized under five categories defined to identify the clusters (Figure 31). Three capabilities have been defined according to the reference framework developed[47]:

[47] This research adopts a definition by Grant (1991, p. 122) who defines a capability as "a routine or a number of interacting routines".

- Complexity perspective in decision-making for products
- Transparency on complexity of the product portfolio & products
- Transparency on complexity in value-chain processes

On the performance side, two main categories are dictated by project type (new products and product variants):

- Effectiveness and efficiency in new product projects
- Effectiveness and efficiency in product variant projects

Complexity Perspective in the Decision-Making for Products	**Transparency on Complexity of the Product Portfolio & Products**	**Transparency on Complexity in Value-Chain Processes**	**Effectiveness and Efficiency in New Product Projects**	**Effectiveness and Efficiency in Product Variants Projects**
▪ Consideration of complexity drivers ▪ Main criteria to integrate the impact on process complexity ▪ Criteria which show the impact on value-chain	▪ Assessment of portfolio complexity ▪ Knowing the impact of additional complexity ▪ Indicators to steer product complexity ▪ Baseline metric for complexity ▪ Indicators to steer portfolio complexity	▪ Main burden of complexity ▪ Quantification of complexity impact ▪ Calculation of complexity costs ▪ Complexity indicators along value-chain ▪ Individual complexity costs ▪ Transfer in monetary figures ▪ Rules of thumb for costs ▪ Consideration in pricing	▪ Date for market introduction is met ▪ Quality requirements are met ▪ Customer satisfaction is achieved ▪ Project costs are met ▪ Target sales are met ▪ Competitive advantage is realized	▪ Date for market introduction is met ▪ Quality requirements are met ▪ Customer satisfaction is achieved ▪ Project costs are met ▪ Target sales are met ▪ Competitive advantage is realized
Complexity Management Capabilities			**Effectiveness and Efficiency**	

Figure 31: Dimensions for clustering the survey sample

Each of the categories is calculated as the average of the results for the items. The items are weighted equally in the calculations. The two dimensions "Complexity Management Capabilities" and "Effectiveness and Efficiency" are then calculated as the average of the categories assigned to the dimensions. The scores within these dimensions are calculated for each of the 175 participating companies in the survey. Figure 32 illustrates that there is a positive correlation between the two dimensions.[48] It can be argued that a comprehensive implementation of complexity management capabilities leads to higher effectiveness and efficiency in projects for new products and product variants.

[48] Pearson correlation coefficient r = 0.65. The Pearson correlation coefficient is a measure of the strength of the linear relationship between two variables.

Figure 32 also shows the distribution of the survey participants across the two dimensions. Each of the data points (diamonds) represents one participant in the study. Two main clusters are identified:

1. Top 10 percent of the sample which are called Leaders (n = 17)
2. Rest of the sample (90 percent) which are called Laggards (n = 158)

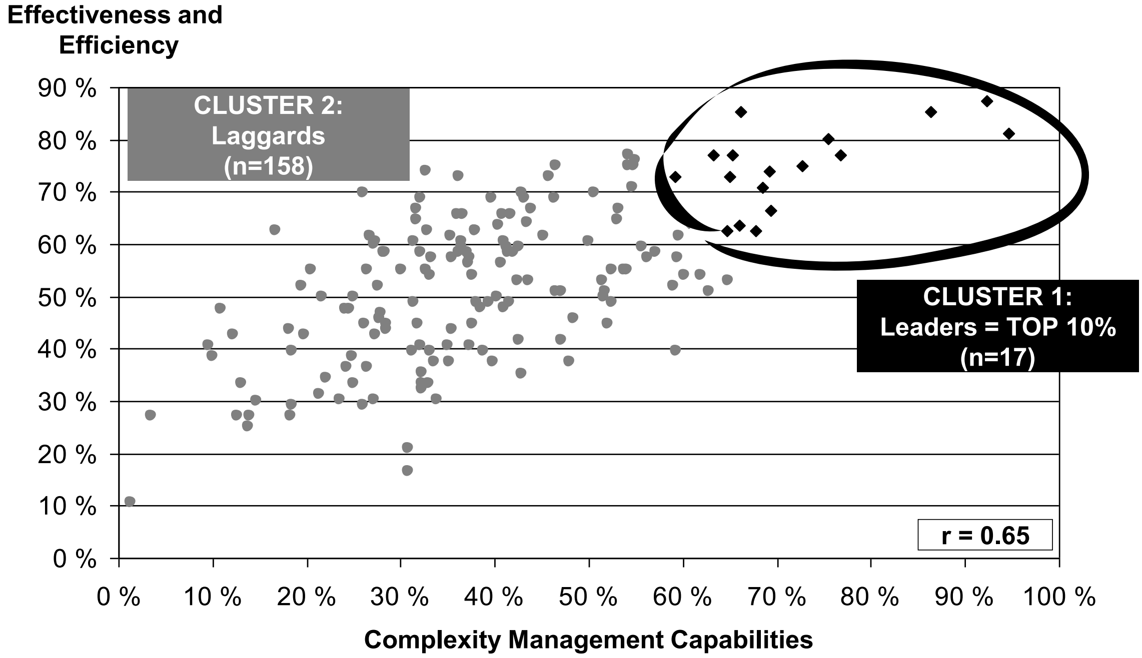

Figure 32: The relationship between capabilities and performance

The detailed comparison of the implementation of complexity management approaches and practices is drawn based on the clusters identified as "Leaders" and "Laggards". It is assumed that the Leaders are most interesting to investigate as they achieve a very high level of effectiveness and efficiency supported by their complexity management.

4.1.5 Differences in managing variety-induced complexity

The following sections describe the differences between the two clusters in the implementation of complexity management.[49]

[49] The findings are based on the calculation of the mean for Laggards and Leaders as the scale for most of the questions is a 5-point Likert-scale. Likert scale of the questions is divided as follows: Strongly disagree = 1; Disagree = 2; Not sure = 3; Agree = 4; Strongly agree = 5.

Differences in the evaluation of product portfolio and architecture complexity

Leaders evaluate both types of complexity, on a portfolio and on an architecture level. In particular, Leaders have a mean score of 4.3 compared to 3.2 for the Laggards for the evaluation of portfolio complexity. Leaders also understand the consequences of changes in the product portfolio. The mean score of 4.0 shows that Leaders know the impact of additional complexity of the product portfolio on value-chain processes better than the Laggards with a mean score of 3.0.

To steer complexity in their product portfolio, Leaders make use of indicators (mean score of 3.7) or even determine the complexity of the product portfolio with a fully comparable baseline metric (mean score of 3.2). Additionally, Leaders show a good use of indicators to steer product complexity. They increase their level of transparency by a comprehensive use of indicators to evaluate variety-induced complexity. The cluster of Laggards, on the other hand, reveals a low implementation of indicators to steer portfolio (mean score of 2.0) and product architecture complexity (mean score of 2.1) in their companies.

Differences in the evaluation of value-chain processes complexity

Not only were differences in the evaluation of portfolio and product complexity observed, but significant gaps in the understanding and evaluation of value-chain processes complexity were also revealed. Leaders are aware of the processes and activities which bear the main burden of complexity in the value-chain (mean score of 4.0 compared to a score of 3.1 for the Laggards), i.e. they know "who" is affected by increased product variety. Leaders are therefore able to initiate targeted actions to manage complexity in their most affected processes. In contrast to the Laggards (mean score of 2.2), they base their complexity optimization projects on the transparency created in processes (mean score of 3.9).

Both possible approaches to evaluation, non-monetary and monetary, are implemented more strongly at the Leaders than at the Laggards. In general, the evaluation of value-chain complexity is done regularly by Leaders (mean score of 3.8). Some of the Laggards also evaluate complexity but only seldom and less regular (mean score of 2.1). Leaders state that they explicitly quantify the impact of complexity on value-chain processes due to new products and variants (mean score of 3.7) compared to Laggards with a mean score of 2.2.

Leaders are creating transparency on value-chain processes complexity by tracking certain non-monetary indicators. They have defined complexity indicators for single value-chain processes (mean score of 3.8 for Leaders and 2.0 for Laggards). Figure 33 illustrates that Leaders, on average, cover more processes with complexity indicators than Laggards. More than 70 percent of the Leaders cover their core value-adding processes from Development to Manufacturing. The calculation of a fully comparable baseline complexity metric for value-chain complexity consisting of a number of indicators is only done by some companies. Leaders have a mean score of 2.8 for the determination of a baseline metric whereas Laggards only have a mean score of 1.7.

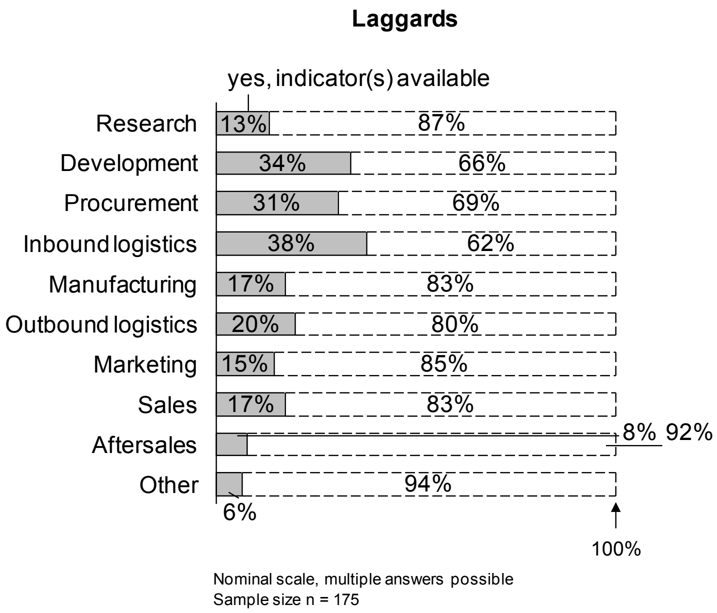

Figure 33: Complexity indicators in single value-chain processes

Additionally, Leaders evaluate value-chain processes complexity by calculating complexity costs (mean score of 3.5) compared to a mean score of 2.0 for Laggards. In fact, Leaders state a stronger implementation of an evaluation method for complexity costs (mean score of 3.4 compared to 1.9 for Laggards). As a result they are able to make individual complexity costs for products and product variants transparent. The outcomes of this monetary evaluation are also used by Leaders to improve the estimation of real project costs (mean score of 3.4 compared to 2.9 for Laggards) and the accurate pricing of products and product variants (mean score of 3.7 compared to 2.6 for Laggards).

Differences in decision-making for products and variants

The investigation of differences in decision-making is separated into two main parts: The characteristics of decision-making processes for new products and variants and the complexity perspective integrated in decision-making.

Leaders involve more stakeholders (departments) in their decisions in all major decision types such as for new products, for new product variants, for "face-lifts" (mid-generational product refreshes) and for phase-outs of products. Specifically, Leaders involve on average 7.7 stakeholders compared to 6.6 stakeholders for Laggards in decisions for new products. For product variants, Leaders involve 7.4 stakeholders and Laggards involve 6.2 stakeholders. This observation points to the level of cross-functionality in decision-making processes, which is more intense at the Leaders.

The analysis of the clusters reveals that Leaders have significantly more standardized processes and a higher level of formality in decision-making than the Laggards. Nonetheless, the Leaders have very flexible decision-making processes which are evident in the implementation of express lanes for decisions and a categorization regarding the complexity level of decisions. Also, Leaders emphasize cross-functionality in decision-making by implementing permanent cross-functional teams and liaison roles for coordination. Figure 34 summarizes the key mechanisms of decision-making and the differences in their implementation between Leaders and Laggards.

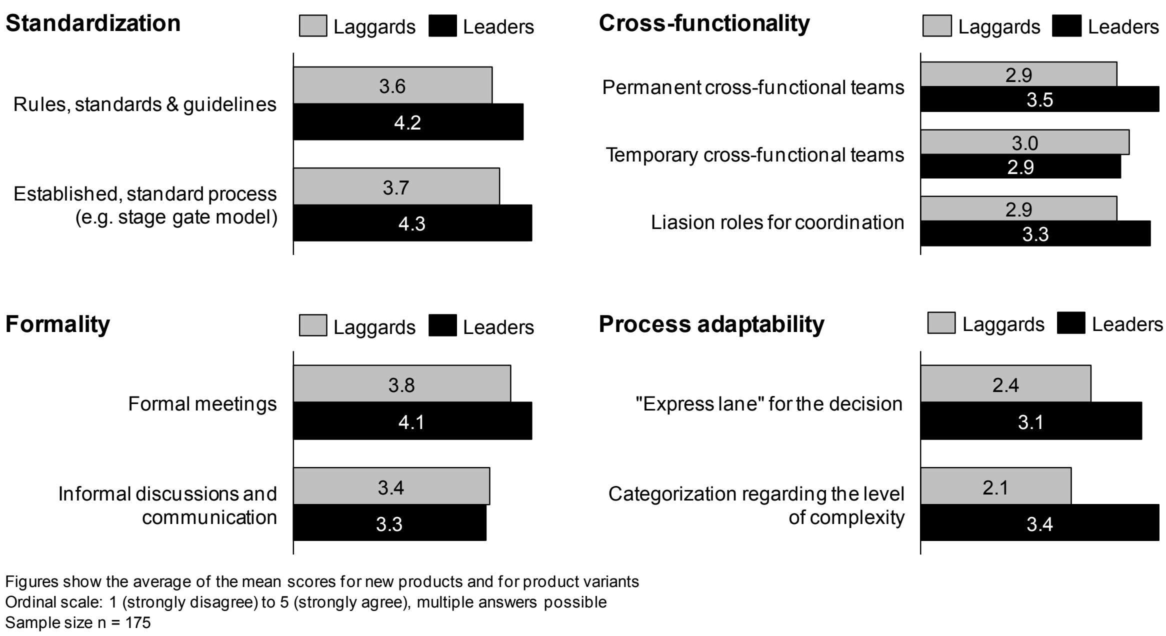

Figure 34: Differences in decision-making mechanisms

Decision-making processes of Leaders are less dominated by political behavior by departments (mean score of 2.0 compared to a score of 2.5 for Laggards) and intuition by decision-makers (mean score of 2.2 compared to a score of 3.0 for Laggards). Leaders, in fact, put more emphasis on rationality to increase objectivity in decision-making than Laggards. The decisions of Leaders are dominated by financial figures such as ROI, NPV or PBP (mean score of 4.3 compared to a score of 3.6 for Laggards).

The findings in the detailed investigation of criteria used in decision-making for products and product variants correspond to strong degree of rationality. Generally speaking, Leaders base their decisions on criteria which are pre-defined in a template or simple tool (e.g. business case). Explicit criteria specific to products and to product variants, in decision-making are illustrated in Figure 35. Apparently, Leaders make more intense use of criteria which reveal the complexity effort induced by the decision for a new product or a product variant, such as total project cost until market introduction and product maintenance cost after market introduction. Across the entire sample, criteria revealing the benefit of product variety dominate the effort-related criteria in decisions for new products and product variants.

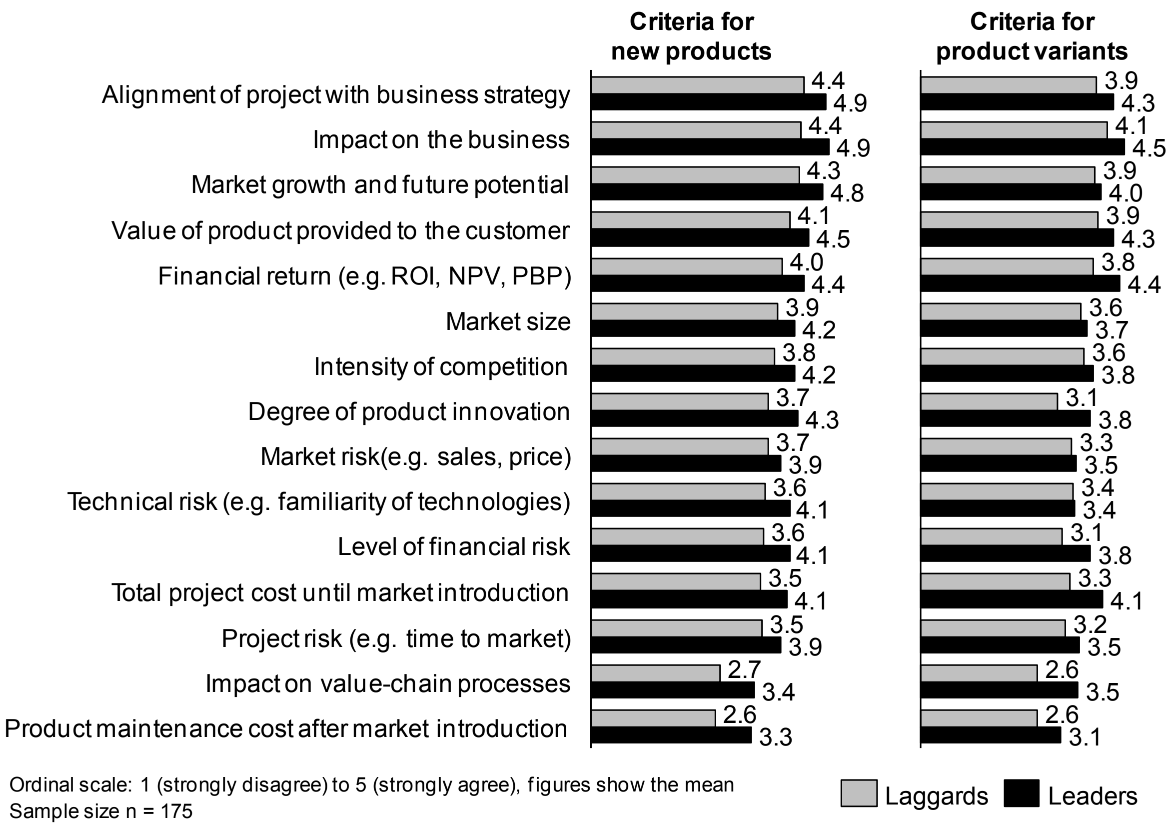

Figure 35: Differences in the decision criteria for new products and variants

To integrate a balanced complexity perspective in decision-making, Leaders make benefits and effort of complexity transparent and make use of this transparency in early decision phases. To Leaders, the benefits generated as a result of the decision are clear (mean score of 4.3 compared to a score of 3.5 for Laggards) as is the effort resulting from the decision (mean score of 4.1 compared to a score of 3.2 for Laggards). In practice, Leaders integrate explicit criteria which show the impact of complexity (mean score of 4.1 compared to a score of 2.4 for Laggards).

4.1.6 Summary of survey findings

Competence in complexity management is considered critical to achieving and sustaining a competitive advantage, but only few companies claim to have a successfully implemented complexity management. Complexity in manufacturing companies is a result of external (mainly demanding and globally scattered customers) and internal drivers (mainly from complex product architecture).

Leaders apply a combination of transparency on complexity and integration of complexity perspectives in decision-making to master variety-induced complexity. On the one hand, they assess product portfolio and product complexity and understand the consequences of changes in the product portfolio due to the application of tools for visualization. On the other hand, besides monetary quantification (complexity cost calculation), Leaders use defined complexity indicators in their process complexity evaluation to increase transparency along their entire value-chain.

In early decision phases, Leaders make benefits and effort of complexity transparent and use this transparency for improved decision-making. They set a stronger focus on criteria showing the complexity effort resulting from the decision. Leaders place emphasis on cross-functionality (involvement of multiple stakeholders), rationality (in terms of financial figures and tools) and standardization (e.g. complexity-adjusted processes) to increase objectivity and reliability in decision-making.

4.2 Selection of the case study companies

The survey analyses led to first insights into complexity management and in particular into the evaluation of complexity and its integration into product decision-making based on a broad sample of manufacturing companies. Although the survey answers the question “What are companies doing to manage complexity?” to a large extent, it only partially answers the question of “How and why do companies manage complexity with these specific approaches?”. The case study research presented in the following sections was conducted to answer the latter question with the objective of understanding complexity management capabilities in detail.

The companies for the case studies were selected on the basis of the survey with 175 participating companies. As the investigation of the clusters revealed that there are companies which achieve a high level of effectiveness and efficiency with the support of complexity management, these 17 companies (Top 10 percent, which are named Leaders) were expected to be most interesting for the qualitative analysis. Indeed, the research is geared towards finding innovative approaches for the evaluation of complexity and for complexity integration in decision-making. Leaders are the companies to learn from as they offer valuable insights into successful complexity management.

At least one telephone interview with each of the 17 Leaders (60 to 120 minutes) was conducted to verify the answers in the questionnaire and gather additional details on the companies' complexity management. Interview partners were one or more employees responsible for the companies' approach to managing complexity. They were questioned by applying a semi-structured interview. Ten out of the 17 Leaders were selected after the telephone interviews. Based on the interview results, ten companies were described in detail in a short case study (three pages) to summarize complexity management based on the information given in the questionnaire and the interview. These short case studies were presented in an anonymous format to a consortium of six manufacturing companies for the final selection of the case study companies. This selection was a personal and structured discussion with 15 company experts from the six companies in an eight-hour meeting. The consortium ranked the companies regarding their maturity, innovativeness and success of the companies' complexity management illustrated in the short cases. In particular they rated the companies according to their learning potential.[50] Ultimately, the five most interesting companies were selected and investigated in depth in the case studies for this research.

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[50] Eisenhardt (1989) suggests the selection of the companies with the highest learning potential for case studies in management research.

4.3 Introduction to the case studies

The five companies selected for the case studies state a high maturity, innovativeness and success of their complexity management in the questionnaire. These answers were verified by the answers in the telephone interviews. Both data gathering phases were guided by the reference framework derived from literature. The unit of analysis for the qualitative case study research is the complexity management within the respective company. The case study investigation is based on data gathered in semi-structured interviews and on-site workshops at the case study companies. Multiple stakeholders from various functions and hierarchy levels were involved in the data gathering at the companies.

As the research intends to provide guidance with a generic concept for manufacturing companies, the companies selected have certain similarities but also differences in their overall characteristics as well as in specifics of their complexity management. The names of the companies have been disguised to ensure confidentiality.[51]

Table 12 provides these key characteristics for each of the case study companies on a detailed level. To support the hypothesis that a successful complexity management effort leads to a high effectiveness and efficiency in projects for new product and product variants, Table 13 is added showing the details of the companies' project success rates.

[51] In this research, the companies are referred to under fictitious company names. For example, the name Automobile Inc. replaces the company's actual name.

Table 12: Characteristics of the case study companies

	Automobile Inc.	Mechanical Engineering Inc.	Automation Technology Inc.	Assembly Systems Inc.	Consumer Goods Inc.
Company size	Over 20,000	5,001-20,000	5,001-20,000	501-2,000	Over 20,000
Industry	Automotive	Machinery & Equipment	Electronics; Machinery & Equipment	Machinery & Equipment	Consumer Goods
Position in value-chain	OEM	OEM	OEM	OEM	OEM
Processes in-house	Entire value-chain from research to after-sales	Entire value-chain from research to after-sales	Entire value-chain from research to after-sales	Entire value-chain from research to after-sales	Entire value-chain from research to after-sales
Degree of product individualization	0 % ETO 5 % MTO 35 % ATO 40 % PTS	20 % ETO 0 % MTO 65 % ATO 15 % PTS	10 % ETO 0 % MTO 80 % ATO 10 % PTS	10 % ETO 5 % MTO 80 % ATO 10 % PTS	0 % ETO 5 % MTO 25 % ATO 75 % PTS
Main business type	B2C	B2B	B2B	B2B	B2C
Duration of product life cycle	3-7 years	> 15 years	7-15 years	3-7 years	3-7 years
Regions served	Global market	Global market	Global market	Global market	Global market
Maturity of main market	Weak growth (< 5% per year)	Mature/ Decline	Strong growth (> 5% per year)	Strong growth (> 5% per year)	Weak growth (< 5% per year)
Sales development (last 3 years)	Improved 10 % - 30 %	Stayed about the same -5 %/+5 %	Improved 10 % - 30 %	Improved 30 % - 50 %	Improved 10 % - 30 %
Market share development (last 3 years)	Stayed about the same -5%/+5%	Stayed about the same -5 %/+5 %	Improved 10 % - 30 %	Improved 10 % - 30 %	Stayed about the same -5 %/+5 %
EBIT development (last 3 years)	Improved 10 % - 30 %	Stayed about the same -5 %/+5 %	Improved 10 % - 30 %	Improved more than 50 %	Improved 10 % - 30 %
ROI development (last 3 years)	Improved 10 % - 30 %	Stayed about the same -5 %/+5 %	n/a	n/a	Improved 10 % - 30 %

Table 13: Success of projects in the case study companies

… for new products	**Automobile Inc.**	**Mechanical Engineering Inc.**	**Automation Technology Inc.**	**Assembly Systems Inc.**	**Consumer Goods Inc.**
Date of market introduction is met	> 95 % of projects	80 - 95 % of projects	65 - 80 % of projects	65 - 80 % of projects	> 95 % of projects
Quality requirements are met	80 - 95 % of projects	> 95 % of projects	> 95 % of projects	80 - 95 % of projects	> 95 % of projects
Customer satisfaction is achieved	80 - 95 % of projects	> 95 % of projects	80 - 95 % of projects	80 - 95 % of projects	> 95 % of projects
Planned project costs are met	80 - 95 % of projects	65 - 80 % of projects	65 - 80 % of projects	50 - 65 % of projects	> 95 % of projects
Target sales volume is met	65 - 80 % of projects	65 - 80 % of projects	80 - 95 % of projects	80 - 95 % of projects	50 - 65 % of projects
Competitive advantage is realized	n/a	80 - 95 % of projects	65 - 80 % of projects	80 - 95 % of projects	80 - 95 % of projects
… for new product variants					
Date of market introduction is met	> 95 % of projects	80 - 95 % of projects	80 - 95 % of projects	65 - 80 % of projects	> 95 % of projects
Quality requirements are met	> 95 % of projects	> 95 % of projects	> 95 % of projects	80 - 95 % of projects	> 95 % of projects
Customer satisfaction is achieved	80 - 95 % of projects	> 95 % of projects	80 - 95 % of projects	80 - 95 % of projects	80 - 95 % of projects
Planned project costs are met	> 95 % of projects	65 - 80 % of projects	80 - 95 % of projects	80 - 95 % of projects	> 95 % of projects
Target sales volume is met	80 - 95 % of projects	65 - 80 % of projects	50 - 65 % of projects	80 - 95 % of projects	65 - 80 % of projects
Competitive advantage is realized	n/a	80 - 95 % of projects	65 - 80 % of projects	65 - 80 % of projects	65 - 80 % of projects

In the case study research emphasis is placed on the creation of transparency on portfolio, product and process complexity as well as on complexity integration in decision-making. Both issues are covered in the companies' complexity management.

However, the understanding of the business environment, drivers of complexity and overall approach to complexity management is also crucial in order to derive meaningful conclusions from the investigation. Therefore, some of the aspects presented do not strictly adhere to the reference framework but place priority upon certain specifications of the company's approach to complexity management and the handling of product variety. Fundamentally, four blocks build the structure of the case studies:

1. Company profile and complexity drivers: This block discusses the company's business and environment. It includes key information about markets, customers, products, processes and competitive situation as well as the resulting main drivers of complexity.

2. Complexity management: This block presents the overall approach towards complexity management conducted by the company. It discusses the trigger and development, the main priorities and organizational aspects of the initiative.

3. Transparency on variety-induced complexity: This block describes the creation of transparency on product portfolio complexity, product architecture complexity and value-chain processes complexity carried out by the company.

4. Complexity perspective in decision-making for products: This block discusses the processes of decision-making for new products and variants run by the company. Moreover, it presents the reasoning and mechanisms predominant in the decisions as well as the integration of a complexity perspective in early decision-making.

4.4 Case 1: Automobile Inc.

4.4.1 Company profile and complexity drivers

Company business and environment

Automobile Inc. is one of the largest manufacturers of premium automobiles in the world. The production network of this company comprises more than 10 facilities world-wide, including a number of joint ventures and plants specialized in the manufacturing of key components and modules. The company owns a number of premium brands and sold close to 2,000,000 cars worldwide in 2011. Also, eight new automobile models (new product lines and face-lifts) came onto market in 2011. Like other automobile OEMs, the company is working hard to produce hybrid and electric cars in large-scale series in the coming two to three years. Automobile Inc. states the following main competitive priorities to win customer orders:

- Superior product design and quality
- Superior conformance to customer specifications
- Wider product range
- Offer products that are more innovative

Five years ago, the company re-aligned its strategy to put emphasis on the premium segment around the globe to increase profitability and long-term growth. A broad product portfolio is considered a key enabler to achieving these company goals. Although it is not intended that all cells in the product matrix shown in Figure 36 should be filled in, additional models will certainly be added or even new automobile types and segments defined. Competition is fierce in the premium segment and constant renewal of the portfolio is a necessity if Automobile Inc.'s strong market position is to be maintained.

Segment \ Type	Sedan	Large Sedan	Coupe	Convertible	Roadster	Cross-SUV	Large C-SUV	Sports Car
High-End Luxury	Model 1 & 2 (Brand 1 & 2)		Model 3 (Brand 1)	Model 4 (Brand 1)				
Luxury	Model 5 (Brand 2)		Model 6 & 7 (Brand 2)	Model 8 (Brand 2)				
Premium Mid-size	Model 9 (Brand 2)	Model 10 & 11 (Brand 2)				Model 12 (Brand 2)	Model 13 (Brand 2)	Model 9A (Brand 2)
Mid-size	Model 14 (Brand 2)	Model 15 (Brand 2)	Model 16 (Brand 2)	Model 17 (Brand 2)	Model 18 (Brand 2)	Model 19 (Brand 2)		Model 14A (Brand 2)
Compact	Model 20 (Brand 2)		Model 21 (Brand 2)	Model 22 (Brand 2)		Model 23 (Brand 2)		Model 20A (Brand 2)
Small	Model 24 (Brand 3)	Model 25 (Brand 3)	Model 26 (Brand 3)	Model 27 (Brand 3)	Model 28 (Brand 3)	Model 29 (Brand 3)		Model 24A (Brand 3)

Figure 36: Product portfolio of Automobile Inc.

Drivers of complexity

The company states that 50 percent of the product variants are triggered by external stakeholders such as customers whereas 50 percent are triggered by internal departments such as development and sales. Experts at Automobile Inc. observed a high level of interdependence between external and internal complexity drivers. Complexity drivers were identified in the first phase of the company's complexity management program by asking the question: "Where does complexity have its origin?". Two main drivers behind complexity were identified by the company: Actions by competitors as the main external driver and increasingly complex product architecture as the main internal driver.

Actions by competitors, especially by established premium automobile OEMs, drive variety in parts, components and materials at the company. The objective for Automobile Inc. is to integrate leading-edge innovations in its products. If a competitor decides to foster the use of a new material (e.g. carbon), Automobile Inc. often needs to evaluate it for application in its own upcoming car models. There is constant competition among the premium manufacturers to be the pioneering company by bringing innovations on the market. Competition, therefore, affects the product portfolio, single components and modules as well as the processes for product creation.

Product architecture is affected by the high degree of innovation brought into new products and face-lifts in the short timeframe of three years. The company even intends to shorten the product life-cycle in the coming years. Automobile Inc. is aware of its complexity drivers and has specifically identified four main categories of drivers which lead to an increase in product architecture complexity. Firstly, global requirements and country-specific requirements of emerging markets cause adjustments in products and processes. Successful certifications are necessary to serve these lucrative markets. Established markets are also changing, e.g. in their legislation on CO_2-emissions. Secondly, the differentiation within the brands is increasing. Design and size of product variants are proliferating which leads to a more complex product portfolio. For example, Brand 3 contains seven models today compared to two models three years ago. Thirdly, additional technological functions and colors are added to the models with the objective of reaching market niches and satisfying increasing individualism of premium customers. Fourthly, the broadening of the portfolio of different engine types is adding components to the entire automobile. The trend observed at Automobile Inc. is a renewal of engines and adding of engines for new models, which is expected to further intensify with the development of hybrid and electric car concepts in the next years.

4.4.2 Complexity management at Automobile Inc.

Automobile Inc. fell victim to the typical "pitfall" of product variety. Return on investment deteriorated in recent years which led to specific actions to counter-act this trend. The company intended to increase market share and enable company growth by adding new automobile models to the portfolio. As large commodity markets were already covered by existing product lines, the new models in the portfolio were niche products with a lower volume. Consequently, product variety and variance across product components increased. Adding low-volume products induced a complexity cost increase which was disproportional compared to the increase in sales volume. Lower overall profitability was the result for company.

Although there had been projects targeting the issues of increasing product variety in the past, these were mainly isolated improvements of certain product components or cost reduction programs. The impact of these non-integrated projects in single departments was limited. Therefore, a decision was taken by the management board and product line leaders to re-enforce complexity management to escape the pitfall of product variety. The announcement made by board members was: "The board has assigned a cross-functional team for complexity management to make variance in the company measurable and steerable. A key task is to determine the average indirect complexity cost per component".

Complexity management as a holistic approach was initiated in 2009 and consisted of four main phases. In the first phase, the initiative set the focus on benchmarking to understand the variety offered by competitors, complexity cost calculation and short-term actions for product models in the pipeline. The analysis revealed that Automobile Inc. had more individual components and parts than the "best-in-benchmark" competitors. Also, an explosion of variants and complexity costs was created by option bundles (interior packages) for recent models. In the second phase, levers to reduce variance in the earliest phases of product design were investigated and piloted in one production plant for two upcoming automobile models. Standards to influence product design were defined in this phase. Additionally, targets for the reduction of part variety were set and actions to achieve these targets were approved. The third phase set a specific focus on levers to manage complexity in the production and supply processes as well as to validate the complexity cost calculation and indicators developed. The phase resulted in standards to manage variance on plant level (including logistics and supplier processes) and in the final determination of the complexity costs per part. Moreover, it included an agreement with the key departments regarding responsibilities and roles for a sustainable anchoring of complexity management. To anchor the approaches, methods and tools developed across the entire organization, the fourth phase was defined. The complexity management team set a focus on preventative actions by implementing tools to control variance. The roll-out of approaches proven in pilots (product lines and plants) was conducted across the entire corporation including all product lines and brands, the entire production network and key suppliers.

A central unit located in the department of purchasing was integrated into in the organizational structure and staffed with experienced experts with various backgrounds. Due to the fact that the department "Purchasing" is a key function at Automobile Inc., the decision was taken to house the division for complexity management in this department. Also, the department of purchasing is "neutral" and objective with a low level of "own interests", which might hinder the successful management of complexity. Complexity management is concerned with the entire company including all brands and product lines, i.e. the division is responsible for three major brands and all product variants within these brands. As Figure 37 illustrates, the division of complexity management is not isolated but has distinct links to key departments which are coordinated by the division. These cross-functional links are realized with teamwork (e.g. for the development of new product modules) and constant reporting (e.g. to the management board).

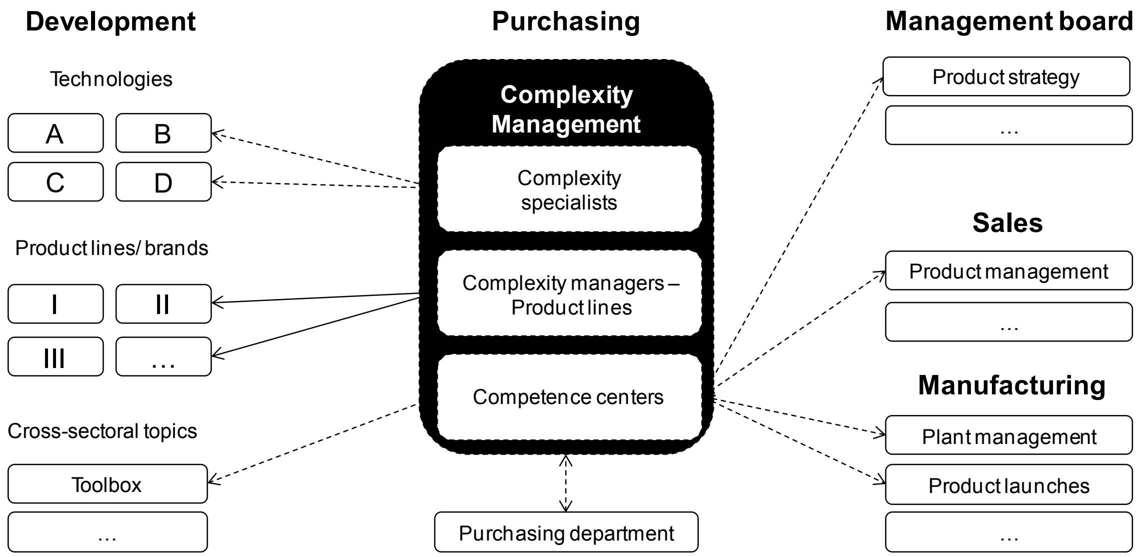

Figure 37: Organizational anchoring of complexity management at Automobile Inc.

4.4.3 Transparency on variety-induced complexity

Creation of transparency played a major role in two stages of the company's initiative: Initially in creating awareness and in the long term in tracking progress and efficacy of the actions. In general, each of the four initiative phases contains transparency-related tasks, e.g. the definition of key complexity indicators and complexity costs as well as the validation of these approaches. As Automobile Inc. intends to save over one billion Euros over seven years and to achieve a significant reduction in new parts numbers, historical data has been gathered, analyzed and specific future targets derived for complexity management (Figure 38).

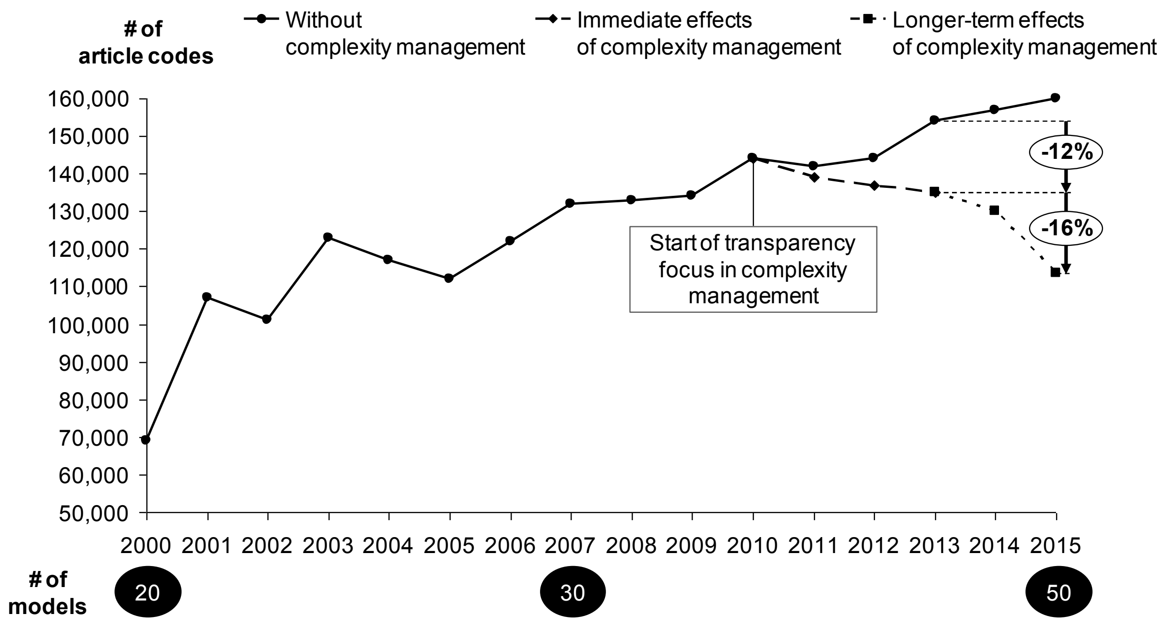

Figure 38: Reduction of the number of article codes at Automobile Inc.

Transparency is considered critical to driving specific actions. For instance, to optimize the engine portfolio a minimum production volume was defined which answered the question as to whether a certain engine type makes sense or not. Moreover, guidelines for upper limits for options are defined which are used to decrease the number of options for certain segments provided in the next model generations.

Transparency on product portfolio and product architecture complexity

In an initial assessment of complexity, the increase from 2005 to 2010 in sales volume, the number of combinations of engines and steering, the number of article codes (parts) of engine and steering components as well as the number of product variants of engine and steering was considered (Figure 39). This validated the hypothesis that sales volume is growing at a slower rate than variety-induced complexity. The ultimate task of complexity management at Automobile Inc. is to turn this trend around.

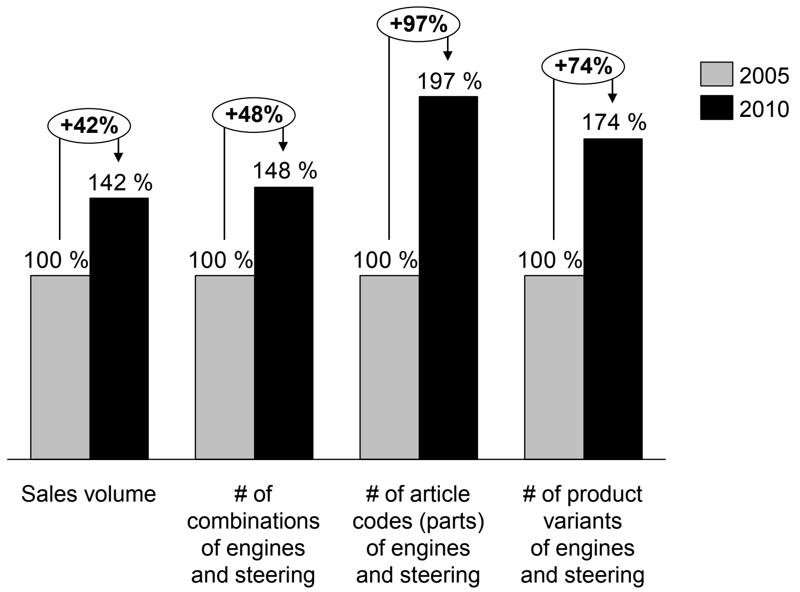

Figure 39: The link between sales volume and complexity at Automobile Inc.

To track the progress of optimizations, complexity indicators were defined on all portfolio and product levels: Variants, engines, options (exterior and interior) and article codes. Figure 40 illustrates the structure behind this, a so-called variant pyramid, which enables a very detailed look into the complexity of the product. By tracking the indicators behind the different levels of the pyramid, it is possible to steer and optimize complexity across four key portfolio and product levels in the company. For a holistic assessment of complexity, it would be too restricted to only evaluate it on the "variants level" due to the fact that variants are the result of specific engine, options and article code combinations.

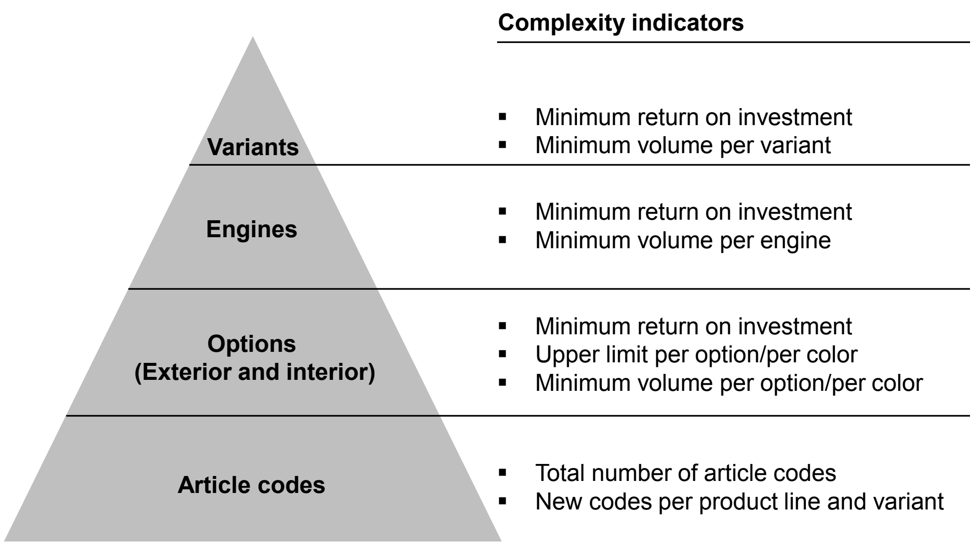

Figure 40: Indicators for product and portfolio complexity at Automobile Inc.

Transparency on value-chain processes complexity

Complexity along the value-chain of Automobile Inc. is evaluated monetarily, in terms of complexity costs, and non-monetarily, in terms of process-related complexity indicators for key processes. Both are equally important and regularly reported. With status reports the management board and product steering committees are informed about the development of variety and complexity.

For the monetary complexity evaluation a clear definition was a necessity for the company. In close cooperation with controlling experts, complexity costs in the company were defined "as costs that change with variety in product lines and value-chain processes. These costs were, until now, not allocated and only visible in the medium term, e.g. in an increase in fixed costs". Figure 41 shows a breakdown of complexity cost for a component, differentiating between direct and indirect complexity costs. The assessment as a basis also reveals the processes bearing the main cost burden along the company's value-chain. The complexity cost estimations are summarized in a complexity cost factor which makes complexity cost transparent and applicable in early decision-making.

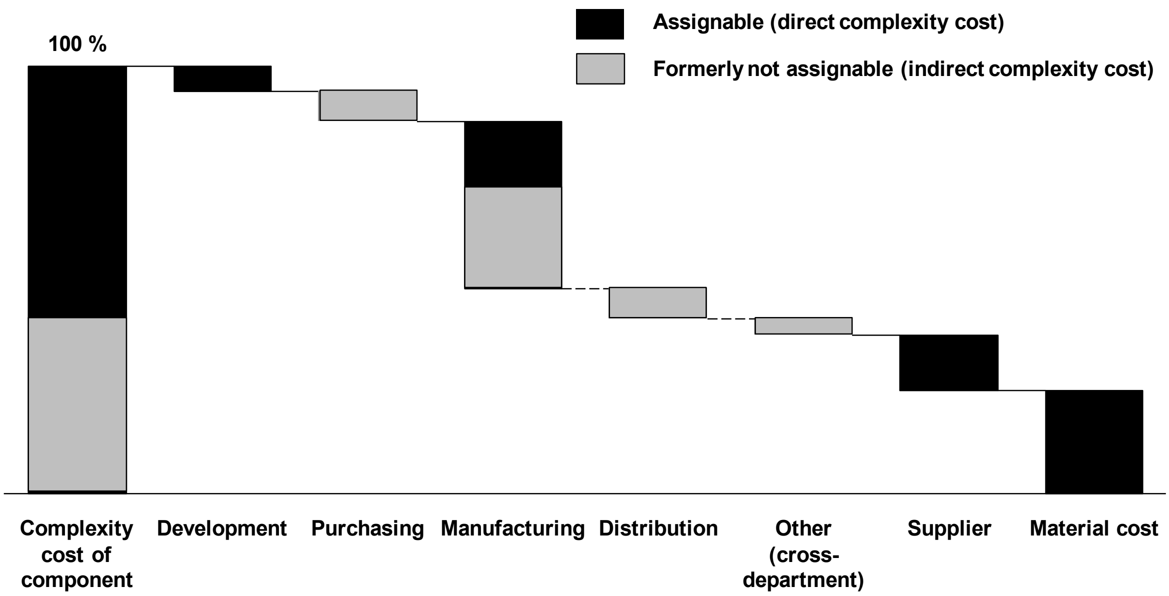

Figure 41: Breakdown of complexity cost for a component

The complexity cost calculation is accompanied by specific complexity indicators. In extension to the detailed consideration of portfolio and product complexity and their respective indicators, the complexity management team at Automobile Inc. decided to develop a comprehensive set of indicators for the evaluation of value-chain process complexity. In particular, this so-called complexity cockpit includes indicators showing the impact on technical implementation in development, on purchasing processes, production plant processes and sales (Figure 42). These are the processes in the value-chain bearing the largest part of complexity.

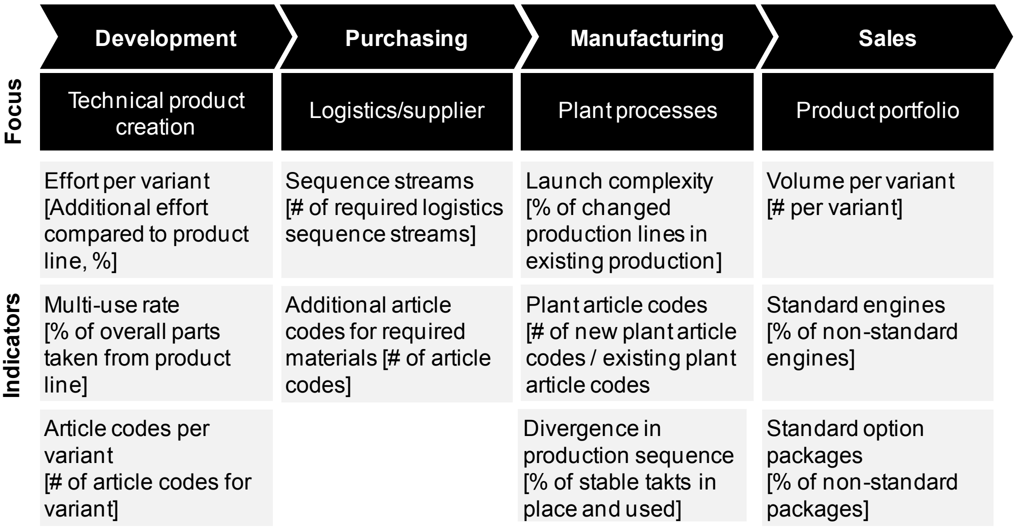

Figure 42: Complexity indicators cockpit at Automobile Inc.

Critical results of the initiative are directly reported to the board and the second decision instance called product committee. Reporting structures for this important initiative are defined including a regular slot in board and product committee meetings. In addition, a status report for variants management is created to monitor progress and illustrate it to the initiative's sponsors on the Automobile Inc. board.

4.4.4 Complexity perspective in decision-making for products

The focus of Automobile Inc.'s complexity management moved from a reactive clean-up of unnecessary complexity in the portfolio to a proactive approach of avoiding complexity. The question behind that change is: "What should be done in early project phases to create a variant-optimal solution?". Consequently, Automobile Inc.'s initiative targets complexity in early decision-making for design and development of new models to create a variety-optimized solution.

Decisions on variants and new products are made on the product line level and multiple departments are included in decision-making. Ten different departments are involved in the decision process for new products and the final decision is made by the department for product strategy. In decisions for product variants Automotive Inc. three more stakeholders, e.g. a board member, are included in the decision. The final responsibility for the decision to create a product variant lies with the department for product management.

Decisions for new products and product variants at Automobile Inc. are made very rationally. Individual interests of persons or departments are restricted by the defined use of a pre-defined template for the business case. As the process of decision-making is highly standardized, intuition and gut feeling of stakeholders or of those in responsible positions plays only a minor role (Figure 43). Strict criteria in the decision template, such as the "impact on business" (market size and growth), the financial return (NPV, ROI and PBP) and total project cost until market introduction, ensure objectivity. Decision-making for variants is even more standardized (including rules and guidelines) and formal than decision-making for new, typically strategic, products. Another key element in variants decision-making is the importance of coordinators in charge of communication and information flow between 13 different stakeholders.

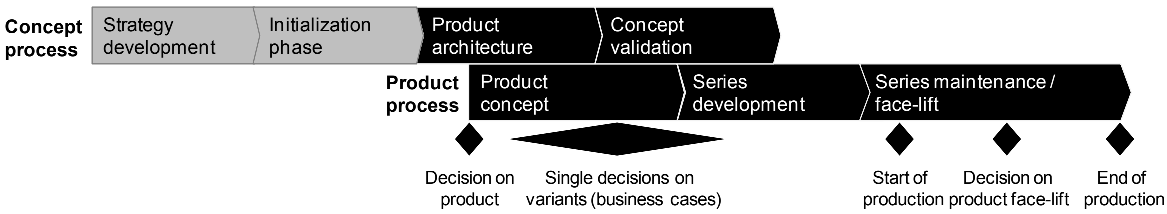

Figure 43: Product processes and decision points at Automobile Inc.

At Automobile Inc., the benefits generated and the effort required by internal processes are made transparent in early decision phases. Criteria showing the impact of complexity have been added to the standard criteria already mentioned. These criteria are called "variant criteria":

- Number of parts/components affected
- Number of interfaces with other parts/components
- Impact on the affected module in the portfolio across models
- Degree of change in existing manufacturing processes
- Additional space required (e.g. in logistics and manufacturing)

An index of these variant criteria (each with a specific scale) is calculated on a 5-point scale (1-3 is considered not critical; 4-5 is considered critical) similar to the indices for safety, emissions and other key aspects. This variant index is accompanied by the criteria "Increase or decrease in part/component variety" because the company intends to decrease the rate of new parts and with it to increase the number of standard modules across product lines in the coming years. Additionally, the cost block in the business case is enhanced by the estimation of indirect complexity cost per part. It is a defined cost mark-up based on the comprehensive analysis of past project experiences and historical data. Although this indirect complexity mark-up is not a 100 percent accurate number, it represents an important estimation of the complexity effort in the value-chain. The estimation has been reliable in recent decisions for which complexity costs have been determined.

Most variant-related criteria can be compiled directly using the data from complexity management. Additional information for the "variant criteria" is gathered and verified by complexity management representatives in each product line and departments such as sales, development and strategy, then prepared by the complexity management unit and presented to product line committees for final decisions. Therefore, the organizational division for complexity management at Automobile Inc. is integrated in all decisions on major product and variant projects across the three brands.

The newly introduced criteria and the index are weighted with equal importance in the decision like other key issues such as safety- or emission-related aspects. The objective is to avoid exotic variants which are only built very rarely although these variants are still worthwhile from an initial economic point of view. The complexity-related criteria are also reported to the board; especially in cases when a product variant would not meet variant-related criteria. If a certain product line decides that the variant is required although it does not fulfill the "variant criteria", the decision is passed on to the management board. There is a standard process for this escalation of the decision and an assigned steering committee, including board members, which evaluates and makes the final decision.

4.4.5 Summary

Automobile Inc. has a holistic complexity management in place with a high level of priority and commitment by the management board. Organizationally, a division for complexity management has been set up to ensure objective evaluations and support. It is explicitly linked to key stakeholders and departments in the organization.

In the initiative, transparency creation is considered a key element at the beginning and during the implementation of complexity management. Indeed, the combination of complexity indicators and cost calculation ensures a high level of transparency of product, portfolio and process complexity.

Automobile Inc.'s decisions are characterized by intense standardization, formality and cross-functionality. The complexity perspective in decision-making is realized by the integration of distinct variant criteria and the, formally invisible, indirect complexity costs. This "complexity combination" enhances the established criteria and represents a vital element in decision-making.

4.5 Case 2: Mechanical Engineering Inc.

4.5.1 Company profile and complexity drivers

Company business and environment

Mechanical Engineering Inc. is a global leader in providing products, solutions and services for the precision mechanical engineering industry. Coordinated from its headquarters in Germany, the company employs more than 10,000 people around the world and achieves 80 percent of its revenues outside of Germany. Its main production and development facilities are located in Germany, but the company also runs smaller production plants in Europe, the United States and China as well as more than 200 service offices around the world. In total, the company achieved a sales volume of more than two billion Euros in 2011. Mechanical Engineering Inc. states the following main competitive priorities to win customer orders:

- Superior product design and quality
- Superior conformance to customer specifications
- Reliable deliveries
- Faster deliveries
- Superior customer service (after-sales and/or technical support)

The company, an Original Equipment Manufacturer (OEM), covers the entire value-chain from R&D to After-Sales internally. It is known for leading-edge technological solutions with a high percentage of in-house production of sophisticated parts and assembly groups. The company is very focused on its core technologies which support a number of applications at its customers.

200,000 customers, typically small to medium-sized businesses, are globally maintained by Mechanical Engineering Inc. which leads to a broad product portfolio due to diverse customer requirements regarding machines and equipment. Consequently, the level of complexity is considered a differentiating factor in the market.

The products have an average life-cycle in the market of 40 years. Therefore, the company has to run production and processes for certain parts and modules, keep spare parts available and provide after-sales services for this long time span. Indeed, the long life-cycle contributes to the complexity the company has to manage.

In recent years, the company has been exposed to severe changes in its business environment as a result of the financial crisis. Main markets of the company have collapsed and have not recovered since. As a consequence, the company is currently restructuring and re-focusing to meet the business challenges ahead. Managing complexity is considered a key capability for success in a difficult market environment today and in the future.

Drivers of complexity

The company states that complexity is driven by a number of different external and internal aspects. Externally, the customer is the major "source" of complexity accompanied by the rising power of competitors. The size of the customer base in combination with individual product requirements by customers led to a tremendous internal complexity increase in the last decades. Today, the company is also facing a higher globalization of their customers compared to the past decades when the main markets in Europe and North America were served relatively easily. Expectations of customers from the BRIC countries (Brazil, Russia, India and China) are forcing the company to adjust products. This leads to an increase in new parts and modules required for the products. For example, the company serves the Chinese market with simple highly standardized machines which represent an extension of the existing product portfolio.

However, complexity is not limited to the customer but also driven by actions of competitors. Established competitors in the market are providing more flexible machines for a lower price and new Asian competitors are competing purely on product price. Consequently, Mechanical Engineering Inc. sees itself forced to reconsider its "high-tech, high price" philosophy which has been successful in the past decades, but could now prove to be outmoded.

Internally, complexity is driven by three aspects: The products, the process structure of product creation and the corporate culture. The diverse mix of product lines in combination with a high number of customer-specific changes represents a challenge. An exhaustive portfolio, developed in the "glory" years when markets were booming, today represents a severe threat to the company as products in the market require after-sales service for 40 or more years. Also, products differ significantly from one another because synergies between products were not a priority. Indeed, in the past, technology-driven developers placed no limits on increase in the number of parts and components. This "inherent" complexity is set to burden the company for a while yet.

Additionally, in these "glory" years, high investments were made to meet high demands. Today, the production structure is considered a driver of complexity in the company. Investments were made in equipment which, although now under-utilized, still absorbs coordination, maintenance and overhead resources. A technology- and innovation-driven culture and a high number of management tiers in the company contributed to the build-up of variety-induced complexity. Components and modules are typically developed from scratch at Mechanical Engineering Inc. as a result of missing communication between departments and across layers.

4.5.2 Complexity management at Mechanical Engineering Inc.

Efforts towards complexity management at Mechanical Engineering Inc. began due to significant changes in the company's business environment. The financial crisis led to a breakdown of important markets such as North America and thus to a decrease in the company's revenues. As markets did not recover, Mechanical Engineering Inc. was obligated to find new ways to become more efficient in its processes and to focus on the control of complexity.

The board members at Mechanical Engineering Inc. recognized the necessity to initiate a holistic program. A permanent cross-functional team was assigned to develop the approach, processes and methods to manage complexity. The first step was the illustration of the need to optimize complexity. The gap between revenue development and part development in the last ten year served as proof of this. In fact, in recent years, sales revenue had deteriorated by 30 percent and the number of parts had increased significantly. In the second step, the characteristics of complexity (product, production and part variety) were described. The statement of a vision for complexity management represented the third step. In the fourth step, the team set up a project plan to draw near this vision in the following years.

An initial cross-functional workshop series resulted in the identification of the two main focus areas for complexity optimization: Market complexity and product complexity. These areas were targeted with focused initiatives in the frame of complexity management. The final program consisted of six initiatives, each with assigned initiative leaders and clear timelines, saving targets and reporting structures:

1. Product portfolio clean-up: This initiative intended to eliminate historically grown portfolio complexity resulting from the company having neglected to phase out products in the past.
2. Market segment-aligned product architecture: This initiative is concerned with the adaptation of product architecture to suit specific market segments. Product architecture should avoid over-engineering, include a high degree of modularity and meet customer’s applications.
3. Complexity reduction in core value-adding as well as in administrative processes: This initiative is closely linked to business excellence approaches to optimize processes. In particular, it deals with delayed process differentiation which is feasible with a high percentage of standard modules in the product architecture.
4. Process complexity in the product lifecycle: This initiative targets spare parts and service complexity after market introduction. Although after-sales service is lucrative it is still complex and has optimization potential.
5. Implementation of a complexity management system: The initiative led by the cross-functional core team of complexity management has the objective of designing a holistic system for continuous optimization.
6. Controlling of complexity management: This initiative provides a basic system to keep constant track of the effects of complexity management.

Figure 44 illustrates the vision of Mechanical Engineering Inc. which is geared towards providing a large external variety with a market-aligned portfolio and decreasing internal complexity to reduce costs for creating product variety.

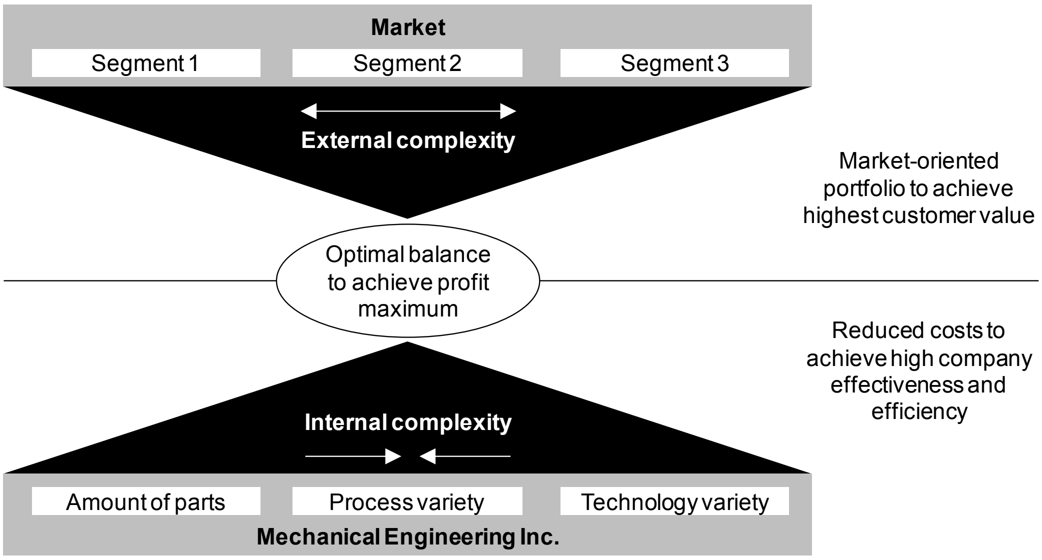

Figure 44: Vision of complexity management at Mechanical Engineering Inc.

Although the complexity management program has clear saving targets (50 million Euros per year) and is closely linked to other optimization processes, complexity management is seen more as a cultural change for the entire company. To manage and to control the complexity of a company's products and processes all divisions are, of necessity, involved in this process of changing mindsets. For the complexity management committee it is simple: "We will only reach our goals together and achieving these results is critical for our company's success".

For this reason, the project team decided to set up communication tools such as a brochure and a so-called complexity room. The room consists of two large areas in manufacturing and is used to communicate complexity management issues to employees and to create company-wide awareness of complexity management. The room illustrates challenges and improvement potential of the company with regard to complexity aspects and it presents methods and tools used in complexity management. Training sessions and workshops were conducted and board meetings were also held. In summary, communication tools increase the understanding of how to better manage complexity.

4.5.3 Transparency on variety-induced complexity

Creation of transparency is newly emphasized by the company and is a key element to creating awareness among employees. In fact, Mechanical Engineering Inc. gave no particular consideration to development parts, modules or variants in the past from a complexity management point of view.

Illustrative charts, showing complexity trends, are now presented in the complexity room to people from all departments and hierarchy levels.

Additionally, to understand complexity in the company, the complexity management team determined the characteristics of complexity on multiple levels. Figure 45 shows that the company is exposed to variety along the entire value-chain, e.g. in product specifications, technologies, number of suppliers and production processes. Variety and its characteristics are highly interdependent and as the team states "not completely straightforward". Building on these characteristics as a first framework and on the differentiation between external and internal complexity, the company defined a set of complexity indicators as well as a complexity cost calculation.

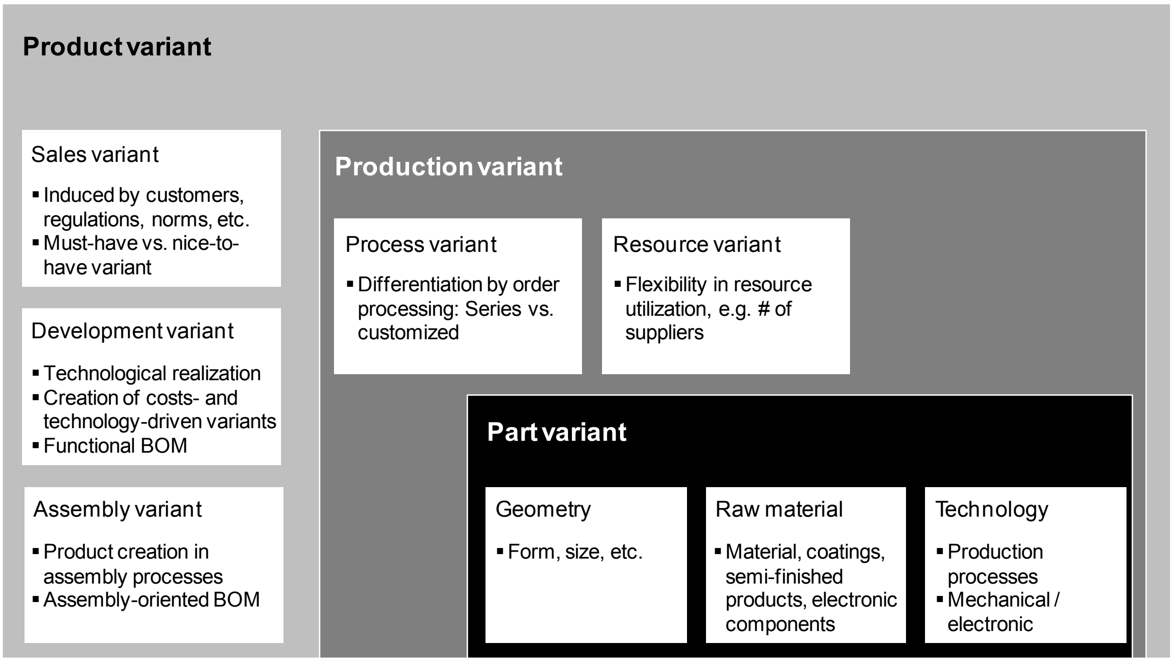

Figure 45: Characterizing variety at Mechanical Engineering Inc.

Transparency on product portfolio and product architecture complexity

An investigation of the product portfolio and single modules at Mechanical Engineering Inc. revealed that machines often include different technological solutions to fulfill the same function. Although the product lines have some minor functional differences, the basic technological principles of the machines are the same. Transparency on the similarities of products, components and parts is crucial to making complexity management viable throughout the organization. The management board and the team decided to define complexity-related indicators to increase the level of transparency and the ability to monitor actions.

By applying the differentiation between external and internal complexity, Mechanical Engineering Inc. defined seven indicators to steer complexity in the product portfolio and in product architecture (module and part level). Table 14 explains the key complexity indicators and shows the courses of action taken to improve their scores.

Table 14: Complexity indicators at Mechanical Engineering Inc.

Scope	Indicator	Definition	Explanation	Exemplary course of action
External	Options variety	Sum of options available on market and of models orderable by sales	Shows the variety visible for the customer beyond standard products	Optimization based on customer value-oriented variants planning
	Options dependency	# of dependencies between options available on market	Shows the restrictions for the customer	Optimization of option combinations and module interfaces
	Sold options	# of machines with specific options divided by the total # of machines sold	Shows options for standard and options for deletion	Optimization based on customer value-oriented variants planning
Internal	Part development	Total sum of parts existing in the company on a certain day in the year	Shows the development of parts over time	Conscious reduction of parts with little revenue/customer value
	Part development per module	Total sum of parts existing in the product on a certain day of the year	Shows the development of parts over time on a module level	Target setting on module level
	Unique parts index	# of unique parts divided by the total number of parts across all variants of a product line	Shows the percentage of unique parts across all variants	Reduction of low-selling variants with unique parts
	Multi-use level for parts	# of part usages in products divided by total # of products	Shows the multi-use level of products	Increase of multi-use parts

Mechanical Engineering Inc. derives specific portfolio-level actions from the indicator scores, i.e. the “offending” product variants are identified and the appropriate product variety is thoroughly analyzed right down to the product architecture level. Target scores, to be achieved in the coming five years, have already been determined for five indicators:

- Options variety from 273 to 228 (decrease of 17 percent)
- Options dependency from 413 to 284 (decrease of 31 percent)
- Part development from 5597 to 3725 (decrease of 33 percent)
- Unique parts index from 58 percent to 40 percent (decrease of 31 percent)
- Multi-use level of parts from 50 percent to 80 percent (increase of 60 percent)

The company expects to achieve these target scores, but is also aware that "decreasing parts is the one aspect; another is the consequences (in terms of savings and simplifications) in the company's processes".

Transparency on value-chain processes complexity

Mechanical Engineering Inc. knows from past experience that certain steps towards optimization of the product portfolio had only little impact on product creation processes. A reduction of product variants does not necessarily lead to a reduction of parts due to the fact that these parts are still used in other products. Surprisingly, product variants deleted by the department of product management did not result in positive effects at the company's production plants. Cost savings were not achieved because scale effects were reduced. Consequently, Mechanical Engineering Inc.'s complexity management emphasizes that the optimization of the portfolio and of product architecture has to make the impact on value-chain processes transparent.

As the company set clear cost saving targets for its value-chain processes, transparency on complexity was achieved by calculating complexity costs. A complexity cost calculation tool based on a variation of the process cost accounting approach was developed in a three-year project. The project objective was to create a holistic concept and a tool to calculate complexity costs. The tool is based on an assessment of the most important complexity cost drivers. Three main types of complexity cost drivers have been identified:

1. Structural complexity which covers the number of BOM items, the number of dependencies, the module structure and the variability of the installation position of modules and components.
2. Parts-induced complexity which covers the number of new parts and components to be changed as well as the number of single-use parts and the number of work processes to be changed.
3. Variety-induced complexity which covers the number of new variant characteristics.

Figure 46 shows the distribution of the complexity cost drivers along the value-chain. The complexity cost tool developed covers the entire value-chain and includes cost drivers such as labor, inventory, production equipment, material, and others. Data for this tool is gathered from the functional departments by the project leader and verified with the controlling department. The experience with this tool is highly positive across all corporate functions. It represents an enhancement of the existing corporate controlling and appears to be reliable and accurate.

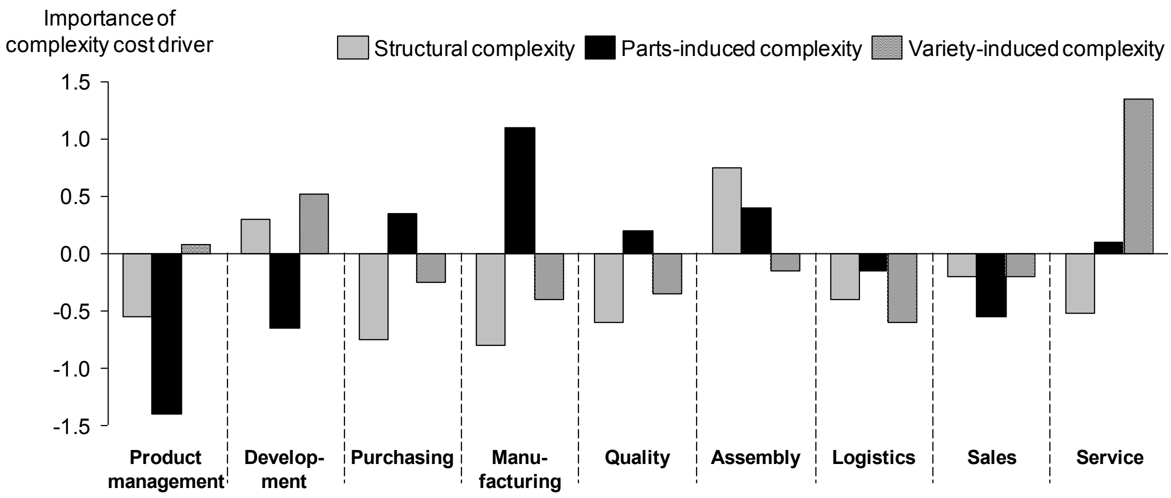

Figure 46: Complexity cost calculation along the value-chain

4.5.4 Complexity perspective in decision-making for products

Mechanical Engineering Inc. intends to grasp the opportunities which variety offers in the market (e.g. value to the customer, differentiation from competitors and unique selling points) and, at the same time, to reduce risks of creeping complexity (e.g. increase in COGS, lengthening of lead times and higher error rate). As the company knows that the best strategy to achieve this is to avoid additional, exotic variants, the complexity impact is integrated in decisions for products and variants.

Decisions on new products and product variants are made by the product council. For new products, this cross-functional committee consists of five stakeholders: Development, manufacturing, business development, product management and the senior executive board. For product variants, the committee consists of six departments: Development, manufacturing, sales, product management, corporate strategy and the senior executive board. The committees for each product line are temporary and staffed with experts from these departments according to the product decision to be made.

In the past, major decisions were made very subjectively by single stakeholders who followed their intuition and gut feeling. Today, the company places emphasis on objectivity by cross-functionality and standardization. Cross-functionality is achieved by integrating the key departments already mentioned in the decisions. Standardization, on the other hand, is increased by running a defined process including relevant gates (Figure 47) and by applying a template covering a balanced set of criteria. Main criteria for new product and product variants are financial figures such as NPV and ROI, market-related criteria such as market size and growth and the financial and market risks associated with the decision at hand.

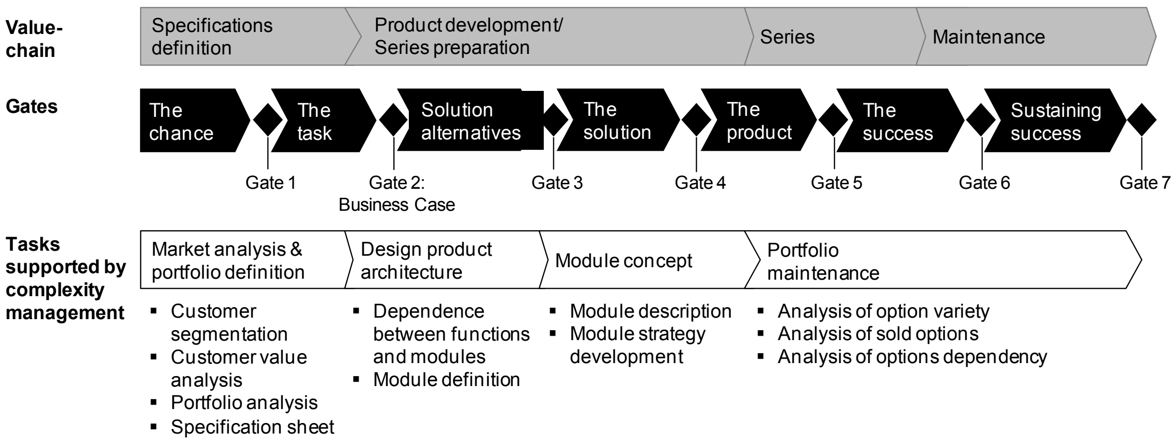

Figure 47: Value-chain and decision points at Mechanical Engineering Inc.

The influence of intuition, gut feeling and domination by stakeholders in decision-making, which is typically negative, is therefore reduced. Subjectivity of decision-maker, which led to economically unwise decisions in the past, is replaced by a high level of standardization, formality and cross-functional discussions.

The company recognizes that traditional criteria in the business case do not entirely reflect the reality after the decision. In particular, estimated market growth and the financial risk assessed in the early phases are not reliable. Furthermore, cost blocks in the decision did not cover all costs occurring along the value-chain. Consequently, Mechanical Engineering Inc. decided to integrate complexity cost calculation in its product decisions. Mechanical Engineering Inc. achieved a shift in its key business case decision for products and product variants. Having run a manufacturing cost approach and indirect cost mark-ups for several decades, the company applied the complexity cost approach in early decision phases. This complexity cost approach across the value-chain (from development to spare parts efforts in after-sales) allocates direct and indirect costs where they occur. This costing approach can be divided into two tools with different levels of accuracy, a detailed variant cost tool and a simplified variant cost tool. The detailed variant cost tool is used in investment appraisals for larger projects and supports decision-making concerning serial and customizing processes. The simplified variant cost tool is designed for "quick" cost calculations and in decision-finding for smaller investments. The results of the complexity cost calculations, either from the detailed or the simplified approach, are used in the NPV calculation in the business case. The data for the complexity cost calculation is gathered by the project leader of the product line in question in close interaction with the controlling department.

4.5.5 Summary

Mechanical Engineering Inc. set up a comprehensive complexity management system as a result of external market pressure and decreasing revenues in recent years. Board members hope that this initiative will help the company to once again become as competitive as it was in the past. The initiative is highly cross-functional involving multiple stakeholders in different projects to find the right level of external and internal complexity. Communication of the overall approach and practical methods are considered key elements for the initiative's successful implementation.

The new-found transparency revealed an increase in complexity (in terms of the number of active parts) and a corresponding decrease in revenue, causing an initial wave of alarm throughout the entire company. In the initiative, transparency on the product portfolio and product architecture is created with specific complexity indicators. These allow for the tracking and steering of internal and external complexity. On the value-chain processes side, complexity is made transparent with a distinct complexity cost calculation which enhances traditional controlling.

Mechanical Engineering Inc. places emphasis on cross-functionality and standardization in its decision-making for products. To avoid subjective and dominated decisions like in the past, the company explicitly involves the key departments and has changed its criteria by taking complexity cost estimations in its business case into consideration.

4.6 Case 3: Automation Technology Inc.

4.6.1 Company profile and complexity drivers

Company business and environment

Automation Technology Inc. is a leading provider of solutions for industrial process engineering. The company supports its customers as a partner in the realization of automation projects ranging from “greenfield” plants to “brownfield” optimization projects. It is therefore a B2B-company serving multiple industries with its systems and components such as Chemical, Food & Beverages, Water, Healthcare, Oil & Gas, Energy, Metal, Paper and Shipbuilding.

Automation Technology Inc. is a family-owned company based in Western Europe with around 10,000 employees, which achieved approximately 1.5 billion Euros in sales revenue in 2011. The number of employees, the number of products sold as well as sales revenue has grown continuously during the last 25 years. The company runs eleven main production facilities in ten countries as well as 40 sales offices around the world to ensure close contact with its key customers. Automation Technology Inc. states the following main competitive priorities to win customer orders:

- Superior product design and quality
- Superior conformance to customer specifications
- Reliable deliveries
- Superior customer service (after-sales and/or technical support)

Automation Technology Inc. is characterized by its constant focus on customer proximity, literally and figuratively, combined with a strong emphasis on innovation. Customer demand is typically the trigger for groundbreaking new solutions, either products or services. The company also heavily invests in innovation which is evident in a total of approximately 5,000 “live” patents worldwide. In total, 1,800 different products, containing a theoretical number of a few billion product characteristics, are the result of this innovation and customer focus. The resulting broad portfolio is considered a key differentiating factor in the company’s market segments.

This said, external variety provided to the markets was not limited by the company as long as the customers paid the price for it. Additionally, internal variety has not been managed optimally but has been allowed to expand unrestrictedly due to the development of new solutions even in cases where an existing solution was already covering the customer problem.

With regard to the organizational structure, the company mainly operates in a decentralized manner. Four key locations produce one key product line each. However, there are certain similarities among the products in the product lines. The potential of these similarities has not been realized by the company. It is expected that these similarities could lead to tremendous synergies (in product architecture and processes). Therefore, complexity management has been implemented in the company's holding, a central organization at headquarters, with the objective of identifying, exploiting and sustaining the synergies across the four key company locations.

Complexity drivers

Automation Technology Inc. estimates that 90 percent of its product variants are triggered by its customers (externally) whereas only ten percent originate internally in the decentralized locations (so-called product centers). Thus, external complexity drivers dominate the company and its complexity management.

As the company serves multiple industries with individualized products, it is exposed to rising globalization of its large existing customers as well as to a number of new customers. Most of the existing customers shift their production plants, which are served with automation technology, to emerging and low-cost countries. Therefore, globalization of the customer base has become the most critical complexity driver in recent years. In the past, Automation Technology Inc. focused on a few key accounts (large corporations) as their primary customers. Nowadays, new market entrants across multiple industries represent a lucrative opportunity for revenue and profit growth. The size of the customer base, another major complexity driver for the company, has grown accordingly. Apparently, individual product requirements by customers from different industries (e.g. size, materials, interfaces, handling, etc.) are a challenging aspect. But variability in demand is considered a more critical complexity driver when serving smaller customers. Large customers with a number of production plants and detailed, long-term investment plans for their networks are much easier to forecast for Automation Technology Inc. than these new customers.

In line with intensified globalization of production plants to be served are challenging country-specific regulations and standards which have to be met by the company's products. Especially customers in promising industries such as Pharmaceutical or Food and Beverages are forced to meet requirements of regulatory bodies (e.g. FDA or EMEA) around the world. These requirements also impact Automation Technology Inc.'s solutions.

The company also states that two internal drivers contribute to the increase in complexity across the company. First and foremost, although the decentralized organizational structure enables short decision paths, it lacks information exchange between the "autonomous" locations. Complexity has been created by this organizational structure because solutions for customer problems and new components for certain products were being built from scratch at each location. The developers simply were not aware of solutions developed at the other locations mainly due to a lack of transparency in the systems. Secondly, the technology- and innovation-driven company culture characterized by engineers led to additional variants and components which were actually not necessary to fulfill customer requests. In fact, products were over-engineered to suit the customer's purpose. Hence, internal drivers, decentralized organizational structure and a technology-driven company culture, contribute to the complexity in the company.

4.6.2 Complexity management at Automation Technology Inc.

Five years ago, the company's slogan "Manage diversity, reduce complexity – Eliminate harmful internal competition" was promoted by the company's owner and it is still valid today. The slogan and corresponding vision to "do the same things the same way" is manifested in the company's strategy. External variety provided by the company to the markets is nearly unlimited, i.e. when a customer has a specific requirement it will be realized. Rather than limiting external complexity, it is the objective of Automation Technology Inc. to transfer a high level of external complexity into a low level of internal complexity. To achieve this transfer and a corresponding competitive advantage with a complex product portfolio, management of internal complexity is a critical capability for the company.

Automation Technology Inc. provides five major product types with 1,800 products and a theoretical number of 25 billion possible variants to its customers. The company has experienced a constant increase in product complexity in the last ten years. In 2010, there were certain product lines with tremendous increases in product options since 2000 (Figure 48).

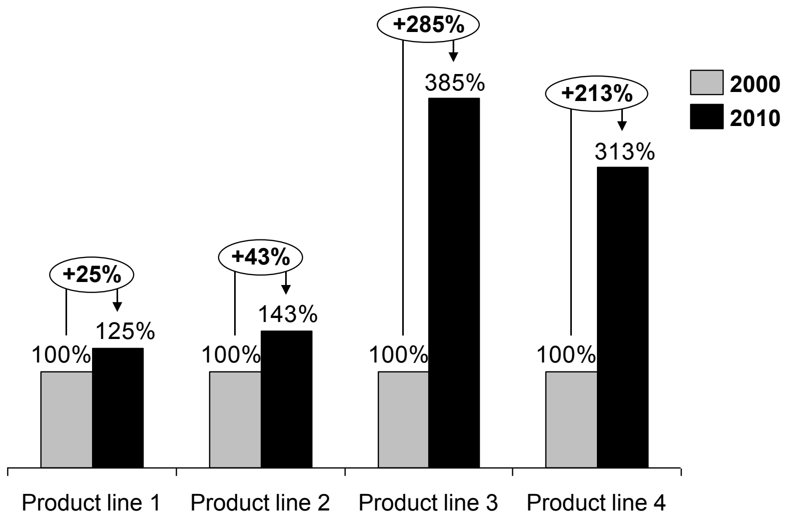

Figure 48: Increase in product options at Automation Technology Inc.

The increase in product complexity was assessed by the company in a first step prior to the design of the complexity management initiative. This created awareness among the departments and stakeholders which were to be involved in the initiative. As a consequence of this assessment, complexity is targeted on two fronts: The portfolio- and product architecture-oriented front which focuses on product platforms and the process-oriented front which focuses on standardization, the availability of information and synergies in processes (e.g. in purchasing). Both fronts are organizationally anchored at high hierarchical levels (staff division for platform management and VP Technology).

Due to the observation of the complexity increase in product architecture, the initial focus of the initiative was set on optimizing product complexity. The initiative is structured in three steps:

1. Identify and leverage similarities in products across decentralized business units
2. Implement standards (norms) for value-chain processes
3. Nurture a corporate culture for optimizing complexity by communicating results of the projects

Automation Technology Inc. decided to apply a project-based approach in order to quickly realize tangible outcomes of complexity management. A project to create a product platform across two separate locations (product centers) was initiated. It was intended to serve as a technological basis for multiple products in the near future and to save costs in development, supply and internal product creation. Following the decision to create a platform, the appropriate supportive organization was set up.

In the past, the separate product centers created internal complexity autonomously by developing different solutions and components for the same application. The historically grown structure of the company was characterized by four major product centers in Europe, each with departments for R&D, manufacturing, logistics, sales, quality assurance and international marketing. Products created at the plants were then distributed by the sales centers. This structure was formerly not centrally coordinated but very autonomous due to different product areas and focus industries at the locations. As making use of synergies across product centers has been identified as one of the major sources for complexity optimization, the organization needed to highlight these opportunities. Therefore, the organization was re-shaped to create a collaboration model called "Integration Development", which consists of a cross-locational technology team and marketing team. The technology team includes members of the R&D department from the product centers and decides about technical communalities and non-variable parts (so-called corporate integration components). The marketing team is built of product management representatives from the product centers and develops common requirements concerning system integration from a customer's perspective. The corporate division "Development and Integration Services" harmonizes the technological requirements and inputs of the product centers. The entire organization is steered by a special committee and the "Corporate Executive Board Innovation".

4.6.3 Transparency on variety-induced complexity

Transparency on product portfolio and product architecture complexity

Automation Technology Inc. states that "transparency in order to foster re-use of product components and modules" is the primary objective of its complexity management. To move towards this objective, the company has defined three basic principles:

1. Transparency: To re-use an object (e.g. module, component, assembly group) it has to be visible, seekable and findable.
2. Re-Use: For an identified object to be re-used, it needs to be made available to the entire value-/supply-chain (development concept – development – manufacturing – logistics).
3. Collaboration: Finally, it is necessary to develop a component, to source a component or to define a platform jointly in a team across product centers.

The products within the company throughout the various product centers include a lot of similar technological functionality. In particular, similarities exist in five product components: Product bodies, electronic modules, software, interfaces to other production equipment and displays. The process implemented by the company to create and maintain product platforms not only involved technological improvements in the product architecture but also increased product value in the eyes of the customer. In automation of production multiple technologies from different suppliers are integrated resulting in interface challenges for the customer. Thus, increased value for the customer is achieved by simpler and more uniform handling of the products supplied by Automation Technology Inc. (including spare parts, software, hardware and product application).

The decision to run a project to combine two product lines from two separate product centers on one platform required a major commitment of the management and an effort by the entire company. In fact, the development of the combined product platform at Automation Technology Inc. required working time and inputs of 60 employees from two product centers for a project length of three years. In total, 60 man-years were invested to develop the product platform.

The unified product platform incorporates the same body, software, components, interfaces, data management and documentation for over 20 product families. In this way, the problem of developing components numerous times for the same function has been overcome by defining the platform across product lines. The success of the platform is also evident in a reduction in effort for the development of product lines based on the platform. Apparently, this platform is also considered a meaningful improvement for customer application because it increases safety and reduces costs due to having fewer interfaces.

To evaluate the level of complexity of products and platforms, a so-called commonality factor has been defined. It reveals the rate of new components and the rate of re-used components in a product. Table 15 shows the weighting of the different product components in the calculation of the commonality factor.

Table 15: Commonality factor calculation at Automation Technology Inc.

Product component	**Weighting in calculation**
Software	20
Sensor (parts)	5
Body (parts)	3
Hardware module (existing)	2
Hardware module (new)	1
Other small parts and components	0.25

The factor is also used as a risk indicator due to the fact that the use of known components involves a lower degree of risk of failure. Moreover, the factor takes into account the dependencies of existing components on other components. The score of this commonality factor is "delivered" by the project leader for the product line or the new product. This simple indicator represents an important argument by the manufacturing department for the discussion with market-related functions such as product management. Furthermore, senior management now makes use of the commonality factor in product decision-making. The importance of this factor is increasing steadily in the company. Figure 49 shows the range of this complexity indicator across the most important product lines of the company.

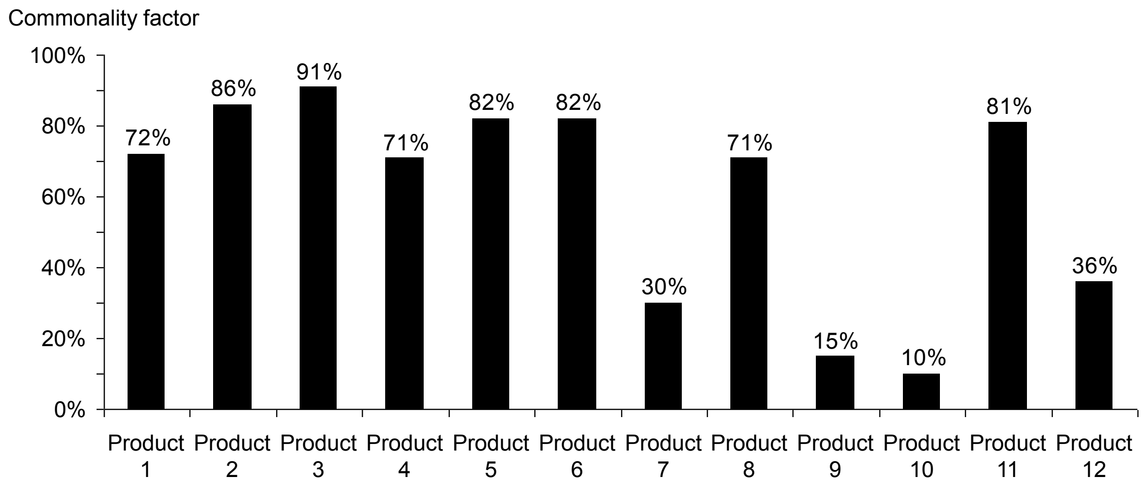

Figure 49: Commonality factor across products at Automation Technology Inc.

Transparency on value-chain processes complexity

The platform strategy applied at Automation Technology Inc. affects the value-adding processes run within the company. As a result of the platform concepts, the company is able to realize the individualization of products (creation of variants) very late in the product creation process. Figure 50 shows the switch from customer-specific end-to-end manufacturing to customer-specific final assembly by implementing a delayed differentiation concept.

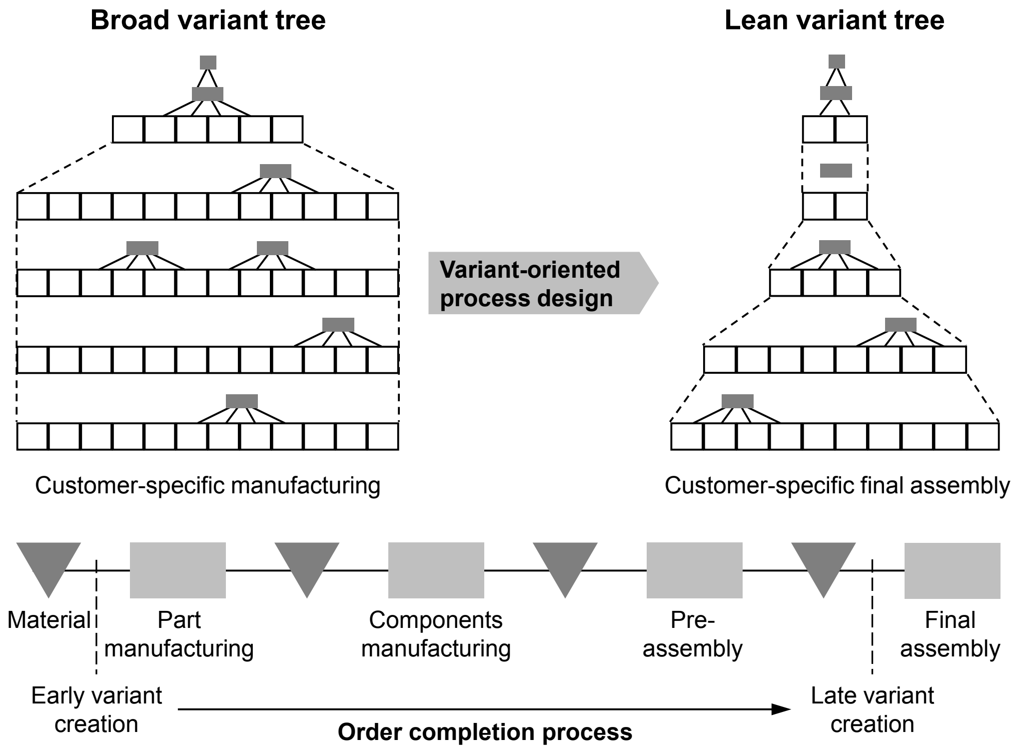

Figure 50: Principle of delayed differentiation in the value-chain at Automation Technology Inc.

Product architecture defines product creation concepts. At Automation Technology Inc. three product creation concepts are differentiated. The first case, covering less than two percent of all products, is customer-neutral. Required value-chain steps are run most economically at one location. In this case high utilization of equipment, low costs for logistics and low inventory is achieved. The second case, covering approximately 95 percent of all products, means the creation of customer individuality in late value-chain steps. Evidently, before the differentiation point, value-adding steps are characterized by high utilization of equipment, low costs for logistics and low inventory. After passing the differentiation point, value-adding steps are run on site at the customer's production plant leading to short delivery times, low inventory and transportation costs. The third case, covering less than five percent, means the creation of customer individuality in early value-chain steps. All value-adding steps are done on-site at the customer's plant which leads to low delivery times, low inventory and transportation costs.

To make complexity in the value-chain processes transparent, experts in the company developed a complexity cost model and piloted it in several projects. The experiences with the allocation of indirect costs to single product and product variants were disillusioning. Due to the fact that the complexity cost approach is based on too many vague, unreliable estimates, the company representatives decided against the use of it. Instead, the company estimates, derived from past experiences, a 20 percent increase in product costs for a product variant.

Based on experiences with monetary evaluation, the company focuses on non-monetary indicators in single value-chain steps which are simple to understand, easy to gather in the eyes of Automation Technology Inc. and more reliable:

- # of projects (in research)
- # of unique customer requirements (in development)
- # of suppliers (in procurement)
- # of baseline products and # of product variants (in manufacturing)
- # of different customer segments (in marketing)

4.6.4 Complexity perspective in decision-making for products

In the past, product variety did not play a significant role in decision-making, i.e. complexity induced by the decision was not considered in early phases. In fact, decision-making was strongly focused on technical feasibility to fulfill customer requirements. For each product or product variant, the product developer responsible for the product architecture was simply asked to make the “best out of existing modules and new customer requirements“.

The results of complexity management changed this approach significantly. The platform strategy is considered a major advantage for the product creation at Automation Technology Inc. and is, as a result, also integrated in decision-making for new products and product variants. In particular, the company considers the level of alignment with the product platform as a new major criterion in decision-making.

Decisions on new products and product variants are prepared in very small teams. For new products, representatives from the research department are working together with the senior management of the company. The final responsibility for the decision for a new, innovative product is made by the top management. For product variants, product management representatives prepare the decision from a market- and a technology-perspective. The final responsibility for the decision lies with the top management. Of course, the decision-making teams gather data from the experts in the department but, as the company is very innovation-driven on the "new products-side" and very customer-driven on the "product variant-side", the company has decided to keep the teams small to realize fast decisions.

Automation Technology Inc. is a family-owned business founded by an entrepreneurial engineer and the company still fosters this entrepreneurial spirit. Decisions on product and product variants are also characterized by this culture. Nonetheless, the company also strives towards standardization in decision-making. It is, indeed, framed by a standard process and permanent cross-functional teams. The standard process, differentiating between four levels of product individuality, for the global order-to-order process is shown in Figure 51. Decision-making processes are aligned according to their level of complexity, e.g. the decision on a QIQ (quick investigation of quality) is made very fast in less than a day whereas a project on a special product takes on average five days for a decision.

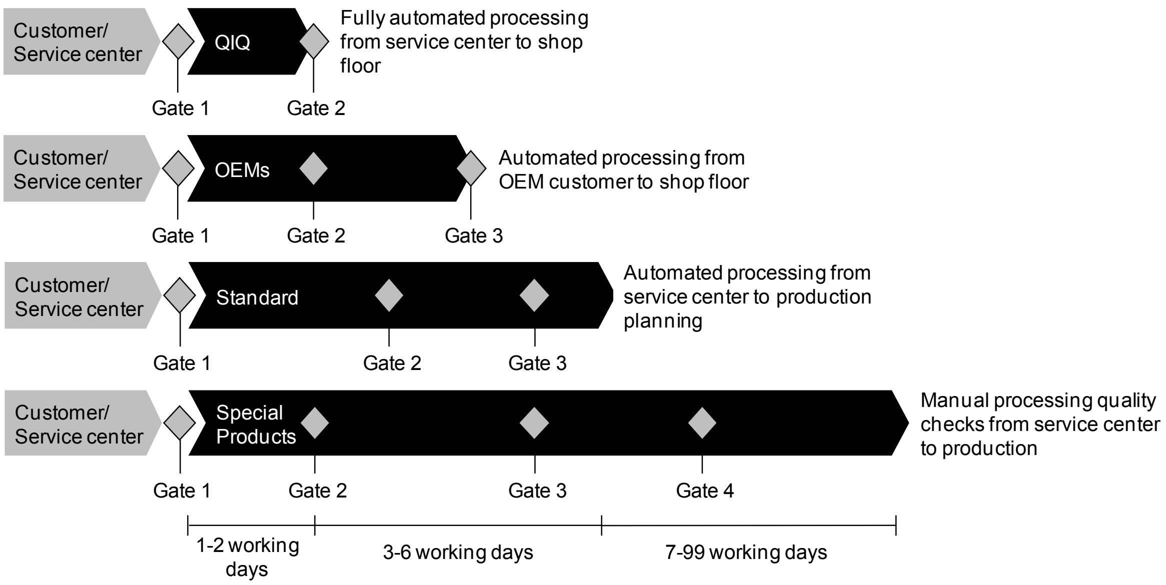

Figure 51: Order-to-order processes at Automation Technology Inc.

To make decisions within these four process types effective, small permanent teams consisting of research and product management representatives are assigned. These teams do not have strict rules or guidelines which limit their decision-making. They rather try to find a consensus in formal and informal meetings within the team, with other departments and the top management.

Formerly, decisions were made on a plant level due to the difference in products between the locations. To consider synergies between the products, decisions are now made in a team covering all the locations and steered by the central holding of the company.

Although key engineers have influenced the company's success for decades, the company intends to reduce subjectivity in terms of gut feeling and intuition by assigning these teams. Criteria applied are a crucial aspect in steering the decision-making processes which are required to be run frequently in the company due to increasing customer individuality.

For decisions on products and variants, a scoring-model has been developed with two criteria: "Strategic importance/alignment of the project with business strategy", which is decisive for new innovative products and "market size", which is decisive for variants. Of course, these two key criteria are accompanied with typical financial figures such as ROI and NPV. New criteria taken into consideration by the decision-making team are the number of unique customer requirements, the number of newly required suppliers and the number of different customer segments served by the product. The permanent team also evaluates the customer request from a commonality angle. The company estimates the rate of new components and the rate of re-used components in a product (commonality factor) in each decision for new products and product variants.

4.6.5 Summary

Automation Technology Inc. initiated its complexity management initiative having recognized potential synergies in products of the four product centers. The company's CEO communicated that it is necessary to do "the same things the same way". As a result, the organization of the company was realigned. A central coordination and improved teamwork between R&D and product management were implemented. Additionally, the product portfolio was optimized from a complexity standpoint by implementing a product platform strategy.

Creation of transparency is also focused on these complexity management issues. The company defined specific complexity indicators, most importantly the "commonality factor", to track and steer complexity in the product portfolio and the product architecture. Moreover, the company defined specific indicators for certain value-chain steps to evaluate complexity in processes. The company decided against accompanying these non-monetary indicators with a complexity cost calculation because pilot projects showed that this would be based on too many unreliable estimates due to the dynamic market environment in which the company operates.

Although Automation Technology Inc. is a company driven by entrepreneurs, it set-out to increase objectivity by implementing a complexity perspective in decision-making. The company places emphasis on effectiveness in decision-making by assigning small teams. Additionally, decision-making processes are interlinked with the order-to-order process and include a new set of complexity criteria. This set includes criteria such as the commonality factor, which is a critical aspect in decision-making.

4.7 Case 4: Assembly Systems Inc.

4.7.1 Company profile and complexity drivers

Company business and environment

Assembly Systems Inc. is a worldwide provider of products, systems and services for large-scale production. As a key supplier of equipment for automotive OEM and Tier-1 supplier production plants, around 80 percent of the company's revenues stem from the automotive industry. In fact, it serves all 20 large car manufacturer companies in the world. Besides the Automotive industry, the company serves Aviation, Mechanical Engineering, Pharmaceutical and Chemical industries with individual production plant technology.

Assembly Systems Inc. has nearly 9,000 employees working in more than 49 plants (including more than 30 production facilities) in 22 countries with a strong presence in Europe, the US and emerging countries such as China. The company, which generated about two billion Euros in 2011, is structured in four divisions each with a specific technological focus. To further structure the company, each of the divisions contains two business units with an industry or technology focus depending on the type of division. Assembly Systems Inc. states the following key competitive priorities for winning customer orders:

- Superior product design and quality
- Reliable deliveries
- Faster deliveries
- Offer products that are more innovative

Assembly Systems Inc. did recover extremely well after the crisis in 2008 as a result of its global presence and emphasis on emerging markets combined with a distinct culture of innovation and long-term customer relationships. Today, customers in emerging markets account for approximately two thirds of incoming orders, which will represent the sales revenue in the next three years.

The company further developed its corporate strategy, from before the crisis, in 2010 under the heading “Assembly Systems Inc. 2015”. The current strategy is based on two pillars: Company growth and optimization. Profitable growth of the company is to be achieved by expanding the business in emerging markets by re-strengthening innovation in products, targeted acquisitions and joint ventures to extend market access and technology base, expansion of the service business and a focus on “clean” and sustainable technology systems.

With regard to optimization, the company, which considers its portfolio complexity and ability to create individualized products fast as a key competitive advantage, focuses on the implementation of global standard processes and optimized allocation of resources. Complexity management as a holistic system is designed to support the optimization of the company by defining standards (in products and processes) and by creating transparency with non-monetary indicators, precise cost scenarios and supportive IT systems. Optimization by managing complexity is therefore directly derived from the corporate strategy.

Complexity drivers

Assembly Systems Inc. is highly dependent on a small number of key customers, who require automation technology for large scale production. Consequently, 70 percent of the product variants created are directly “pulled” by these “key accounts”. The remaining 30 percent are created internally by innovative engineers in development and assembly. The main complexity driver for externally triggered product variety is the set of product requirements stipulated by the customer. Internally, the primary driver of complexity is the product mix resulting from customer requirements, innovations and product improvements made by internal departments.

Although the company serves multiple regions in the world, globalization of the customer base is not considered a critical external complexity driver due to the fact that Assembly Systems Inc. is globally present. Its largest facility near Shanghai was implemented several decades ago and has been growing ever since to serve increasing demands in China. However, standards and regulations in these emerging countries are considered a “secondary” complexity driver for the company.

Assembly Systems Inc. is directly integrated in the long-range planning of investments by its major customers. Therefore, demand variability and actions of competitors are not considered major complexity drivers. Central to external complexity are unique customer requirements which are dependent on production volume, size and layout of the plants, certain country-specifics and, of course, the product to be created at the customer’s plant.

The products provided by Assembly Systems Inc. are typically customer-assembled systems based on standard components developed or purchased by the company. The requirements regarding these production systems are diverse, which leads to a tremendous product mix. For instance, the company’s key division provides the theoretical number of 2.5 million product variants to its customers. In practice, the division is able to configure 28,898 product variants due to technological restrictions. The company provides systems completely individualized to meet specific customer requirements resulting from product functionality, broad product portfolios and organizational networks with suppliers and partners. Therefore, the product mix is considered the major driver of internal complexity. The innovation-driven corporate culture (“engineers love to invent new solutions”) and the length of the product life cycle (approximately 20 years from installation to replacement at the customer’s production plant) are considered secondary drivers of internal complexity.

4.7.2 Complexity management at Assembly Systems Inc.

Assembly Systems Inc. assessed the drivers of complexity and, more importantly, the consequences for the company. Six major complexity effects have been observed:

- Increasing number of parts and associated capital lock-up and costs
- Increasing number of products to be maintained
- Increasing number of R&D projects and rising R&D expenses
- Longer delivery times for an order

- Rising number of missing parts
- More complex and expensive parts

The observation of increasing complexity and its impact on the cost structure of the company led to the design of a complexity management initiative. The assignment of responsibility to the division managers shows the priority the initiative has for the company. Additionally, two key functions, located in the development department to reduce and prevent complexity at its origin, have been implemented within the company: A "Complexity manager" concerned with the overall design of the complexity management initiative and the development of methods and tools to optimize complexity and a "Variant manager" concerned with the parameter definition of products in SAP. These two key functions are supported by nine cross-functional meetings to discuss the optimal product variety and the optimization of variety-induced complexity.

In 2005, the company started complexity management with a focus on the product architecture called "formal variant configuration". Due to the changing market environment, Assembly Systems Inc. recognized the necessity for standardization and modularization of its product program in order to handle and reduce variety as well as capital costs and cycle time. This approach is a combination of standardization, modularization and IT/SAP-support. Initially, the initiative's main purpose was to translate product variants including customer specifications into product parameters and parameter dependencies. The re-use of modular components, including standardized interfaces to guarantee compatibility and functionality and design of the entire system across product lines and product generations are considered key techniques in reducing complexity.

After building modules with specific characteristics, Assembly Systems Inc. established a so-called "catalog robot". The catalog robot is a consequence of the modularization process and a major step towards mass customization of the product program. Through standardization and modularization, Assembly Systems Inc. has reduced the diversity in the product program. It was a targeted approach to handling steadily growing customer diversity. By 2008, "formal variant configuration" had been implemented as a standard procedure for any product request. The effects are impressive: Assembly Systems Inc. was able to reduce the number of robot variants (a key system component) from 28,900 to 144.

In 2009, the approach to manage complexity was extended. Complexity management was implemented as an approach to defining the appropriate amount of variance. Hence, the approach made a transition from product-focused variant configuration to the analysis of variance in the entire company (products, portfolio and processes). Assembly Systems Inc. considers this new complexity management focus as important to targeting complexity holistically but is also aware of certain challenges concerning complexity management. In particular, the following three challenges are experienced by the company:

1. Definition of the standard: Market dynamics call for a constant adjustment of standards and joint evaluation of technologies and markets.
2. Set-up of products to create product variety with a minimum of parts and inventory: Daily finding of consensus between technological performance and cost effectiveness requires the involvement of all departments (not only development and engineering).
3. Set-up of processes, the organization and mindset of employees to master complexity permanently: Manufacturing cost orientation needs to be replaced by complexity cost thinking and, furthermore, synergies in inbound logistics, assembly and distribution need to be leveraged by product, portfolio and process improvement.

To meet these challenges, creation of transparency (e.g. generation of awareness among the departments which are to be involved in complexity management and enablement of complexity cost calculation) and integration in early development decisions (to prevent variety-induced complexity) are considered important areas in the overall complexity management approach.

4.7.3 Transparency on variety-induced complexity

Assembly Systems Inc. works to achieve transparency in three ways. Firstly, the company has implemented tools to visualize complexity. This approach is focused on product architecture and represents a direct support of the modularization and standardization approach in the company. Secondly, the company has defined six complexity management indicators which cover different aspects of the product portfolio and product architecture. The trends of these indicators are reported constantly by the R&D department to the company's CEO. Thirdly, the company sets a focus on complexity cost transparency by calculating explicit scenarios for product variety. The complexity cost calculation enables a more precise allocation of costs along the value-chain and is also used in early decision phases for product variants and extensions of the product portfolio.

Transparency on product portfolio and product architecture complexity

The modularization process of Assembly Systems Inc. has been accompanied by the implementation of several IT-tools to monitor complexity in product architecture. Two key techniques are used for visualization: Attribute trees and variant trees.

To investigate the customer’s perspective on the company’s products, attribute trees are illustrated. They break down the functionality into several dimensions and add their characteristics. For a key product line, the attribute tree revealed 64 different “market characteristics” which are spread across 206 different products. Within this product line, 12 products generate 84 percent of sales revenue whereas a further 194 products only generate 16 percent of sales revenue. The transparency created with attribute trees led to the conclusion for Assembly Systems Inc. that the product platform architecture needs to cover these 12 products and their functionality and does not need to cover all theoretically possible products in the product line.

The variant tree extends the visualization techniques at Assembly Systems Inc. by taking a company-internal perspective on product portfolio complexity. As with the breakdown in attribute trees, the functionality of the products is broken down. However, it mainly focuses on the components to be added to create the product or system. This technique revealed that multiple components all serving the same functionality are used throughout the company’s products. The analysis enabled the company to identify potential for optimizing functionality to drive modularization across products and to influence future product development significantly.

Visualization is considered a good approach to illustrate technological characteristics for various types of product architecture. However, the company realized that there are indicators which are often easier to pinpoint than the visualizations. To increase clarity of the complexity management progress, Assembly Systems Inc. has defined six complexity management indicators (Table 16). In this set of complexity management indicators, the company differentiates between consumable parts, spare parts, preferred parts, active parts and one-time parts due to the fact that complexity of the systems built is mainly driven by the degree of individualism of parts.

Table 16: Complexity management indicators at Assembly Systems Inc.

Indicator	Definition	Current status
Individualized orders	Orders including parts with status “preferred”, “active” and “one-time part” as a percentage of the total number of orders [%]	Stayed stable, approximately 50 percent of the orders have a certain degree of individuality
Configurator coverage	Orders designed with the variant configurator as a percentage of the total number of orders [%]	Coverage decreased slightly in the last year
Change rate of development parts	Percentage of changes in parts developed in-house with status “preferred” and “active” [%/year]	Rate decreased significantly
New parts rate	Total # of new parts with status “preferred”, “active” and “one-time part” [# per quarter]	New parts rate increased in the last quarter
New-to-inactive parts rate	Relation of new parts with status “preferred” or “active” compared to inactive parts [%]	Adding of new parts was compensated by changing the status of other parts to “inactive”
Individualized inventory	Free inventory space of parts with status “preferred” and “active” [square meter]	Minor increase in free inventory space

Assembly Systems Inc. tracks these indicators continuously to monitor the development of variety-induced complexity over time. The data is gathered by the complexity manager in close interaction with the R&D department. For each indicator the company has determined a target line in order to foster continuous improvement and to measure the effects of specific complexity management activities. However, the indicators are limited to the product portfolio and the product architecture and only target complexity along the value-chain marginally (e.g. the indicator “Individualized inventory” points to complexity occurring in the logistics process). Therefore, the company decided to develop an approach to identify efforts occurring along the value-chain as a result of variety.

Transparency on value-chain processes complexity

Transparency on value-chain complexity is strongly focused on costs occurring in the key process steps. As the company intends to allocate costs more precisely, the cost model covers not only manufacturing cost but all overhead and indirect cost for product creation. It comprises one-time investments, e.g. for development or manufacturing equipment, and running costs, e.g. for spare parts inventory.

To implement monetary evaluation, Assembly Systems Inc. has developed a complexity cost IT tool. With this tool, the company analyzes the costs of different alternatives to serve customers. Assembly Systems Inc. quantifies complexity and cost reduction potential for specific scenarios. Table 17 illustrates an example showing that the company is explicitly looking for new product configurations to reduce the number of variants and, at the same time, to increase lot sizes to achieve scale effects. In this example, Assembly Systems Inc. identified a cost reduction potential of 848,000 Euros per year when implementing the one-variant solution.

Actions derived from the scenario calculations lead to improvements, not only in terms of costs, but also with regard to simplification of processes. In fact, higher same parts rates as a result of the calculations enable Assembly Systems Inc. to customize the product in the latest stages of the assembly process. In most cases, the entire customization can be done at the customer's production plant. Also, the higher volume of parts realized by complexity optimization supports the utilization of new processes and equipment, e.g. in manufacturing.

Table 17: Scale effects due to the reduction of product variants at Assembly Systems Inc.

	Old (4 variants)				**New**
	Variant 1	**Variant 2**	**Variant 3**	**Variant 4-6**	**Only 1 variant**
Share	48 %	22 %	21 %	9 %	100 %
Units per year	300	145	140	60	600
COGS per unit [Euro]	2,300	2,700	2,300	2,750	1,200
Total COGS [Euro]	1,568,500				720,000
Overhead costs per year [Euro]	567				86
Non-recurring costs [Euro]	1,494				249

It is obvious to the company, that the cost calculation cannot reveal all complexity effects taking place in the value-chain. However, it brings the complexity impact to the surface and makes it tangible to all employees and decision-makers in the company.

4.7.4 Complexity perspective in decision-making for products

Competitors of Assembly Systems Inc. are strictly reducing the number of product lines and are limiting the support for older products. Assembly Systems Inc. takes a different approach. The company targets these new niche markets because new customers are now coming to the company asking for individualized and long-term product support no longer provided by competitors. These niche markets are quite lucrative for the company. However, the benefits associated with increasing complexity are somewhat offset by the effort involved.

One cause of complexity is historically grown variety. Analyses by the company show that active variants exist which have never actually been built. Therefore, controlling and reducing the total number of variants has a high priority for the company. Top-down management pressure slows down uncontrolled growth of variety by asking the simple question “Do we really need this variant?” in each decision meeting.

Assembly Systems Inc. involves its key stakeholders in decision-making for new products and product variants. As new products are intended to target a new market involving high risk and requiring a substantial investment, the company involves business development, product management and the company’s top management in these decisions. The final decision for an innovative new product is made by the company’s top management. Decisions on product variants are driven by existing markets and specific customers. The decisions are more greatly affected by the understanding of market dynamics and customer requirements. Therefore, the company involves sales and after-sales, in addition to the development and product management department. As the fulfillment of customer requirements determines the success of a product variant, the final decision on a product variant is taken in cooperation between sales and development.

The company places emphasis on cross-functionality in decision-making. Assembly Systems Inc.’s decisions are based on discussions between several departments which typically take place informally. As guidance, the company implemented a number of standards such as the established process shown in Figure 52. It includes the key phases, meeting and reporting structures and the critical decision points (most important are decision points 3 and 4) to enable smooth product releases.

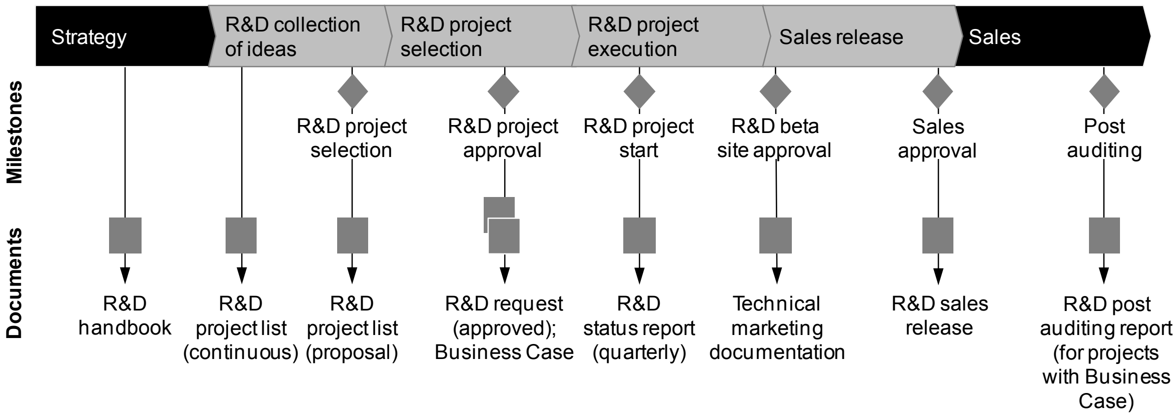

Figure 52: R&D process and decision points at Assembly Systems Inc.

Additionally, standards are implemented in a set of criteria used in decision-making and in guiding rules for early product development. Assembly Systems Inc. recognized that existing criteria such as technical risk, intensity of competition and the impact on the company's business position were not sufficient to steer the complexity level of the company in early decision phases. Efforts associated with variety-induced complexity, visible in costs, were under-represented in the decision-making process. In fact, estimates of project costs and financial risk were formally not reliable in early decisions due to shortcomings in the costing approaches applied.

The company did implement a "solution alternative" approach, which is run in a cross-functional team for each decision. Table 18 shows an example in which solution 1 based on an integral architecture covers 100 percent of the products. In solution 2 a-c, by dividing into three module-based alternatives the company is able to realize a cost advantage of 330,000 Euros in COGS per year. Although it seems like a complexity increase for the company because of the move from one to three products, product modularization as a result of complexity management facilitates this move and enables higher customer value and a cost advantage for the company.

Table 18: Early complexity cost evaluation at Assembly Systems Inc.

	Solution 1 for the component	Solution 2 a-c for the component		
		2a	2b	2c
Share	100 %	60 %	10 %	30 %
Units per year	500	300	50	150
COGS per unit [Euro]	1,500	900	1,500	500
Total COGS [Euro]	750,000	270,000	75,000	75,000
Overhead costs per unit [Euro]	1.15	1.29		
Total overhead costs [Euro]	575	645		
Non-recurring costs [Euro]	329.93	835.63		

The R&D process of Assembly Inc. shown in Figure 52 is characterized by a single document which contains all relevant data and specifications. Complexity management is an obligatory chapter in this document. The complexity management team, in close cooperation with experts from the development department, has developed a list of rules. The observation of daily conflicts in objectives, e.g. customized products vs. high-tech standard or low manufacturing costs vs. additional overhead costs, made these rules for daily handling of complexity necessary. These guiding rules explain how to consider issues of complexity in early development and decision phases[52]:

1. Rule for market complexity management: Product development starts when the sheet for technical specifications for a new product or variant is signed.
2. Rules for product complexity management:
   - Products consist of a low number of parts with a high volume.
   - Product architecture needs to allow late differentiation in final assembly.
   - Product development needs to involve other departments such as purchasing and manufacturing/assembly in the evaluation of solution alternatives.
3. Rules for process complexity management:
   - The optimal product architecture and its implementation in product releases take into account both manufacturing and complexity costs.
   - Assembly and material handling follow the principle of assemble-to-order.

[52] Each of the rules is further specified in a separate document available for product developers.

By applying these rules in every development project in intense cross-functional discussions and by accompanying decision-making with complexity cost evaluation, Assembly Systems Inc. explicitly includes complexity aspects as a matter of course.

4.7.5 Summary

Assembly Systems Inc. observed several alarming effects of complexity which led to the set-up of complexity management. Initiated by the company board, the first focus of the initiative was set on modularization and standardization to improve product architecture. In view of the positive effects of this optimization, the company extended the effort towards holistic complexity management.

The company creates transparency on complexity by using tools for visualization, complexity management indicators and a newly introduced complexity cost calculation method. These approaches cover portfolio, product architecture and processes complexity.

Cross-functional discussions are the primary element in decision-making for products and variants within the company, which include debates about the benefits and efforts associated with variety. Further, Assembly Systems Inc. applies the complexity cost calculation by calculating alternative solutions for each product request. Furthermore, to steer complexity in early development phases, the company has defined rules which guide internal R&D processes.

4.8 Case 5: Consumer Goods Inc.

4.8.1 Company profile and complexity drivers

Company business and environment

Consumer Goods Inc. is a multinational corporation and one of the largest consumer goods companies in the world. The company is mainly known for its brand building and marketing competences, but it also manufactures almost all of its products in-house in a decentralized production network. In total, the company sells close to 100 brands across several business segments in over 100 countries.

The company is known for its efforts in developing innovative new products. Before initiating customer-oriented innovation projects, the company carries out extensive market research. Indeed, market research enables the company to better serve and communicate with billions of consumers. The focus upon innovation (either in-house R&D or purchasing of innovative companies and brands) has contributed to the company's growth for several decades. Consumer Goods Inc. states the following key competitive priorities for winning orders in marketplaces around the globe:

- Superior product design and quality
- Superior conformance to customer specifications
- Offer new products more frequently
- Offer products that are more innovative

The business of fast-moving consumer goods is a competitive and very dynamic one. Consumer Goods Inc. therefore continuously tries to improve internal processes and its interface to the consumers. A key principle in achieving this is that the corporation acts as an integrated company across market segments and brands. The corporation in its entirety aims to make use of advantages of scale by allocating resources more strategically and by emphasizing teamwork which would be unfeasible for its individual businesses.

The company has remodeled its organizational structure to support the realization of these scale effects. Many of the traditional overlaps and inefficiencies that exist in other large companies have thus been removed. This new organization combines global scale benefits and the necessary local focus to fulfill region-specific needs.

Corporate business units are responsible for global innovation projects and profitability targets to fulfill shareholders demands. The interface between the cooperation's innovation outcome and the regions' and countries' business plans are coordinated by the business development organization. Two service organizations support this structure. The business services organization is in charge of human resource management and external partners (suppliers, distributors, etc.). Capability improvement as well as complexity and lean management are organized by the lean business services of the company.

Complexity drivers

The intense market research conducted by Consumer Goods Inc. leads to a deep understanding of the customers (large supermarket chains) and consumers. This customer knowledge is used for the creation of new products and product variants which leads to an estimated 70 percent proportion of externally triggered product variants. 30 percent of the product variants stem from the company's innovation activities. They are therefore triggered by internal departments, namely the corporate business units, involving experts from R&D and product management. Drivers of complexity are very dependent on the business dynamics. Two main external drivers are acknowledged by the company: Product requirements by customers and the actions of competitors to occupy new and established market segments. Internal complexity drivers in the company's focus are the diverse mix of brands and products provided and the length of the product life cycle.

A company which is providing close to 100 brands including 60,000 unique products in multiple regions and more than 100 countries is primarily affected by the product mix. Individual needs of these countries have to be served. For example, some countries in Africa do not have heated water to wash clothes. The laundry detergent provided by Consumer Goods Inc. has to be able to wash clothes with non-heated water, meaning that a different formula is necessary for this country-specific detergent. Such specifications contribute to portfolio complexity within the company. Additionally, actions by competitors drive complexity. Consumer Goods Inc. differentiates between global competitors, serving multiple markets with their brands, and local competitors, which only serve a single country or region. Both types of competitors are a threat to the company's position in the region. The consumer goods business follows a basic rule: The brand having the highest market share for a product category (e.g. laundry detergent) designs the shelves at the supermarkets in this country. Competitors target very lucrative product categories in emerging countries which forces Consumer Goods Inc. to introduce new product variants to maintain these categories. As the company actually wants to concentrate on creating global brands and product variants to achieve scale effects, the introduction of unique products for country-specific categories represents a trade-off.

The product mix as a consequence of the fulfillment of product requirements is considered the primary driver of internal complexity. In the past, the product mix has diversified in an uncontrolled way. Thousands of unique, often unnecessary, formulations have been added. This resulted from the belief that more products generate more market share. However, recent investigations conducted by the company's complexity management refute this belief. They have revealed that a simplified shelf provided by the company is leading to a better shoppers' experience and to an increase in sales. Also contributing to internal complexity is the length of the product life cycle. Most of the company's products have a life cycle of less than two years. For some, a "product refresh" takes place every six months, e.g. in artwork, package design or formula improvements. These product refreshes permanently add new active product variants to the portfolio leading to a massive increase in product variety in recent years. An initial analysis of the key complexity drivers as a basis for the complexity management initiative showed that complexity is growing faster than sales and revenues. This is considered a crucial aspect for the success of the company (Figure 53).

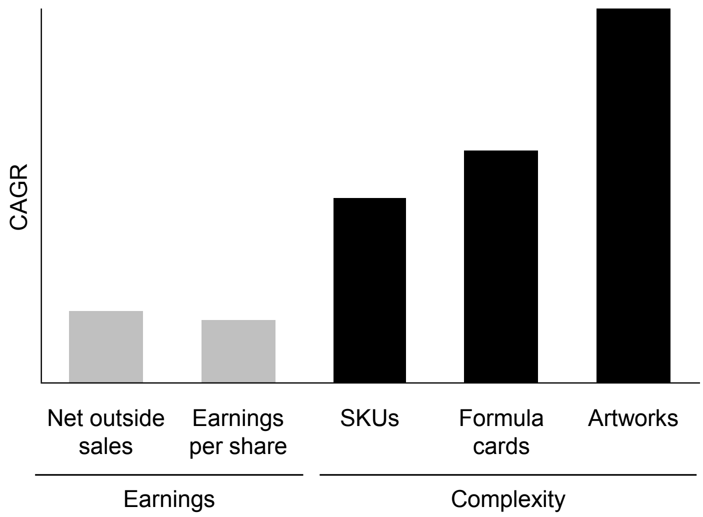

Figure 53: Complexity growth at Consumer Goods Inc.

4.8.2 Complexity management at Consumer Goods Inc.

Productivity is considered a critical driver of growth for Consumer Goods Inc. because improved productivity frees resources to invest in innovation and drives top- and bottom-line growth. Simplifying the portfolio and processes by means of a comprehensive complexity management is a key contributor to increasing productivity.

Consumer Goods Inc. runs complexity management under the positive term "Simplification". It is divided into an operational simplification and a SKU portfolio optimization program. Operational simplification means complexity optimization which is not directly visible to the customer. It has the objective of consolidating technology platforms and standardizing across brands and products to leverage scale effects in manufacturing and purchasing. Affected by this program are e.g. product formulas, materials, components, packaging artworks and work processes. Table 19 presents the four phases of the operational simplification program.

Table 19: Operational simplification approach at Consumer Goods Inc.

Phase	Issue	Objective
1	Data transparency	Identify the current state value-chain complexity and costs
2	Future vision "Lighthouse"	Define the ideal state and value to reset the value-chain
3	Migration plan	Create disruptive technology platforms to standardize and simplify
4	Sustaining result	Nurture a simplification and standardization culture to sustain results

For Consumer Goods Inc. it is critical to adopt a comprehensive customer perspective when optimizing the portfolio. SKU portfolio optimization means product simplification which is visible to the customer. To cover the entire experience by the customers when shopping the product and when using the product, the SKU portfolio optimization differentiates between the shopper, the customer and the consumer. In 2012, the program defined it as their "primary target to champion the integration of consumer and shopper insights and take a customer focus to define the right product assortment by product category". Figure 54 illustrates multiple issues in the approach to optimize the SKU portfolio at the company. In short, the program representatives realize a transition from a traditional portfolio clean-up to a complexity-optimal portfolio management.

From	To
Cut the poor performing SKUs	Driving a winning brand and SKU portfolio
Right SKU for the consumer	Right SKU for the consumer, shopper, customer or channel, and company
Design for all needs	Design for a category specific shelf space in line with business strategy
Product supply cost cutting	Multi-functional business building
Periodic	Sustained and integrated into the organization
Reactive	Proactive, strategic and with strong execution
Silos	End-to-end and collaborative with trade partners

Figure 54: Shift in SKU portfolio optimization at Consumer Goods Inc.

Both programs are designed to break the rising proliferation experienced in recent years. They are therefore explicitly hardwired to the corporate strategy and have been explained in the annual reports of the company for the past three years. The sponsor of the programs is the board member responsible for global operations who defined the strategy which is cascaded down across the corporate organization.

In addition to this top management commitment, a supportive dual organizational structure has been implemented. At first, a central coordination team at the corporate level in a multi-functional “Center of expertise” carries the programs’ global responsibility. This center is divided into two teams one for each program, which consist of experts from R&D, product management and the supply chain organization. These cross-functional teams provide training and teaching to the regions. They develop tools to deal with product variety from an end-to-end perspective. However, as implementation is carried out on a regional level, the business leaders in the regions are accountable for the results and for the achievement of the programs’ targets. It is obvious to Consumer Goods Inc. that multi-functional business processes and the role of sales are critical for the success of this program. Appointed decentralized project leaders implement the newly developed complexity management approaches in the regions and countries.

4.8.3 Transparency on variety-induced complexity

Transparency on product portfolio and product architecture complexity

The operational simplification program at the company aims to reduce product architecture complexity. The vision behind is to reduce complexity, which is not evident to the consumer in order to improve productivity, costs and speed of innovation. In particular, optimized product architecture and the establishment of platforms will enable fast and concurrent product launches across regions.

The program was started in 2007 when profit in a key business segment stagnated. Initial simplification efforts were focused on this business segment to achieve short-term results. In 2008, the company achieved first significant effects by optimizing the numbers of brands and SKUs in this business segment. The success led to the chartering of a company-wide program on artwork printing and bottle structure simplification to reduce packaging and artwork complexity. To emphasize the lighthouse role of the project in this market segment, the "product architecture areas" with the highest potential were targeted. For instance, before the simplification the company had 10,000 different inks used in printing its package artworks. The company was able to decrease this high number of inks significantly. Today, seven inks and a few special colors (in total 200 colors) are defined which cover the printing of all the colors used in the market segment's products.

Positive effects of the program in this market segment convinced the company's organization to roll out this operational simplification program to reduce complexity throughout the entire company. Additionally, a competitor benchmark in the fast-moving consumer goods industry showed that competitors have some form of simplification or complexity reduction program. In particular, simplification of packaging is the most common focus in the industry. However, Consumer Goods Inc. decided to deploy the program in a more comprehensive manner covering the four main areas shown in Figure 55.

Products & materials	Packages & artwork	Platform management	Work systems
▪ Increase formulas' productivity ▪ Increase material specifications productivity	▪ Increase packages' productivity ▪ Simplify artwork colors and inks	▪ Simplify types of manufacturing platforms ▪ Improve cost of capacity (towards industry benchmark)	▪ Improve work processes and productivity ▪ Improve culture survey results

Figure 55: Operational simplification scope at Consumer Goods Inc.

To pave the way for optimization, organizational alignment is also part of the simplification effort. The intent is to leverage synergies across the diverse areas of the company. For this purpose, Consumer Goods Inc. defined five technology clusters valid for all business units and brands to create a basis for the subsequent holistic simplification.

The optimization of products (formulas, materials, platforms) throughout this new organization led to significant improvements. For example, the program led to a 50 percent reduction both in complexity in the data base containing formulas and in raw materials needed for the bulk product and packaging. An initial analysis of the data points in the IT-systems of the company revealed that there were, for instance, hundreds of unique data points for water. This means that most existing data points were actually not being used by the product developers. In addition to "hard" savings in terms of cost savings (e.g. by reducing inks to save millions of USD), the program also intends to free up people to engage them in value-adding activities to strengthen the innovation portfolio, which is the most important objective for the growth of the company.

Product portfolio complexity is improved by the SKU simplification program. The focus of the portfolio complexity optimization is set on stock-keeping units because they represent a core driver of complexity at Consumer Goods Inc. and an important indicator for the company's customers (e.g. supermarket chains like Wal-Mart). In the past, failure to incorporate the needs of the customer into the design of the company's portfolios, continued overuse of small product initiatives that clutter the shelf, and not having the right process in place to eliminate underperforming portions of the portfolio led to less than optimal portfolios. Today, the company manages 60,000 SKUs worldwide. As the first step of SKU optimization, the program representatives clearly defined what a SKU is and how it is counted. Secondly, they investigated the correlation between market share and share of SKUs. They found that increasing and maintaining market share is best achieved when a brand has its "fair share" of shelf space, i.e. sales levels correspond to the share of shelf space in the respective product category and not solely on the number of SKUs. Also, the product in the category is more easily selected by the shopper when the share of SKU offerings is low. Consequently, SKU simplification leads to a higher market share for the company.

Consumer Goods Inc. considers portfolio complexity from an internal and external perspective and has defined two indicators for making complexity as seen from both perspectives quantifiable (Figure 56). SKU-related indicators were chosen for this purpose because SKUs are also the most important issue for the company's main customers due to inventory levels and the associated costs.

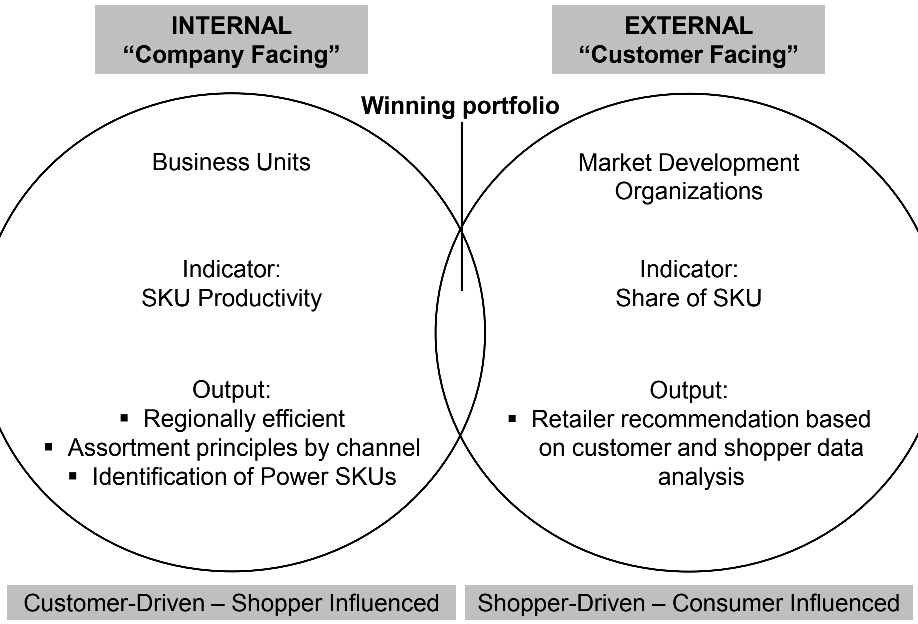

Figure 56: Perspectives on product portfolio complexity at Consumer Goods Inc.

To reflect the customer focus of the company, customer-oriented complexity indicators have been defined:

1. To measure internal complexity from a customers' perspective:

$$\text{SKU Productivity} = \frac{\text{Sales Volume}}{\text{SKU}}$$

2. To measure external complexity from a shoppers' perspective:

$$\text{Share of SKU} = \frac{\text{Share of SKU}}{\text{Shelf}}$$

The company has learned from experience that keeping such indicators simple and the number of indicators low leads to higher acceptance across the organization. Both indicators are weighted equally in the corporate and regional decisions for optimizing the portfolio because the internal indicator "SKU Productivity" must be balanced with the external indicator "Share of SKU". The indicator "SKU Productivity" is expected to be increased in the coming years with the support of the operational simplification program. Due to the fact that Consumer Goods Inc. is working to decrease complexity, SKU productivity needs to grow faster than complexity (SKU count). In addition, the indicator "SKUs per share point" is reported and regularly compared with competitors' scores to track progress.

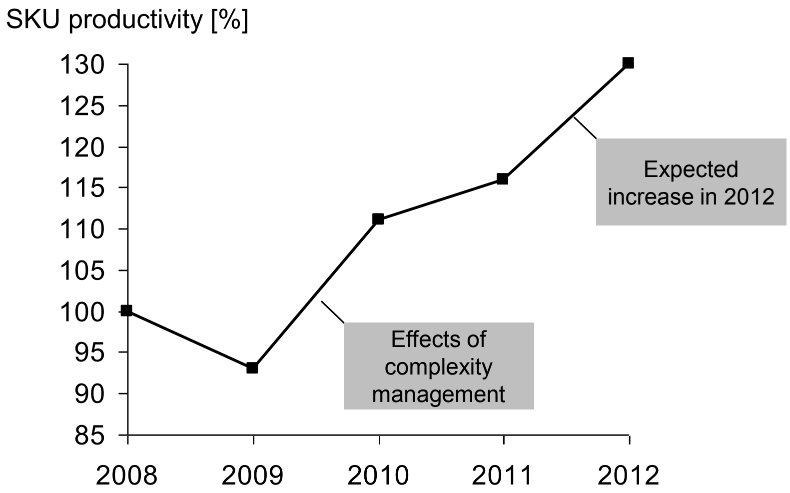

Figure 57: Complexity indicator development since starting the simplification programs

Transparency on value-chain processes complexity

Consumer Goods Inc. simplification programs are not merely limited to product architecture and portfolio, but are also intended to target complexity end-to-end along the entire value-chain. An investigation of complexity along the value-chain is illustrated in Figure 58.

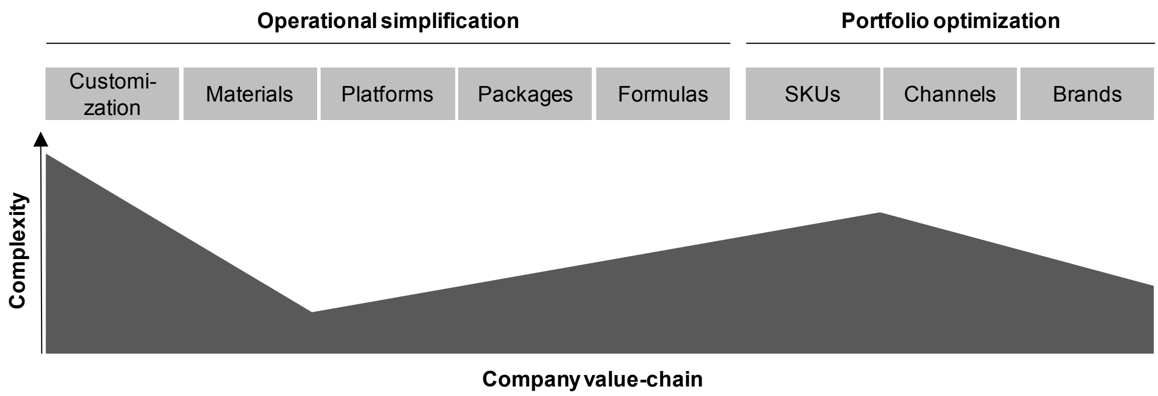

Figure 58: Value-chain complexity at Consumer Goods Inc.

At Consumer Goods Inc., complexity along the value-chain is primarily made transparent by visualization and simple indicators. Most important for the company is to create "understandable transparency" on complexity. Therefore, the company decided to turn its back on highly complicated metrics and a large number of metrics. Today a few simple, yet significant, indicators have been defined (e.g. SKU Productivity). In keeping with this, the company uses only a few indicators for value-chain complexity such as the number of suppliers, the number of parts, the number of active formulas and the number of material specs for the bill of materials. These indicators are reported regularly (monthly and fortnightly) to the corporate functions (global business leaders) by regional business leaders.

In addition to these indicators, there is a recommended standard model for calculating costs of complexity (focused on supply chain and manufacturing costs) provided by the global team. However, it is up to the regional business leaders to apply this cost calculation tool. The simplification teams have discovered that there are regions which apply this tool frequently and others which do not apply it at all. In general, the focus of evaluation of value-chain complexity at Consumer Goods Inc. is clearly on the non-monetary side. The company (in particular the regional and global business leaders as well as the board members) is convinced that these non-monetary indicators are more meaningful than the cost calculation, although there are sophisticated activity-based approaches available.

4.8.4 Complexity perspective in decision-making for products

Consumer Goods Inc. is a company which launches and "kills" products on a daily basis. This adds up to several thousand changes per year in the product portfolio. Each of these changes starts with a product-related decision by the company. Because these decisions are daily business, the company decided to consider the simplification effort in these early day-to-day decisions.

Decisions on new, innovative products and on product variants are made in cross-functional teams staffed with the same functions: R&D, business development, marketing, product management, finance and senior management (global business leaders). The difference in the decisions lies in the final responsibility. The SKU optimization program explicitly defined the decision authority in the company: With the exception of the business unit president, who sets the tone on business strategy and takes responsibility for innovative products which are launched globally, the decision-maker is the regional business unit leader (general manager) in close partnership with the sales department. The combination of these stakeholders leads to improved execution of product-related decisions.

In the past, personal interests of these decision-makers were significantly influencing decisions. This has changed a lot since an analysis of past decisions and their subsequent project execution revealed biased, non-optimized decision-making. The core of improved decision-making at Consumer Goods Inc. is characterized by four guiding rules:

- Reliable financial figures which show a comprehensive benefits and effort perspective associated with the decisions are most important.
- The standard business case template should be completed and approved at the defined “business case gate” in the stage-gate process.
- Cross-functional communication in permanent teams and formal meetings is the basis for a balanced decision.
- Lessons learned from past decisions and projects are compiled by liaison staff at headquarters and actively integrated into new decisions.

Every decision made within the company has the potential to induce complexity. The company tries to create awareness among decision-makers by enhancing the scope of the simplification programs with “proactivity in early decisions”. By making the two key complexity criteria, SKU productivity and share of SKU, mandatory in decision-making, the simplification teams pushes the decision-makers to be aware of the complexity resulting from their decisions. These two criteria are estimated by the decision-makers based on past experiences and newest results from market and customer research.

4.8.5 Summary

Consumer Goods Inc. runs a broad complexity management initiative with an explicit focus on the customer. The company decided to implement programs to leverage synergies across products and processes and to optimize the product portfolio from a multi-faceted customer perspective. A board member, who intends to save USD 500 million with the initiative over the next years, sponsors the programs. These are based at headquarters where cross-functional teams run a "Center of Expertise" which also serves project managers in the business regions.

Creation of transparency is a key element in the company's simplification initiative. The complexity management teams are investigating crucial complexity aspects, e.g. inks used in product artwork, as a basis for optimization. Additionally, two portfolio complexity indicators are defined which represent the customer focus of the programs and are easy to understand and to compile. Tracking portfolio complexity and the evaluation of complexity in value-chain go hand in hand: A few simple indicators illustrate the complexity development along the value-chain.

The company's routine decision-making on new products and product variants is characterized by a strict set of financial figures, a high level of cross-functionality and standardization and learning from past decisions. The complexity perspective is integrated in the standard stage-gate processes by estimating the two defined complexity criteria for any decision. This integration of a complexity perspective improves decision maker's awareness of variety-induced complexity.

5. Conceptualizing companies' approach to managing variety-induced complexity

This chapter presents the refinement of the reference framework based on the survey results and in-depth case studies conducted. Chapter 5.1 provides a summary of the commonalities and differences across the five case study companies. It results in a set of practice-related issues which are to be compared with literature in the cross-case analysis. Chapter 5.2 includes a discussion of the empirical findings which draws on existing research. Therefore, it enhances the practice-originated issues with a theoretical perspective. Finally, Chapter 5.3 presents the conceptual model which is built upon the reference framework, the new elements found in the empirical investigation and the literature-based discussion.

5.1 Single-case comparison

The case studies are structured according to the reference framework derived from literature. However, the interview and workshop series at the case study companies revealed issues which were not covered by the original reference framework. To harmonize the most crucial findings, the single-case summary is structured around the following categories:

1. Overall characteristics of the complexity management approach
   - Priority of complexity management
   - Organizational set-up of complexity management
   - Cross-functional involvement in the implementation of complexity management
2. Focus areas in complexity evaluation
   - Scope of evaluation (portfolio, product, processes)
   - Type of evaluation (monetary or non-monetary)
   - Cross-functional involvement in the evaluation
3. Focus areas in complexity integration in decision-making
   - Mechanisms of decision-making
   - Complexity integration

5.1.1 Overall characteristics of the complexity management approach

Complexity management was set up in the case study companies (except for Automation Technology Inc.) as a holistic approach around three to four years ago. Automation Technology Inc. did implement complexity management based on a single project but intends to build on this experience to design a holistic complexity management initiative. The company wanted to see the effects of complexity management first. The holistic approach demonstrates that there is an underlying structured concept, that existing concepts in literature have been considered and that complexity management is more than "just another isolated improvement initiative" by targeting complexity management on multiple fronts. These fronts can be split into three main groups, which represent the scope of the initiatives at the case study companies: Product portfolio, product architecture, and value-chain processes.

Complexity management is run with a high priority in all of the case study companies. This priority becomes evident in different forms. At Automobile Inc. and Consumer Goods Inc., two large corporations, the initiative is explicitly triggered by members of the board. At Assembly Systems Inc. the CEO is personally involved in the design of the initiative.

With regard to the organizational structure, complexity management is anchored in different departments. At Automation Technology Inc. and Assembly Systems Inc., complexity management is implemented in the development department because these companies want to target complexity during early development phases in which most complexity is created. At Automobile Inc., however, complexity management is assigned as a central staff unit in the purchasing department. The department is very neutral with few own interests but has a major role in project execution for new products and product variants.

Although the departments in which complexity management is anchored are not similar, two other organizational characteristics are: Cross-functional involvement in the implementation and the organizational network. The case study companies have either assigned a cross-functional team or even a cross-functional staff unit. Both types of implementation have a distinct network throughout the organization, i.e. central contact points in key stakeholders in the departments are maintained by the cross-functional team. For example, complexity management at Automobile Inc. includes competence centers with direct lines to certain departments and complexity specialists who are linked to the technology departments in development.

The starting point of complexity management at the five case study companies was the creation of awareness on variety-induced complexity. Consumer Goods Inc. and Automobile Inc., for instance, observed that complexity is growing faster than sales, which represented an alarming sign to the company's stakeholders. Furthermore, main tasks of complexity management in the case study companies are the creation of transparency by evaluation and tracking, providing of methods and tools for operational optimization of complexity, identification and leveraging of synergies across products and processes and steering of variety-induced complexity in early decision phases. Table 20 summarizes the key characteristics of the companies' complexity management.

Table 20: Complexity management characteristics in the case study companies

	Automobile Inc.	**Mechanical Engineering Inc.**	**Automation Technology Inc.**	**Assembly Systems Inc.**	**Consumer Goods Inc.**
Approach	Holistic	Holistic	Project-based	Holistic	Holistic
Maturity	> 5 years (re-initiated 3 years ago)	4 years	3 years	7 years (extended 3 years ago)	3 years
Priority	High	High	High	High	High
Scope	Portfolio, product, processes	Portfolio, product, processes	Portfolio, product, processes	Portfolio, product, processes	Portfolio, product, processes
Organizational anchoring	Purchasing/ Supply	Manufact-uring	Development	Development	Portfolio management
Organization of the initiative	Cross-functionally staffed unit	Cross-functional team	Cross-functional team	Cross-functional team	Cross-functionally staffed unit
Organizational reach	Network	n/a	Network	n/a	Network
Crossfunction al involvement	High	High	High	High	High
Starting point of initiative	Create awareness on complexity	Create awareness on complexity	Create awareness on complexity	Create awareness on complexity	Create awareness on complexity
Tasks of initiative	Transpar-ency, methods, steering	Transpar-ency, synergies, methods, steering	Transpar-ency, synergies, steering	Transpar-ency, synergies, methods, steering	Transpar-ency, synergies, methods, steering

5.1.2 Focus areas in complexity evaluation

Complexity evaluation represents an important element in the companies' complexity management initiatives. In fact, all five case study companies have some type of evaluation for portfolio, product and value-chain processes complexity. They have therefore implemented a suitable evaluation concept but with very different foci.

Complexity in the product portfolio and in product architecture is evaluated non-monetarily among the case study companies. Each of the companies has defined and implemented a number of complexity-related indicators. They range from quite sophisticated indicator-systems like at Automobile Inc., Mechanical Engineering Inc. and Assembly Systems Inc. to a low number of indicators which are easy to understand and to gather. These simpler approaches are chosen by Automation Technology Inc. which applies the commonality factor as the key indicator and by Consumer Goods Inc. which uses two key indicators to evaluate internal and external complexity.

Except for Mechanical Engineering Inc. which has chosen to use monetary evaluation although they have also developed a non-monetary concept, the companies state that non-monetary concepts are of great relevance to them. In keeping with this important role, these non-monetary concepts have been applied widely throughout the companies' departments. For example, the concepts are adapted by developers for investment decisions, by sales representatives for product pricing and by senior management as key criteria for product decision-making. Companies also have a high degree of cross-functional involvement in the evaluation of portfolio and product complexity. Multiple departments are involved in data gathering, calculations and interpretation (how to optimize) of the evaluations.

Complexity induced by product variety in the value-chain processes shows a more scattered picture. Whereas Assembly Systems Inc. evaluates value-chain complexity monetarily by calculating complexity cost scenarios, Automation Technology Inc. focuses strictly on non-monetary evaluation due to its disillusioning experiences with its costing approaches. Three of the case study companies evaluate value-chain complexity using a combination of monetary and non-monetary approaches.

Similar to the relevance of portfolio and product architecture evaluation concepts, value-chain evaluation concepts have a high relevance at three of the case study companies. At Automation Technology Inc., the non-monetary evaluation is not yet fully implemented but is becoming increasingly important. At Consumer Goods Inc. non-monetary evaluation with the two complexity indicators dominates the complexity cost calculation which is used to a lesser extent. At Automobile Inc. and Mechanical Engineering Inc. the level of utilization of the evaluation concepts is high, whereas at Automation Technology Inc., Assembly Systems Inc. and Consumer Goods Inc. utilization is at a medium level because the concepts are not fully mature yet. The suitability and success of the evaluation concepts is still to be proven in running projects on new products and product variants.

A broad involvement of multiple departments and stakeholders is observed at three case study companies especially where monetary and non-monetary evaluations are being used in combination. In the non-monetary evaluation at Automation Technology Inc. and monetary evaluation at Assembly Systems Inc., only a medium level of cross-functionality is found. For instance, the monetary evaluation at Assembly Systems Inc. is done solely by the complexity manager of the development department in cooperation with a colleague from the controlling department. Table 21 shows the characteristics of the complexity evaluation approaches at the case study companies.

Table 21: Complexity evaluation at the case study companies

		Automobile Inc.	**Mechanical Engineering Inc.**	**Automation Technology Inc.**	**Assembly Systems Inc.**	**Consumer Goods Inc.**
Portfolio & product complexity	Approach	Non-monetary	Non-monetary	Non-monetary	Non-monetary	Non-monetary
	Relevance	High	Medium	High	High	High
	Utilization	High	Medium	High	High	High
	Cross-functional involvement	High	Medium	High	High	Medium
Value-chain processes complexity	Approach	Monetary & non-monetary	Monetary & non-monetary	Non-monetary	Monetary	Monetary & non-monetary
	Relevance	High	High	Medium	High	Medium
	Utilization	High	High	Medium	Medium	Medium
	Cross-functional involvement	High	High	Medium	Medium	High

5.1.3 Focus areas in complexity integration in decision-making

The case study companies have added a complexity perspective to their established mechanisms of decision-making for products. Prevalent mechanisms at the case study companies are rationality, cross-functionality, standardization and formality. Rationality is operationalized with a strict set of criteria which must be fulfilled by a project request for a new product or product variant. These criteria are the core of a standard template (e.g. business case in question), which is to be completed at a defined decision point along the process. Both elements, the template and defined process, lead to the intense standardization of early decision phases in the case study companies. Decision processes are staffed very cross-functionally among the companies. They involve a number of different corporate departments, not only in the completion of the business case template but also in the discussions at the decision points. The meetings for discussion are typically formal to avoid personal influence and autonomous group building which can bias a decision. Informal meetings and discussions occur only sporadically in the processes at two of the case study companies.

Intuition and political behavior, two key mechanisms in manufacturing companies, are not pronounced at the case study companies. In fact, the emphasis placed on higher standardization and formality has reduced the role of these two mechanisms in decision-makers. Mechanical Engineering Inc., for example, had previously experienced the negative effects of a high level of intuition which led to wrong decisions on products. The company was forced to implement a complexity management initiative to reduce historically grown based on non-optimal decision-making in the past.

The complexity perspective at the case study companies has been integrated depending on the focus of the evaluation concept for variety-induced complexity. Mechanical Engineering Inc. and Assembly Systems Inc. have adapted their sophisticated complexity cost approaches in early decision phases. At both companies a simplified version based on past project experience and experts' estimations provides an accurate enhancement of the established costing approaches. At Consumer Goods Inc. and Automation Technology Inc., on the other hand, non-monetary complexity criteria, which are derived from the complexity indicators, are estimated in early decision phases. Additionally, decision-making at Assembly Systems Inc. and Consumer Goods Inc. is accompanied by specific rules to guide developers and other stakeholders in the product creation process. Due to the fact that Automobile Inc. does not want to rely purely on a complexity costing approach, the company deploys a combination of the costing approach and a set of non-monetary complexity criteria which are summarized in a so-called variant index.

Although it was only development between one to three years ago, the relevance of the complexity perspective is high at all case study companies. At Automation Technology, the relevance is even increasing in decision-making, which means that the traditional focus on manufacturing costs is shifting to the defined commonality factor as the key criterion. At all five case study companies the complexity perspective is explicitly integrated in the business case templates. For example, at Automobile Inc. the "complexity chapter" in the business case is equally as important as prominent criteria on emission reduction or safety. Table 22 provides the summary of the decision-making mechanisms and the integration of a complexity perspective in decision-making at the companies.

Table 22: Complexity integration in decision-making at the case study companies

		Automobile Inc.	**Mechanical Engineerin g Inc.**	**Automation Technology Inc.**	**Assembly Systems Inc.**	**Consumer Goods Inc.**
Mechanisms of decision-making	Rationality	High	High	High	High	High
	Intuition	Low	Low	Medium	Medium	Low
	Political behavior	Low	Low	Low	Low	Low
	Formality	High	High	Medium	Medium	High
	Standardizati on	High	High	Medium	High	High
	Cross-functionality	High	High	High	High	High
Complexity integration	Complexity perspective	Complexity criteria and complexity cost	Complexity cost	Complexity criteria	Complexity cost	Complexity criteria
	Additional complexity-related elements	Variant index calculation	-	-	Rules throughout the process	Guiding rules
	Relevance of perspective	High	High	High	High	High
	Integrated in business case	Yes	Yes	Yes	Yes	Yes

5.1.4 Summary of emerged issues from case studies

The single-case summaries reveal that there are similarities and differences in the complexity management among the case study companies. One similarity is that all the initiatives have the same broad scope covering portfolio, product architecture and value-chain processes complexity. In this comprehensive scope, the complexity management focuses on four main tasks: Creation of transparency, identification of synergies, developing methods for optimization and, finally, steering of complexity. Although there are differences in the organizational anchoring of the complexity management initiative, the initiatives reveal that a high degree of cross-functionality in the implementation is a crucial element for success.

Evaluation of complexity represents an important aspect in creating transparency, not only as a starting point to provoke awareness but continuously to track progress. To evaluate complexity in product portfolio and product architecture, all companies defined non-monetary complexity indicators rather than trying to evaluate it monetarily. In the evaluation of value-chain processes complexity, however, there are monetary, non-monetary and combined approaches implemented. In line with this observation are the approaches applied to integrate the complexity perspective in decision-making for products. Different approaches are implemented in the case study companies (Figure 59).

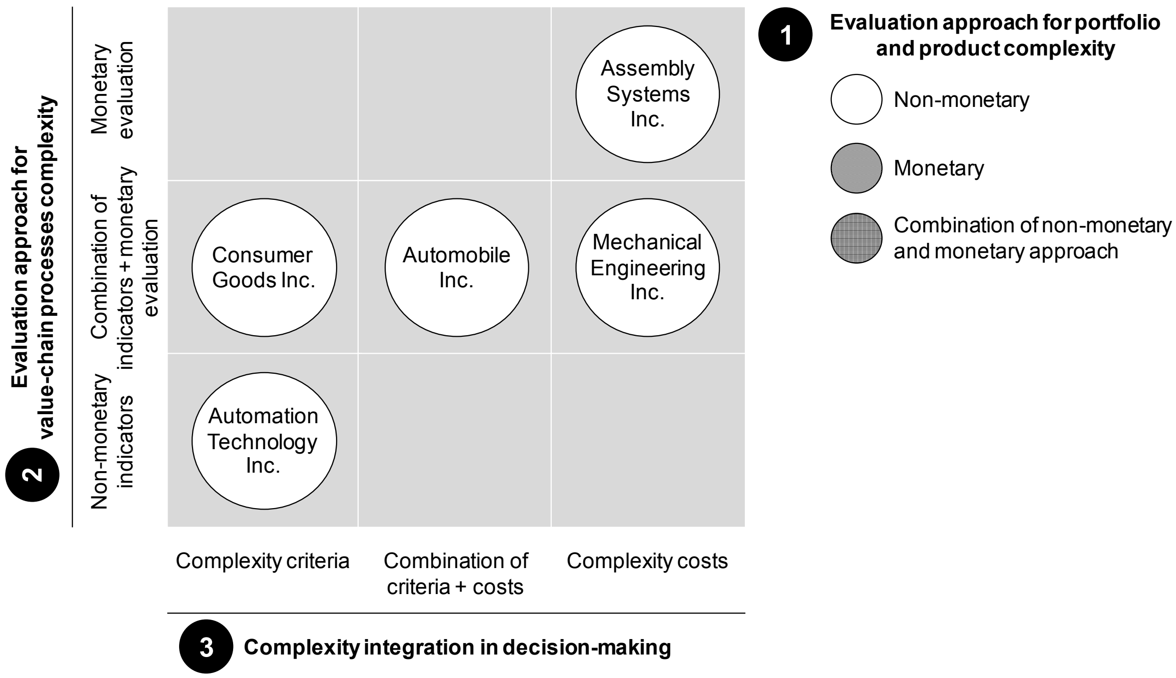

Figure 59: Approaches for transparency of complexity and their integration in the case study companies

As the evaluation approaches for variety-induced complexity and their integration in product decision-making are part of an overall complexity management initiative, it is necessary to consider the characteristics (organization, priority, etc.) of this initiative. Furthermore, the initiative involves more core tasks than mere complexity evaluation and integration in decision-making, namely the identification of synergies and the development of methods and tools for optimization.

In conclusion, the evaluation approach and the integration approach are not only influenced by external and internal complexity drivers but by complexity management characteristics and other tasks in the companies' complexity management. Based on the issues arising from this single-case summary, the enhancement of the reference framework is to be elaborated in the cross-case analysis.

5.2 Cross-case analysis

The cross-case analysis extends the emerged issues from the single case summary by taking a more focused look at the case study findings and by studying these findings in the light of existing literature. Although the reference framework presented is derived from literature, these new issues require an additional view on literature because they have not yet been covered in the literature review.

The new perspective in a structured cross-case analysis will lead to grounded new theory on the topic of complexity management. In fact, the cross-case analysis goes beyond the findings of the single-case analyses. It collates common points and creates relationships between elements to refine the initial reference framework. Nevertheless, to ensure internal validity, generalizability and the theoretical basis for the case study research, the cross-case analysis permanently refers back to multiple research disciplines which discuss the new element or relationship (Eisenhardt 1989).

The case studies reveal that complexity management consists of several interdependent elements. To investigate complexity management in manufacturing companies, the initiative need to be regarded holistically taking all its elements into account. The elements can be categorized into so-called enabling factors and activity areas. Enabling factors describe the framing elements such as the organization of complexity management, the priority of the initiative within the organization and the cross-functional involvement in the implementation. These factors are the basis of the activities in complexity management. The activity areas cover the key tasks of complexity management such as the creation of transparency, development and distribution of methods and tools, the identification of synergies to leverage and the steering of complexity in early decision phases. In these activity areas evaluation of variety-induced complexity and integration in product decision-making take place. In summary, the enabling factors are prerequisites for complexity management and the activity areas are actions executed as part of the complexity management initiative.

The following cross-case analysis is based upon these two interrelated categories:

1. Enabling factors of complexity management
   - Priority and commitment by top management
   - Anchoring complexity management in the organization
   - Cross-functionality in the implementation
2. Activity areas of complexity management
   - Transparency creation by implementing indicators and costing approaches
   - Guidance by providing methods and tools to optimize complexity in the portfolio, product architecture and value-chain processes
   - Synergies across products and processes
   - Proactivity by reasoning and process design of decision-making for new products and product variants.

5.2.1 Enabling factors of complexity management

Priority and commitment by top management

Complexity management has a very high priority within the case study companies. This priority becomes evident in different forms (Table 23), but the underlying strong commitment by top management is evident in all the case study companies. At Automobile Inc. and Consumer Goods Inc. complexity management representatives have a permanent reporting line to a member of the board. At Automation Technology Inc. the company owner pushed the topic of using synergies by coining the slogan "Manage diversity, reduce complexity" for the company's complexity management. At Assembly Systems Inc. complexity management is not only driven by the CEO's mission statement but the CEO is personally involved in the design of the initiative.

Table 23: Priority and commitment by top management at the case study companies

Automobile Inc.	▪ Top management (board member) re-enforced complexity management ▪ Board member's objective: "Determine the average indirect complexity cost per component" ▪ Constant reporting of complexity management to the board
Mechanical Engineering Inc.	▪ Market situation forced the top management to find new ways to become more efficient ▪ Objective of top management to save 50 million Euros per year
Automation Technology Inc.	▪ Company owner pushed the initiative with the vision: "Manage diversity, reduce complexity"
Assembly Systems Inc.	▪ Complexity management initiated by the CEO ▪ Personal involvement of the CEO in the initiative's design ▪ Regular reporting to the top management
Consumer Goods Inc.	▪ Initiative is a key element in the corporate strategy to increase productivity and to drive innovation ▪ Board member's objective: "Save USD 500 million in the coming years"

Commitment by the top management is recognized in management science as a critical success factor for strategic initiatives (Bourgeois & Eisenhardt 1988; Hoffman & Hegarty 1993). In fact, top managers are considered to be the driving force behind these initiatives to achieve excellence in an organization (Kanji 2001). Ahire & O'Shaughnessy (1998, p. 16) commented on this as follows: "Without the support of management the behavior of the members of the organization is unlikely to change".

In strategic planning, top managers provide the vision, mission and overall objectives (Ahire & O'Shaughnessy 1998). These are then broken down by the complexity management representatives into sub-goals and milestones as guidance for the initiative to achieve the vision. The top managers' task is also to challenge existing work practices and mindsets (Senge 1990a). As they have an overview of the entire company and "lower-level" managers are typically single-focused on their area of responsibility, top managers are in a position to trigger cross-sectorial initiatives. Furthermore, if top managers get involved in strategic initiatives, either by providing guiding elements or by personal participation in design, they serve as a role model for the organization and thus encourage change in the organization (Senge 1990a; Bourgeois & Eisenhardt 1988). Indeed, researchers state that top management commitment does not only positively influence the first phase of an initiative but all subsequent deployment phases (Rodgers et al. 1993).

Studies have also been carried out to investigate the influence of a high initiative priority and top management commitment on performance (e.g. Ahire & O'Shaughnessy 1998; Flynn et al. 1995). They confirmed a positive relationship between high priority and high performance. A comprehensive analysis of 39 qualitative studies by Rodgers & Hunter (1991) found that initiatives with a high level of top management commitment achieve a five times higher productivity than initiatives with a low commitment. In complexity management, a high commitment influences the effectiveness and efficiency in projects for new products and product variants.

In summary, the case study companies show a fundamental commitment and set a high priority on complexity management with the objective of improving projects' effectiveness and efficiency. Top managers show their involvement by providing guiding elements such as slogans, visions and objectives and by their personal participation in the initiative's design. In the course of the initiative, they are constantly involved by reporting structures, discussions on priorities and re-enforcements of the initiative.

Anchoring complexity management in the organization

The organizational anchoring of a complexity management in the company appears to be very different across the case study companies on first sight. For example, at Automation Technology Inc. and Assembly Systems Inc. it is organizationally anchored in technical departments whereas at Consumer Goods Inc. it is located in a market-related department (Table 24). However, upon closer examination it becomes evident that there are two similarities in the case studies regarding organizational structure. Firstly, the departments where complexity management is located are crucial functions to fulfill the company's objectives. But, at the same time, these departments have a very low level of own interests in the respective companies. Apparently, companies locate their complexity management in "neutral" departments to ensure a high level of objectivity in deploying the initiative.

Secondly, the organizational unit of complexity management is closely linked to other functional departments. They have created an organizational network across the entire company. For instance, at Consumer Goods Inc. the complexity management is located at corporate headquarters but has distinct communication paths to regional businesses all over the world. Moreover, it is linked to other corporate departments such as market research, product development and innovation, and others.

Table 24: Organizational anchoring of complexity management in the case study companies

Automobile Inc.	▪ Central unit located in purchasing/supply, which is a key department coordinating all internal production plants and suppliers ▪ Explicit organizational links to technical and market-oriented departments, which are maintained by complexity managers and competence centers
Mechanical Engineering Inc.	▪ Located in the department "Business Excellence", which is in charge of all optimization efforts ▪ Reach across the entire organization by following the statement "We will only reach our goals together"
Automation Technology Inc.	▪ Located in the company holding in the department "Technology" and in the market-oriented division "Platform Management" ▪ New organizational structure "Integration Development" which contains clear information flow between the departments and product centers
Assembly Systems Inc.	▪ Located in the product development department because complexity should be targeted in early product creation ▪ Clear connection to other departments such as assembly, logistics, sales and controlling
Consumer Goods Inc.	▪ Located in a powerful "Center of Competence" at headquarters ▪ Distinct links to business units (regional process leaders) and other departments such as innovation, development and market research

The role of the organizational structure is a long-standing subject of discussion in management science. In this context, the challenge of coordination in a specialized organizational structure is examined (Lawrence & Lorsch 1967; Child 1972). As complexity management can be understood as a coordinating function handling information from the environment and the company, these organizational views in research are valuable in the analysis of the case findings.

To monitor environmental information and transfer it into company-internal knowledge, the respective function or department needs to avoid bias in the up-to-date information (Tushman 1977). Researchers also suggest paying attention to the difficulties and inefficiencies in transferring knowledge beyond structural interfaces (Roberts et al. 1974). In fact, accuracy and objectivity in the evaluation and cross-sectorial transfer of information are critical elements for such an organizational unit (Caves 1980). By locating such a unit in a department with few priorities of its own, these difficulties in the organizational structure are reduced.

The literature on organizational design increasingly deals with the role of intra-organizational networks, organizational connectedness and coordination mechanisms. A complexity management unit, which can be regarded as a coordination function, is important for managing interdependencies between departments to achieve a high performance (Gittell & Weiss 2004). It enables the collaboration in which the expertise of the departments involved is utilized (Grant 1996; Goold & Campbell 2002) and teamwork emphasized (Goh 1998; Detert et al. 2000). Examples in literature show that such coordination functions have a number of links to other key departments in the organizational charts (e.g. De Toni & Tonchia 1996).

In summary, the organizational unit for complexity management is most successfully located in departments which have a low level of "own interests" and therefore work for the good of the entire organization. Additionally, the complexity management unit should be the coordination center of a network across the entire organization.

Cross-functionality in the implementation[53]

The optimization of complexity needs to cover two sides: External complexity mainly traced by departments which are in close contact with the market and internal complexity which spreads across all internal departments and hierarchical levels. A holistic complexity management should therefore foster teamwork beyond department boundaries. Therefore, cross-functional involvement in the implementation of complexity management is another element which is emphasized by the case study companies and supported by the organizational network created to cover the entire company (Table 25).

At Automation Technology Inc. the transition from an "isolated" approach to a cross-functional team effort is most remarkable. The company's complexity management recognized that the power of teamwork between departments, hierarchy levels and geographically separated product centers had not been fully exploited. Departments were literally "fighting" for their individual interests in meetings. With today's emphasis on cross-functionality, single departments set aside these interests and instead work together towards the optimum for the company as a whole.

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[53] Cross-functionality with regard to decision-making has already been discussed in Chapter 2.5 Dimensions of decision-making for products. Due to its significance as revealed in the case studies, cross-functionality in the implementation of complexity management is discussed in this section.

Table 25: Cross-functionality in the implementation at the case study companies

Automobile Inc.	▪ Organizational network as formal structure for increased cross-functional cooperation ▪ Integration of multiple hierarchical levels, e.g. operators in manufacturing develop their own ideas to handle variety which are then integrated into the initiative
Mechanical Engineering Inc.	▪ Appointed cross-functional team for the development of a holistic complexity management system ▪ Six initiatives throughout the entire organization including project leaders from multiple functional departments such as portfolio management, marketing, after-sales, development, manufacturing, controlling
Automation Technology Inc.	▪ New organizational structure fosters teamwork across functional departments and geographical locations ▪ Close collaboration between technology and market-related teams to develop a customer-oriented product platform
Assembly Systems Inc.	▪ Extended complexity management initiative does not only focus on R&D issues, but involves perspectives by product management, manufacturing, and others ▪ Nine mandatory cross-functional meetings concerning optimal product variety and the optimization of complexity
Consumer Goods Inc.	▪ Two cross-functional expert teams which are organized in a competence center and connections to regional project leaders from various departments ▪ Integration of functional departments' intelligence (e.g. recent market research insights) into the implementation

Researchers have long since recognized that divergent interests of departments and individuals are unavoidable when people from different departments are working together on projects (Lawrence & Lorsch 1967). This phenomenon can impede the project and reduce its chances of success. It has been suggested that the first step of project management should be to create an environment of cross-functional cooperation to integrate knowledge from various functional areas (Bonoma 1985). It also avoids the information processing problem caused by organizational interfaces (Galbraith 1971).

The establishment of cross-functional teams in non-routine projects, as carried out by the case study companies' complexity management, also has a positive influence on the organization's competitiveness (Dumaine 1990). Mostly discussed is the influence of cross-functionality on new product development (e.g. Griffin & Hauser 1996), but it also has an impact on other departments' performance (Holland et al. 2000) and company performance (Gray & Meister 2004).

In summary, as complexity management affects technology- and market-related functions likewise, the involvement of related functional departments in the implementation improves the success of the initiative and performance of the organization.

5.2.2 Activity areas of complexity management

Creating transparency[54]

The creation of transparency is named as the primary objective in all of the complexity management initiatives investigated. Although this transparency is realized in different forms, it is clear to the companies that it is necessarily a basic activity for directed optimization actions. Apparently, monetary and non-monetary evaluation concepts are applied in several phases of the initiatives. In addition, tools and methods for visualization are used to promote clarity on variety and complexity development (Table 26).

Table 26: Transparency creation at the case study companies

Automobile Inc.	▪ Initial assessments (incl. technical benchmarking of competitors' products) reveal the complexity problem (# of article codes vs. sales revenue) ▪ Continuous monitoring with a complexity indicators pyramid and the complexity indicators cockpit
Mechanical Engineering Inc.	▪ Established process-oriented calculation of complexity cost ▪ System of external and internal complexity indicators
Automation Technology Inc.	▪ Assessment of increase in menu items in the last 10 years as the starting point of the complexity management initiative ▪ Rule: Objects need to be visible, seekable and findable beyond product center boundaries
Assembly Systems Inc.	▪ Six complexity indicators which are tracked and reported regularly ▪ Mandatory IT-Tools for visualization and product configuration
Consumer Goods Inc.	▪ Assessment of complexity growth vs. net sales to create awareness ▪ Two high-priority complexity indicators which are defined to reflect the customer perspective ▪ Additional tools for visualization of value-chain complexity

[54] The creation of transparency has already been partially discussed in 2.4 Evaluation of complexity. However, as the case studies reveal, transparency is not only created by evaluations but also by the use of other tools and methods (e.g. visualizations). Consequently, the element is discussed in this section.

The importance of transparency is stated by Bushman et al. (2004, p. 208) as follows: “The availability of information is alleged to be a key determinant of the efficiency of resource-allocation decisions and growth in an economy”. In corporate projects, transparency creation, in terms of knowledge sharing, is recognized as a key task to increase employee trust (Cavaleri et al. 2012). In particular, in problem-solving activities which permanently take part in a complexity management initiative, the degree of transparency in the company is found to have a direct influence on the project success (Cavaleri et al. 2012). In this context, the evaluation process is named as an essential element in strategic optimization projects (Dyson 2000; Womack & Jones 1996). These evaluations can be monetary by applying costing approaches and non-monetary by deploying indicators (Dye & Sibony 2007). During projects these evaluation approaches are enhanced by methods for visualization. For instance, Hines & Rich (1997) provides seven mapping tools which build the basis for “lean management“ optimization projects.

In summary, the creation of transparency is a core activity of complexity management which can be put into practice in form of monetary (complexity cost calculation) or non-monetary evaluations (indicators) as well as methods for visualization.

Providing guidance

Variety and complexity are not solely optimized by complexity management experts in the company, but by colleagues in the functional departments of the company. The complexity management initiative should empower the organization to realize this optimization. Therefore, complexity management experts guide, train and consult the functional departments. This includes not only the development of operational-applicable methods and rules, indispensable for the implementation of complexity management, but also the entire communication regarding the development of variety and complexity or the start of the next initiative phase (Table 27).

At Automotive Inc. the complexity management team considers itself as an internal provider of expertise and actively promotes new methods through a number of communication channels. The case is similar for the communication efforts at Mechanical Engineering Inc. and Assembly Systems Inc., who state that the approach has found a high level of acceptance as a result of good communication. At Consumer Goods Inc. the organization is also guided by so-called lighthouse projects in certain business segments or functional areas. They provide a role model for optimization in the entire organization.

Table 27: Guidance of complexity management at the case study companies

Automobile Inc.	▪ Complexity management unit considers itself as an internal provider of expertise, methods and tools ▪ Intranet page, brochures, posters to communicate approach and newsletter about complexity management
Mechanical Engineering Inc.	▪ Physical "Complexity Management Rooms" to demonstrate the overall thinking behind, but also the operational methods and tools of complexity management ▪ Flyers and posters to explain the approach of complexity management
Automation Technology Inc.	▪ Impulse project to develop product platform which included the development of specific methods and technical tools ▪ Fundamental rules for complexity management based upon three principles: Transparency, re-use and collaboration
Assembly Systems Inc.	▪ Methods and IT-tools provided through an Intranet platform ▪ Defined complexity rules throughout the development process, applicable for each stakeholder within the process
Consumer Goods Inc.	▪ Lighthouse projects to create role models for the organization-wide optimization of complexity ▪ Methods and tools provided to the regional businesses through an Intranet platform

Guidance by communicating the vision and empowering others is discussed as the center of change initiatives in organizations. These two points are steps four and five in the famous eight-step transformation process by Kotter (1995). Methods and tools provided in these initiative's steps should encourage colleagues to take risks, question traditional approaches and develop new ideas for improvement (Kotter 1995). Phaal et al. (2006) point out that management tools should not only be robust and flexible but also practical to implement. In improvement initiatives it is also argued that strict rules or guiding principles are very supportive to govern their deployment (Brennan et al. 2011).

Researchers have also found that companies often communicate insufficiently with employees (e.g. Recardo 1995). Apparently this is harmful to interdepartmental initiatives. A three-way communication is suggested for such initiatives: Top-down from top management, horizontally across departments and bottom-up to integrate employees' ideas (Recardo 1995).

In summary, providing guidance by the development of applicable methods, strict guidelines and usage of a broad communication throughout the organization is considered an important activity area of complexity management.

Leveraging synergies[55]

Synergies contain the highest potential for improvements. These can be leveraged by complexity management. As different functional areas or geographically distributed locations often do not know about the similarities with other organizational units, complexity management has the task of identifying synergies and enabling the functional areas to leverage synergies. Although synergies in product architectures are most obvious due to its understandability, the activity also involves synergies throughout the product portfolio in formally separated business areas and in processes in the value-chain. In general, these three aspects are interdependent. For instance, at Automation Technology Inc. the creation of synergies affects not only product architecture but also the product portfolio at the product centers. Moreover, it influences the processes by economies of scale in purchasing processes. Table 28 shows that the case study companies run this three-dimensional strategy to identify and exploit synergies in their companies.

[55] The identification and leveraging of synergies has already been partially discussed in 2.3 Basic concepts of complexity management. In line with the presented discussion, case study companies are leveraging synergies across three dimensions: Product portfolio, product architectures and value-chain processes. The combined perspective on synergies is discussed and reflected on literature in this section.

Table 28: Leveraging synergies at the case study companies

Automobile Inc.	▪ Complexity management is concerned with the entire company, containing three brands and multiple product lines ▪ Synergies in product architectures, portfolios and processes are identified and optimized across brands and product lines
Mechanical Engineering Inc.	▪ The six sub-initiatives involve synergy creation in product portfolios, product architecture and life-cycle processes ▪ "Lighthouse" examples show the opportunities to standardize and to create synergies: Similar machine control unit across products and corresponding standardization of tools used in manufacturing
Automation Technology Inc.	▪ Platform concept which was initiated to leverage synergies in product architectures of over 20 products, in the portfolio of three major locations, also has positive effects on value-chain processes
Assembly Systems Inc.	▪ Modularization of product architectures has also positive effects on the product portfolio (number of robot variants from 28,900 to 144) and processes (increased purchase volume from key suppliers)
Consumer Goods Inc.	▪ Synergies are explicitly created in all three dimensions: Product architectures by standardization (e.g. colors, materials), portfolio re-alignment from a customer perspective and the optimization of value-chain processes by driving economies of scale globally

The identification and leveraging of synergies is discussed in various forms in management literature. Especially in inter-company acquisitions and mergers, synergies are a major factor to be considered because companies want to benefit from increased profitability between the two parties (Mahajan 1988). This is also valid for intra-company synergies (Goold & Campbell 1998). In fact, literature suggests implementing active synergy management to "add value by identifying and realizing synergies" (Vizjak 1994, p. 26). Positive effects are reported mainly in terms of portfolio management (Clarke & Brennan 1990), but they also reach out to product architectures (Ramdas 2003) and processes in the value-chain (Gruca et al. 1997).

In summary, identifying and leveraging synergies across product portfolios, product architectures and value-chain processes is an important area of activity when optimizing complexity. It improves the effectiveness and efficiency of projects on new products and product variants.

Fostering proactivity[56]

The case study companies were selected due to their learning potential for managers and corresponding implications for management science. A key aspect which is found to be a differentiating point is the ability to "front-load" complexity-related actions, i.e. to move from a reactive approach to a proactive approach. Similar to the different approaches applied for the evaluation of variety-induced complexity, are the approaches to proactively manage complexity (Table 29). At Automobile Inc., for example, complexity criteria and complexity cost estimations are both integrated in business cases. Common to all of the approaches observed at the case study companies is that complexity is targeted in some form in earliest phases of projects.

Table 29: Proactivity in complexity management at the case study companies

Automobile Inc.	▪ Integration of variant criteria, an variant index and indirect complexity cost in early business case decisions ▪ Variant-related criteria are ranked equally with other key criteria such as safety and emissions in the decision for a product or variant
Mechanical Engineering Inc.	▪ Simplified estimation of complexity cost in early phases to improve objectivity in decisions for products and to control complexity
Automation Technology Inc.	▪ Integration of platform strategy in early phases of new product and variant developments ▪ Commonality factor as a key criterion in early decision phases
Assembly Systems Inc.	▪ Calculation of cost scenarios in early decision phases ▪ Rules support the proactive control of complexity originating in early decision and development phases
Consumer Goods Inc.	▪ Customer-oriented complexity criteria are mandatory in early decision-making for global products and regional product variants

[56] The proactive integration of a complexity perspective has already been partially discussed in chapters 3.4 Process design of decision-making for products and 3.5 Reasoning in decision-making for products. The element proactivity, which emerged from the case studies, is discussed and compared with literature in this section.

Recent research demonstrates that prominent complexity management strategies tend to be reactive and proactive approaches are missing (Abdelkafi 2008). When taking the examples of strategic initiatives and change projects, increased proactivity in an approach improves its success (Butterworth & Witcher 2001). In fact, proactive behavior in organizations, which includes different actions such as seeking opportunities for improvement or challenging the status quo, can lead to increased organizational effectiveness (Bateman & Crant 1999; Crant 2000).

In summary, the activity area for "advanced" complexity management is proactivity. The integration of a complexity perspective (e.g. with criteria, complexity cost estimations, guidelines) in early phases leads to better decisions and increased effectiveness and efficiency in projects; or as the CEO of a case study company commented in a workshop: "The most powerful complexity management strategy is to control variety in early decisions, which means that unnecessary product variants are avoided or stopped".

5.3 Conceptual model

The extension and refinement of the initial reference framework is developed upon the empirical investigation, single-case comparison and cross-case analysis. From analyzing the case study data and reflecting the elements with the aid of additional literature, the conceptual model is constructed. Figure 60 summarizes the elements and their relationships in an illustration of the final conceptual model for managing variety-induced complexity in manufacturing companies.

Complexity management in companies is triggered by external and internal complexity drivers. A holistic complexity management initiative targets all three dimensions: Product portfolio, product architecture and value-chain processes. In particular, it consists of two building blocks:

1. Enabling factors, being the prerequisites for complexity management:
   - A high priority based on top management commitment
   - Organizational anchoring in a "neutral" department with an intra-company network
   - A high degree of cross-functionality in the implementation

2. Activity areas, covering the issues targeted by specific actions:
   - Creating of transparency on complexity by evaluations and tools
   - Providing of guidance with methods, tools and guidelines
   - Leveraging of synergies in products, portfolios and processes
   - Proactivity to control complexity in early phases

A comprehensive implementation of enabling factors and activity areas then leads to a high effectiveness and efficiency in the project fulfillment for new products and product variants.

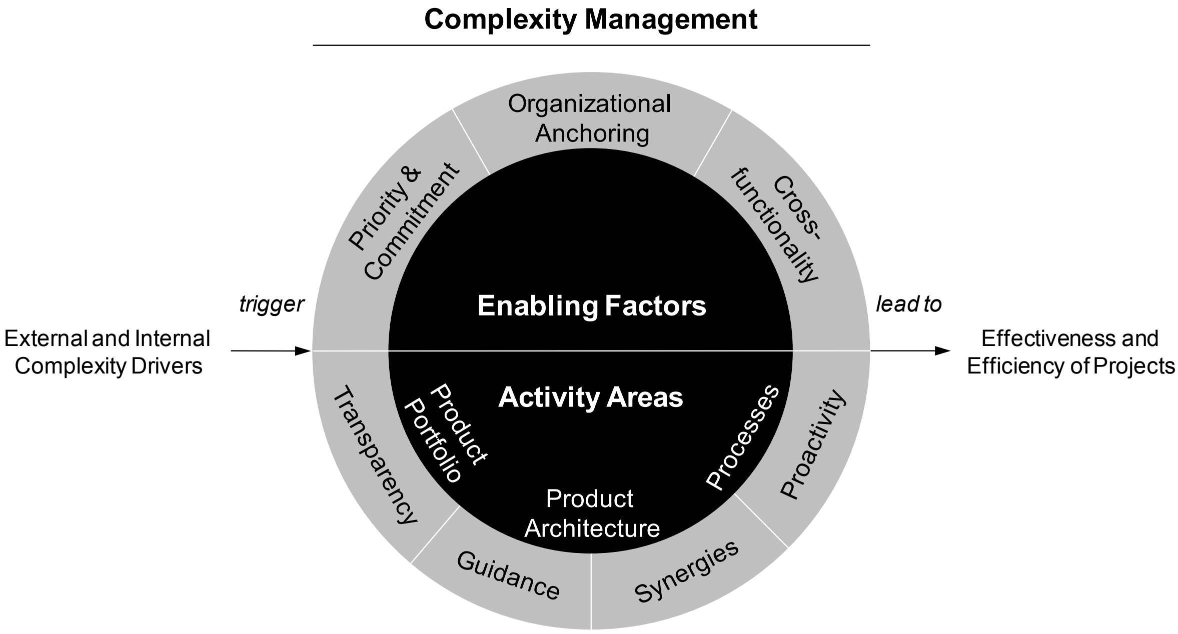

Figure 60: Conceptual model

6. Theoretical and managerial implications

6.1 Theoretical implications

In this section, elements and relationships illustrated in the conceptual model are further described and broken down into research hypotheses for the management of variety-induced complexity. Structured into hypotheses on enabling factors and activity areas, the section thus extends existing research on complexity management.

6.1.1 Hypotheses on enabling factors of complexity management

The analysis of the empirical data reveals that companies place emphasis on three prerequisites in the implementation of their complexity management. These enabling factors form the basis for the activity areas. If companies want to implement their initiative successfully, they need to put effort into both enabling factors and activity areas. The case studies companies presented here have, without exception, found successful ways to consider both in their holistic complexity management initiatives.

Priority & commitment

At the case study companies, the complexity management initiative has a very high priority. In fact, at some companies the priority is higher than for other prominent optimization initiatives such as lean management. Priority is not created by a one-time statement that the initiative is important, but by the constant involvement of the top management in the initiatives.

Top executives show their commitment to the initiatives by anchoring it explicitly in the corporate strategy, by getting personally engaged in the initiative's design and by personally communicating the impact of optimized complexity. They commit resources to encourage employees to get involved in the initiative. High priority of the initiative facilitates the implementation of complexity management. Hypothesis 1 summarizes the role of priority and commitment:

Hypothesis 1

A high priority of complexity management, made evident by top management actions and interactions with complexity managers, has a positive effect on the implementation of complexity management.

Organizational anchoring

The organizational structure behind complexity management is not entirely uniform in the case study companies. However, some organizational characteristics are common. Firstly, complexity management is anchored in a department which is neutral due to its low level of interests in the issues around optimizing complexity. The location does therefore not bias the initiative but is very objective. Secondly, an organizational network is formed around the complexity management unit, which acts as a coordinating center. Due to the fact that the optimization spans across almost all departments, affecting the portfolio, product architecture and core value-adding processes, this networking is necessary to conduct specific inter-departmental complexity management activities. These insights lead to the formulation of hypotheses 2a and 2b:

Hypothesis 2a

The organizational anchoring of complexity management in a neutral department has a positive effect on the implementation of complexity management.

Hypothesis 2b

Forming an organizational network around the complexity management unit has a positive effect on the implementation of complexity management.

Cross-functionality

Complexity management requires the expertise of multiple departments and is not restricted to the knowledge brought together in the complexity management unit. Indeed, the units at the case study companies think of themselves as coordinating and consulting functions which gather, aggregate and communicate information distributed throughout the company functions. A high level of cross-functionality is therefore considered a necessity for complexity management.

The complexity initiative is executed with a broad scope covering the product portfolio, product architectures and processes along the value-chain at the observed companies. Consequently, they integrate experts from multiple functional departments in the design of initiative and the ensuing activities. Single points of contact in the departments are typically defined. Additionally, the organizational units for complexity management are typically staffed with experienced experts from the key departments in the company. The following hypothesis is based on these empirical findings:

> Hypothesis 3
>
> The degree of cross-functionality has an effect on the implementation of complexity management. The more emphasis a company places on cross-functional involvement of departments, the more successful the implementation of complexity management.

6.1.2 Hypotheses on activity areas of complexity management

The case study data reveal four main activity areas which form the central pillars of complexity management. Companies which have successfully implemented complexity management engage in all four activity areas.

Transparency

To create urgency and awareness in the organization, the impact of variety-induced complexity needs to be made clear at the beginning of the initiative. In fact, all the case study companies started with an evaluation of complexity which included the analysis of available complexity-related indicators (e.g. article codes, product options, SKUs). This analysis was enhanced by a comparison with the associated benefits (e.g. sales volume, net sales). In the progress of the initiative, transparency is permanently created by monitoring, reporting and target setting of complexity management actions. Multiple evaluation approaches (monetary and non-monetary) are applied by the case study companies. Transparency is therefore not only crucial at the beginning of the initiative but a permanent activity area. Companies argue that increased transparency on complexity has a positive effect on the success of new products and product variants projects. The hypothesis which emerged from the analysis is summarized as follows:

Hypothesis 4

The creation of transparency on variety-induced complexity in the company by implementing non-monetary and monetary evaluation approaches increases effectiveness and efficiency of projects on new products and product variants.

Guidance

Complexity management requires guidance for its implementation across the organization. Therefore, the implementation of cross-sectional initiatives needs to involve guiding elements otherwise it will not be successful. As discovered in the cross-case analysis, companies emphasize the role of the complexity management unit as a provider of guidance. This means the development and distribution of specific methods, tools and guidelines to improve projects' success. This support for operational optimization is accompanied by an effort to communicate the approach and results of the complexity management initiative through all available "channels". Both aspects are covered in the following two hypotheses:

Hypothesis 5a

The implementation of guiding complexity management elements such as methods, tools and guidelines for operational optimization increases effectiveness and efficiency in projects on new products and product variants.

Hypothesis 5b

Broad communication of the complexity management initiative's approach and results increases effectiveness and efficiency of projects on new products and product variants.

Synergies

Leveraging synergies is considered to be the superior source of improvements by complexity management. Synergies are the result of similarities which have not yet been identified and optimized. They provide the opportunity for improved resource utilization in projects for new products and product variants. As identified in the case study research, companies are not only focusing on synergies in processes (e.g.

to achieve economies of scale) but are extending the active search for synergies to product portfolios (across business segments or locations) and product architecture (e.g. standardization and modularization). Although some of the case study companies began with a certain focus on one area, they quickly realized that complexity management is most powerful by leveraging synergies in all three dimensions. This observation is summarized in the following hypothesis:

> Hypothesis 6
>
> The emphasis on synergy leveraging in product portfolios, product architectures and processes in complexity management increases effectiveness and efficiency of projects on new products and product variants.

Proactivity

An important element emerging from the case study investigations is the proactive consideration of complexity in earliest decision phases. At the case study companies, several approaches for integration in the business case, as the key decision tool, are observed. They range from monetary to non-monetary approaches and combinations of both. It is considered a differentiating activity area in complexity management with a major impact on decision-making. The integration of a complexity perspective in decision-making is expected to improve the success of projects for new products and product variants. Therefore, the following hypothesis emerges:

> Hypothesis 7
>
> The degree to which complexity management is conducted proactively has an effect on the effectiveness and efficiency of projects on new products and product variants. The more intensely the complexity perspective is integrated in early decision phases, the more effective and efficient are projects on new products and product variants.

6.1.3 Summary of hypotheses

Table 30 provides an overview of the hypotheses derived from this empirically-based research.

Table 30: Overview of hypotheses

Concern	No.	Hypothesis
Priority & commitment	1	A high priority of complexity management, made evident by top management actions and interactions with complexity managers, has a positive effect on the implementation of complexity management.
Organizational anchoring	2a	The organizational anchoring of complexity management in a neutral department has a positive effect on the implementation of complexity management.
	2b	Forming an organizational network around the complexity management unit has a positive effect on the implementation of complexity management.
Cross-functionality	3	The degree of cross-functionality has an effect on the implementation of complexity management. The more emphasis a company places on cross-functional involvement of departments, the more successful the implementation of complexity management.
Transparency	4	The creation of transparency on variety-induced complexity in the company by implementing non-monetary and monetary evaluation approaches increases effectiveness and efficiency of projects on new products and product variants.
Guidance	5a	The implementation of guiding complexity management elements such as methods, tools and guidelines for operational optimization increases effectiveness and efficiency in projects on new products and product variants.
	5b	Broad communication of the complexity management initiative's approach and results increases effectiveness and efficiency of projects on new products and product variants.
Synergies	6	The emphasis on synergy leveraging in product portfolios, product architectures and processes in complexity management increases effectiveness and efficiency of projects on new products and product variants.
Proactivity	7	The degree to which complexity management is conducted proactively has an effect on the effectiveness and efficiency of projects on new products and product variants. The more intensely the complexity perspective is integrated in early decision phases, the more effective and efficient are projects on new products and product variants.

6.2 Managerial implications and practical applications

Based on the cross-case analysis and the discussion on the conceptual model, this section presents the managerial implications. As learning from other managers' experiences is embraced by managers, the explanations include selected citations from the on-site workshops conducted with a total of eleven companies. In addition to the overall recommendations for complexity management, specific recommendations contributing to the focus defined for this research are made to increase transparency on variety-induced complexity and to integrate a complexity perspective in product decision-making. These recommendations are enhanced by two single-case solutions which are based upon action research-oriented investigations. These practical applications are presented in order to increase the adaptability of the research results for managers in manufacturing companies.

6.2.1 Overall recommendations for complexity management

Complexity management is most successfully deployed as a holistic initiative. It therefore involves more elements and relationships than those covered in the specific recommendations in sections 6.2.2 and 6.2.4. For the overall complexity management initiative, three main recommendations for managers have been derived from this research.

Ensure prerequisites. As illustrated in the conceptual model for managing variety-induce complexity, the activity areas have need of certain prerequisites: High priority and top management commitment, organizational anchoring and a high degree of cross-functional involvement. These pre-requisites need to be elaborated and clarified before deploying specific actions covered in the four activity areas. It is the first task after the decision to launch such an initiative, or as the Head of Business Development of a mechanical engineering company commented: “The top management push is needed”.

The prerequisites are not solely provided and controlled by the designated complexity managers. They have to be decided and propagated by the top management. Top managers need to be aware that a high priority means the investment of their own resources, but, as discovered in the case studies, this is critical for success. The VP for Technology of an engineering company added: “Commitment of top management to change and acceptance of all employees is necessary”.

Due to their interdependence, the organizational aspects, which include anchoring in the “living” organization and cross-functional engagement, should be implemented after obtaining this commitment. The Complexity Manager of an automobile company added: “The details of the organizational structure are secondary, more important are cross-functionality and the network”.

Broaden the scope. It is well-known to practitioners that strategic initiatives such as complexity management are most successful when implemented as a holistic system. However, most complexity management initiatives are run with a narrow focus on specific issues such as the suboptimal product architectures in a certain product line or late differentiation in selected manufacturing processes. Complexity management bound by these foci does not lead to the overall positive effects expected. It can be said that literature has contributed little breaking free from these limitations because it typically discusses the issues of complexity management very separately.

The term "holistic" becomes more tangible when looking at the case studies presented. Four out of five companies have set up a complexity management with a broad scope and the fifth company is currently working on the development of a holistic system. Initiatives become holistic not by having the most accurate project plans and the most sophisticated presentations but as a result of the content and issues covered. The case study companies take into account the characteristics of complexity and all effects on their company or as the VP for Finance of a consumer goods company mentioned: "Complexity is a two-sided challenge: External opportunity and internal costs. In most companies the cost-focus dominates the opportunity-perspective".

Complexity management as a holistic initiative is not only characterized by cross-functional involvement but by a cross-sectorial scope. The scope, as executed by the case study companies, consists of optimizations of the product portfolio, of product architecture and of processes along the value-chain. In fact, the case study companies report very positive effects of this broad scope summarized in one initiative, e.g. the standardization of components in product architecture impacts the purchasing process and vice versa. Some participants in this research even suggest strengthening the neglected scope towards the value-chain. The Product Platforms Manager of a consumer goods company pointed out: "Complexity needs to be considered across the entire value-chain, not solely at one isolated product module or component".

Integrate cross-functional ideas. Complexity management is not built on a "greenfield" but is fitted into a running organization with a lot of experience and solutions already developed throughout the departments. The role of complexity management is to identify existing ideas and nurture new ideas on how to optimize complexity. This is a difficult task because ideas are spread across the entire company and are often not documented. Communication of the approach and the opportunity to integrate ones own ideas regardless of hierarchy level and department are important elements to encourage colleagues. As the VP for Finance and Supply Chain of a consumer goods company explains: “The interdisciplinary, cross-department approach is the real deal for complexity management”.

The importance of cross-functionality is also stressed by the case study companies. Their experiences make clear that successful implementation is dependent on the involvement of colleagues across nearly all departments. They are a source of inspiration for the design of the initiative and of proven methods and tools for optimization. At the case study companies, the complexity management initiative is also directly linked to lean management approaches. At one case study company, for example, the exchange between initiatives led to the integration of simple, yet practical tools at the operator level (e.g. molding tools and simple visualizations at the workplace) to handle a huge variety in manufacturing. In this context, a Complexity Manager from this case study company commented that: “Successful complexity management depends on the people participating in the network”.

6.2.2 Specific recommendations for increased transparency on variety-induced complexity

Conduct “lighthouse projects”. During the implementation of a strategic initiative, the organization is usually rather skeptical due to the fact that changes in the working procedures require individual efforts. Because of this, the engagement of the organization in such a complexity management initiative at the beginning is not mandatory. Therefore, the initiative needs to be persuasive from the start.

As results of smaller projects are quickly and easily recognizable, sub-projects performed at the beginning of the complexity management process are probably the most important aspect in convincing the organization. These projects have to reflect the entire scope (portfolio, product and processes) of the complexity management initiative but in a smaller package. They should deliver results in a short timeframe which are meaningful enough to create awareness and increase engagement across the organization.

The case study companies show that the illustration of the effects of complexity management demonstrates the feasibility of the complexity management design. By that, a role model is built at the companies for a complete organizational implementation of the initiative. For example, one case study company implemented its complexity management in one of 24 product lines at the beginning. They communicated the positive results (e.g. unique-parts reduction, more economies of scale in processes, and more synergies with other products in the portfolio) to the organization which led to the integration of complexity management in all upcoming product lines and "facelifts" across all three brands. The SVP for Technology of an electronic company expressed the following: "You need to go forward, although you do not always know where North is".

Implement evaluation approaches beyond cost calculations. Evaluations are an integral part of complexity management. They do not only show the impact of complexity management actions, but are crucial for creating transparency on the overall situation and are a welcome tool for operational optimization.

In most companies' mindsets, the cost perspective is the dominant one. In any case, they want to calculate the exact costs for a component which requires the complexity costing approach to allocate indirect costs correctly. However, this remains extremely difficult because costing systems are typically not capable. As the SVP of a consumer goods company mentioned: "I have worked in industry for 40 years and have never seen a company which was able to fully implement activity-based costing". Consequently, companies typically try to get by with rules of thumb after an initial investigation of costs. At one case study company, for example, they estimate that one additional SKU costs 6000 Euros as an initial investment and a further 1000 Euros per year. However, such numbers are to be handled with care as the VP for Technology of an electronics company added in a discussion: "There is a danger of vague and rough cost information for complexity costs calculations".

The case study companies have therefore discarded the costing approach or enhanced their costing approach with non-monetary evaluations. For this purpose, complexity indicators have been defined and implemented in existing KPI-systems. These indicators are typically easier to compile and more reliable when they are defined precisely. As the VP for Finance and Supply Chain of a consumer goods company observed: "Complexity management works without complicated cost data models". Moreover, it is more persuasive to implement a few meaningful indicators than a large set not understood by the departments. As the Head of Business Development of a mechanical engineering company advised: "Better use a limited number of relevant indicators; in some cases aggregated indicators are the right way when they are kept simple".

6.2.3 Practical application: Complexity Index for production plants[57]

The measurement with non-monetary indicators presents an alternative to or an enhancement of costing approaches which are in some cases not deployed very successfully in manufacturing companies. The “Complexity Index” (CI) elaborated is a metric consisting of multiple non-monetary indicators and is designed for application at the production plant level. In fact, this section provides a complexity management tool for product plant representatives and production network managers for the evaluation of variety-induced complexity of production plants. The manufacturing part of the value-chain is chosen for the explorative development of such an comprehensive metric because manufacturing usually has to handle the major portion of complexity (e.g. Rathnow 1993).

The development of the CI was framed by operations management literature differentiating between external and internal complexity (e.g. Pil & Holweg 2004). As presented in Chapter 2.2, external complexity is a result of actors in the company’s environment who stand in a direct relationship with the manufacturing plant. Markets, corresponding customers’ demand and suppliers play a key role for most manufacturers as they influence internal assets and plant processes. Internal complexity is experienced inside the plant when “translating” customer requirements into physical products. This requires a certain product portfolio, clearly defined product creation processes and people on production plant level. Based on the differentiation between external and internal complexity and the corresponding identification of their main dimensions, the CI consists of five dimensions (Figure 61).

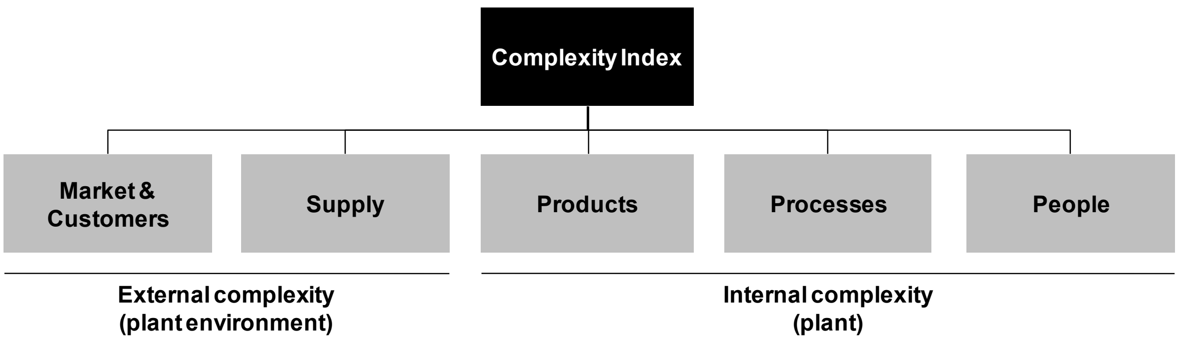

Figure 61: Dimensions of the Complexity Index

[57] Please refer to Götzfried (2012), which includes not only the development of the Complexity Index but also the comprehensive investigation of the link between complexity and operational performance. The publication was presented at the 4th Joint World Conference on Production & Operations Management / 19th International Annual EurOMA Conference in 2012.

The differentiation between external and internal complexity as well as the breakdown into five dimensions, derived from literature, have been verified in discussions (workshops and interviews) with experienced network and plant managers of a global manufacturing company.

To provide operational feasibility of the CI, each dimension has been detailed by defining its underlying complexity indicators. In the first stage, 40 single complexity indicators were identified from literature as well as in open-ended discussions with company representatives. In the next stage, these 40 indicators were discussed in a second round with the company representatives to identify the most relevant ones. The result was the definition of the index along the five dimensions differentiating between external and internal complexity which are operationalized with 21 operational indicators. Table 31 presents the indicators used to calculate the CI including definitions and units.

Table 31: Indicators in the Complexity Index

Scope	Category	Indicator	Definition	Unit
External	Market & Customers	Customer base globalization	The number of customer regions served by the plant.	No.
		Customer count	The number of customers served by the plant.	No.
		Type of customer	The number of external customers as a percentage of all customers.	%
		Customer orders	The number of customer orders at the plant.	No.
		Sales forecast inaccuracy	The inverse score of the percentage of actual orders received compared to the annual sales forecast.	%
		Delivery frequency	The number of customers delivered not frequently as a percentage of all customers.	%
	Supply	Supplier count	The number of active suppliers delivering to the plant.	No.
		Supplier unreliability	The inverse score of perfect order fulfillment (percentage of deliveries shipped in time, in the right quantity and right quality from the supplier).	%
		Supply frequency	The number of suppliers that deliver to your plant only infrequently as a percentage of all suppliers.	%

Table 31 (cont.): Indicators in the Complexity Index

Scope	Category	Indicator	Definition	Unit
Internal	Products	Bulk product mix	The number of different bulk products produced at the plant.	No.
		Product type	The number of different final products produced at the plant.	No.
		SKU count	The number of SKUs at the plant.	No.
		Final product mix	The number of different final products produced at the plant.	No.
		Product launches	The number of new product introductions.	No.
		SKU launches	The number of newly launched SKUs at the plant.	No.
	Processes	Process count	The number of process steps performed at the plant.	No.
		Lot/batch count	The number of lots or batches produced at the plant.	No.
		Non-dedicated equipment	The inverse score of the percentage of dedicated production lines/production equipment.	%
		Changeover count	The (average) number of changeovers performed per month.	No.
		Manufacturing planning instability	The percentage of production orders released within your freezing period as percentage of all production orders.	%
	People	Employee count	The number of employees at the plant.	No.

The CI is calculated with an equal weighting of the indicators. The decision for this equal weighting was taken in close discussion with the company experts and participating plants with the objective of keeping the calculation simple, understandable and therefore applicable in practice. As the indicators in the index have different units, each of the indicators is normalized on 0 to 100 percent range. The CI is then calculated as the average of the indicators in percent ranging from 0 to 100. Accordingly, the external and internal CI scores are calculated by using indicators attributed to either external or internal complexity. Figure 62 illustrates the distribution of the CI across 158 production plants from the pharmaceutical industry as an example.[58] Each of the bars in this figure represents one production plant of the dataset.

[58] The empirical, operational data of 158 production plants for this quantitative analysis was gathered within the "Operational Excellence in the Pharmaceutical Industry" benchmarking conducted at the Institute of Technology Management at the University of St. Gallen.

Figure 62: Complexity Index scores for 158 pharmaceutical production plants

As a supplement to the CI definition, a cluster analysis has been conducted to provide orientation for the analysis of a production network with regard to variety-induced complexity. This is, once again, based on differentiation between external and internal complexity. For both scopes (external and internal complexity) the respective CIs have been calculated for the 158 production plants. The internal CI consists of indicators of the dimensions products, processes and people. The external CI is calculated with the indicators of the dimensions market/customers and supply. As a result, two eye-catching clusters have been identified:

1. Complexity Masters: Production plants which are able to transfer a high level of external complexity into a low level of internal complexity.

2. Complexity Creators: Production plants which are not able to make this transfer. In fact, they create internal complexity not necessary to meet external complexity.

Figure 63 shows the scatterplot for the 158 production plants. The network analysis from a complexity standpoint is done by locating the plants in such a scatterplot. Then the detailed investigation of complexity indicators, operational performance and practices applied throughout the production plants is conducted by the network managers. In the example illustrated, the analysis conducted showed that the plants in the Complexity Masters cluster achieve higher operational performance (e.g. shorter lead times, lower quality and maintenance costs and lower customer complaint rates) compared to the sites in the Complexity Creators cluster and outside both clusters. Moreover, detailed analysis showed that there are practices in place at the plants in the Complexity Masters cluster which should be transferred to the plants in the Complexity Creators cluster.

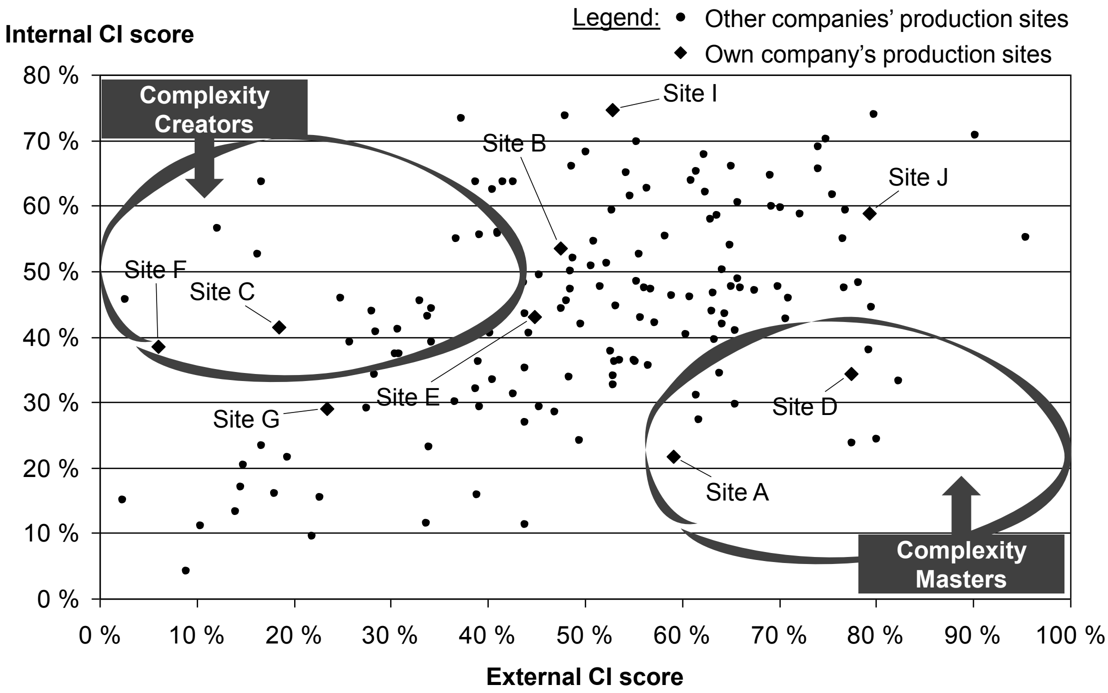

Figure 63: Example for a network analysis using the Complexity Index

6.2.4 Specific recommendations for integrating a complexity perspective in decision-making

Move to a proactive approach. Complexity management in companies consists of a number of approaches such as product platform strategies, product standardization and mass customization. These approaches are, to a large extent, reactive. This means they target complexity already existing within the company. The investigations of the case study companies show that these reactive approaches are quite successful in reducing complexity. However, they are not suited to targeting complexity at its origin. The CEO of a technology company summarized: "We have moved from a variants reduction in the existing portfolio, through process and product optimizations, to the avoidance of new and unnecessary complexity".

The case study companies therefore decided to move from a reactive approach to a proactive approach. They recognized that their approaches will stay reactive as long as complexity is not managed at its origin before entering the corporate processes. Due to the fact that there is a lack of proactive approaches for adaptation, they put emphasis on the development of their own approaches. As pointed out these range from monetary evaluation, non-monetary indicators and combinations of both in business cases to guidelines for developers. They are therefore very company-individual, but all companies target complexity in earliest phases. The Product Manager of a chemical company expressed: "Each company needs to develop its own complexity criteria to be considered in early phases".

Align decision-making processes and reasoning. Proactive complexity management is put into practice by the alignment of decision-making processes and reasoning. Traditionally, decision-making in manufacturing companies covers complexity-related aspects implicitly, i.e. that effects of variety are discussed in sales volume, project costs and other criteria. However, complexity and its impact are typically not explicitly considered in decision-making for product and product variants. Decision-making processes do not differentiate between product requests which induce high complexity and product requests which induce little complexity. Requests are run through the same standard process. Moreover, criteria do not contain explicit complexity criteria. The SVP of a mechanical engineering company added: "To make decisions, e.g. based on a business case, the complexity effects need to be measurable".

The case study companies show that this proactive approach required an adjustment of their decision-making. They have aligned reasoning to contribute to complexity issues. In fact, newly added criteria have the same or even higher significance in the decision than traditional criteria which were observed to not always be reliable. Similar to the evaluation approaches, the companies integrated a range from non-monetary complexity criteria to complexity cost estimations. A Supply Chain Manager of a chemical company mentioned: "We are currently implementing a new concept called active decision-making on product variants which is supported by a comprehensive complexity evaluation".

6.2.5 Practical application: Complexity Assessment in business case evaluations

Complexity is induced by managerial decisions. The consideration of complexity in these decisions is becoming increasingly important to control complexity in early phases. The following assessment has been created in cooperation with a global manufacturing company to improve decision-making for products. The company had the feeling that "product change requests are approved too easily leading to high effort in internal processes".

Similar to other manufacturing companies, decision-making at the company is dominated by a standard business case template (Table 32) and a standard product creation process. These two crucial elements were subject to optimization.

Table 32: Traditional business case criteria at the manufacturing company

No.	Criterion	Excerpt of specifications / description	Appraisal
1	Purpose of product change	Actual milestone in the product creation process determines the characteristics of the business case	Alright, but not decisive
2	Main objective of new product or product variant	e.g. increase functional customer value, increase economical customer value, strategic, higher selling price, cost reduction, increased market share	Alright, but not decisive
3	Strategic fit of the new product	e.g. consistent with area business objectives, consistent with product strategy and road map	Alright, but not decisive
4	Marketing considerations		
	Range of product sales	# of units expected to sell in each of the regions [Euro]	Biased input
	Sales life until year	Final year for each region	Biased input
	Target cost per unit	Estimations for costs per unit over the next four years [Euro]	Biased input
5	Economic considerations		
	Cost reduction per unit	Reduction of costs before and after market introduction [Euro]	Unreliable
	Additional contribution	▪ Sales volume increase [%] ▪ Price increase or decrease	Biased input
	Other benefits and losses	In comparison with another product [Euro]	Alright
	Total bottom line impact	Total cost impact [Euro]	Unreliable
	Project costs	Breakdown across the product life-cycle [Euro]	Unreliable
	Sunk costs	Sunk costs already spent [Euro]	Alright, but not decisive
	Other costs caused	▪ Investment expenditures ▪ Write off needs for investment and inventory	Alright
	Project schedule	Original plan vs. actual plan	Alright, but not decisive
6	Risk consideration	Estimation of market risk, technical risk and project risk [%]	Not meaningful
7	Product portfolio considerations	Elimination of products after introduction of a new/upgraded product	Alright, but not decisive

Table 32 (cont.): Traditional business case criteria at the manufacturing company

No.	Criterion	Excerpt of specifications / description	Appraisal
8	Additional criteria	▪ Time to market introduction shorter than 3 years ▪ Market life longer than five years ▪ Patents generated	Alright
9	Economic summary	▪ Payback period [years] ▪ Sunk costs [Euro] ▪ Net present value [Euro]	Decisive, but unreliable

The illustrated business case criteria show that this global company has set up a comprehensive evaluation tool as a basis for its decisions. On first sight, the business case appears to be balanced and a solid basis for decisions on products. However, certain shortcomings have been identified together with the project team of the company. In numerous interviews and workshops with representatives from product development, manufacturing and supply chain, product management, controlling and marketing, the criteria used at the company have been appraised.

The appraisal (added column to Table 32) reveals that there is only one section in the business case evaluation which is decisive: The economic summary, which includes the payback period, the sunk costs and the NPV. Most other criteria are either not decisive in decision-makers' meetings, based on biased inputs, e.g. from regional sales representatives, or not meaningful due to the lack of definition. And, even more alarming is that the decisive section, economic summary, is unreliable due to unreliable figures making up the input for the calculations (e.g. sales volume and project costs).

An optimization was necessary to eliminate these shortcomings. In close consultation with the company representatives, the complexity perspective was identified as the major aspect missing in the business case. For instance, due to the lack of complexity cost considered in the project cost breakdown, calculations for the NPV and other financial figures were, in most cases, inaccurate.

A so-called complexity assessment (CA) was carried out with the experts from product management, supply chain and controlling of the company. As the company intended to cover variety-induced complexity holistically, the CA involves a comprehensive scope (product, portfolio and processes). It ultimately consists of three levels:

- Level 1 focuses on the impact of a product change on the product/component itself. To assess the complexity resulting for the product, the quantity of new SKUs created for the initially affected modules is estimated.
- Level 2 focuses on the impact of a product change on the system and the portfolio. To assess the complexity resulting for the system, the quantity of new SKUs created for other modules in the portfolio is estimated.
- Level 3 focuses on the impact of a product change on processes. To assess the complexity resulting for the processes a qualitative, four-point scale (minor – moderate – intensive - massive) for each affected process along the value-chain is elaborated.

The CA has been explicitly integrated in the business case template. It extends the existing business case and contributes to an increase in reliability of existing criteria. The improvement of existing criteria takes place by a more detailed investigation of the costs throughout the product creation process and the product life-cycle. In fact, the CA requires the gathering of very detailed cost data for each key process (Figure 64).

Procurement

minor - guideline	minor	moderate	intensive	massive	massive - guideline
▪ Existing and qualified supplier can be used ▪ No new negotiations with suppliers necessary ▪ Material and/or technology well-known and mastered	◉	○	○	○	▪ Unknown suppliers necessary ▪ Qualification/certification of suppliers necessary ▪ Entirely new negotiations with suppliers necessary (e.g. too low volume in future) ▪ Totally new material and/or technology necessary

Main reasons for the decision (by the team)	Show stopper (yes/no)

Procurement costs

Product creation/ life-cycle phase	1	2	3	4	5 (after market introduction)	Total
Costs split per phase						

Supply / Logistics

minor - guideline	minor	moderate	intensive	massive	massive - guideline
▪ Minor increase in stock of products/semi-finished products/components ▪ Only storage of standard components necessary ▪ No substantial increase of space for storage ▪ No substantial impact on value-chain set-up ▪ No major impact on transportation costs ▪ Only marginal increase in lead times	◉	○	○	○	▪ Necessary to increase stock of products/semi-finished products/components substantially ▪ Storage of customer-specific components necessary (moving the order penetration point upstream in the value-chain) ▪ Substantial increase of space for storage ▪ Increase in transportation costs (e.g. by decentralized distribution of parts) ▪ Substantial increase in lead times compared to standard lead time

Main reasons for the decision (by the team)	Show stopper (yes/no)

Supply / Logistics costs ['000 EUR]

Product creation/ life-cycle phase	1	2	3	4	5 (after market introduction)	Total
Costs split per phase						

Figure 64: Excerpt from the Level 3 Complexity Assessment

This newly added CA is accompanied by the following instructions to avoid bias in its routine completion:

- The assessment has to be carried out in a cross-functional team consisting of representatives of the core departments (assessment team).
- The objective of this cross-functional approach is to integrate all opinions and to come to a common decision regarding complexity induced in the affected processes when executing the project.
- Level 3 is assessed on a four-point scale minor – moderate – intensive – massive. "Minor" and "massive" scores are each specified by a guideline.
- For each process, comments regarding the assessment can be added.
- If the assessment team decides for a "massive" complexity impact for a single

process step, it results into a “show stopper”. A show stopper calls for further investigation of the projects’ effects on the process and then a re-assessment of the Level 3 CA.

- For each process the process costs along the product lifecycle have to be added. These costs are newly added to the traditional criteria “Project costs”. This leads to an improvement in the project cost evaluations in the business case.
- The summary of the assessment (a few sentences) represents a commonly agreed decision of the cross-functional assessment team and is considered a main criterion in the business case.

Business case optimization represents a critical part of improvement in decision-making. However, the second crucial aspect, the underlying processes, was also considered by the project team. The existing process was not differentiating between different kinds of product requests. They were all going through the same process (complete business assessment) which led to a major effort for the organization. In fact, some of the biased inputs are a result of “overloading” the organization with business case evaluations and the corresponding pressure to complete these very fast. As a consequence, an improved process design for earliest decision-making was implemented. It consists of a “wedge” to cluster requests for product changes before entering one of three evaluation processes (Figure 65).

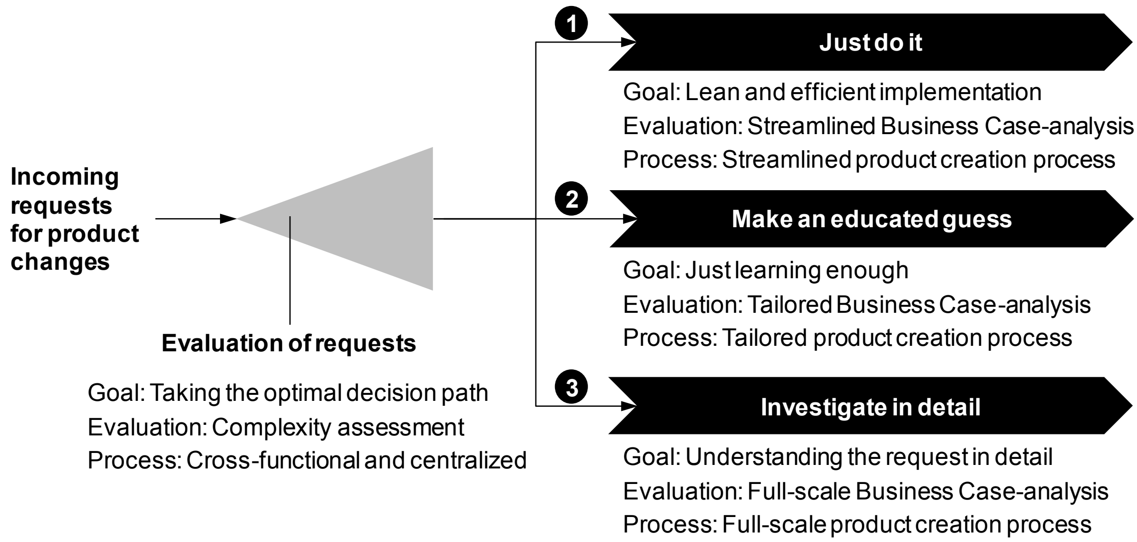

Figure 65: Complexity-adjusted decision-making process

The simultaneous optimization of the business case and the decision-making process as seen from a complexity perspective, led to a significant improvement of the company’s “front-end”. The representatives’ experience is that “today, the company makes better decisions which leads to a closer-to-optimal resource allocation”.

6.2.6 Summary of managerial implications

In total, seven recommendations for managers can be made based on the empirical investigation (Figure 66).

	Recommendation	Actions
Overall complexity management	Ensure prerequisites	▪ Clarify priority and top management commitment, organizational anchoring and cross-functionality beforehand
	Broaden the scope	▪ Operationalize the term “holistic” by targeting complexity on three levels: Product portfolio, product architectures and processes
	Integrate cross-functional ideas	▪ Push and communicate the integration of individual and departmental ideas to increase engagement
Transparency on variety-induced complexity	Conduct “lighthouse projects”	▪ Initiate projects with a smaller range to achieve quick results to be communicated to the organization to remove skepticism
	Implement evaluation approaches beyond cost calculations	▪ Elaborate the opportunities for non-monetary evaluation ▪ Define and implement complexity indicators
Integrating a complexity perspective in decision-making	Move to a proactive approach	▪ Determine the point of complexity origin where the proactive approach is later anchored
	Align decision-making processes and reasoning	▪ Define and implement complexity criteria ▪ Align decision-making processes from a complexity perspective

Figure 66: Overview of recommendations and actions

In addition, the two practical applications illustrated provide orientation for managers concerned with variety-induced complexity. Both are a result of direct research-based consulting projects with manufacturing companies and can therefore serve as basis for adaptation of the application presented or the development of custom-made approaches. They should, in fact, be considered as thought-provoking impulses.

7. Conclusion

Based on the previous analyses and subsequent discussions, this chapter summarizes the contributions to theory and practice. In addition, it states the limitations of the research results, leading on to directions for future research.

7.1 Contributions to management theory

The research presented contributes to the theory and literature of complexity management. As this pertains to several disciplines such as operations management, supply chain management and product portfolio optimization, the theoretical results provided span all of these disciplines. Thus, the research joins researchers working cross-discipline to provide solutions for the management of variety-induced complexity.

Although literature discusses complexity optimization approaches such as product platform strategies, product modularization and mass customization extensively, no comprehensive theory on managing complexity has yet been presented. Moreover, some aspects of managing complexity remain blank spots. There is a salient lack of research on the evaluation of complexity and the consideration of complexity in early decision-making. Therefore, this research enlarges previous research by examining the elements of complexity management initiatives as well as the role of evaluation concepts and integration approaches in early decision-making.

Due to the cross-discipline literature review, the first stage of the research contributes to the integration of the literature streams. The consolidation of contributions made by existing literature builds the theoretical basis of a theory on holistic complexity management.

The reference framework based on literature and refined by new empirical insights led to the development of a conceptual model. Due to the careful selection of the case studies and in-depth observations of the complexity management initiatives, the conceptual model contains a set of elements which are structured to illustrate their roles and relationships. Complexity management is triggered by certain external and internal drivers. These drivers induce a complexity management which is structured upon two building blocks: Enabling factors, which constitute the prerequisites, and activity areas, which cover company actions to target complexity issues. A comprehensive complexity management goes beyond the implementation of isolated approaches to build synergies (such as product platform concepts). In fact, it consists of four major activity areas which cover a broad scope of complexity in the product portfolio, product architectures complexity and value-chain processes. These areas are, in turn, closely dependent on the establishment of a high priority and management priority, a well-planned organizational anchoring and a high level of cross-functional involvement. The comprehensive implementation of the building blocks' elements leads to a high effectiveness and efficiency in projects for new product and product variants.

To describe the elements' relationships in the conceptual model, research hypotheses have been presented. They discuss the three enabling factors and the four activity areas. Firstly, hypotheses to formulate the role of the enabling factors point to the importance of these for the implementation of complexity management. Secondly, to emphasize the impact of the activity areas on the effectiveness and efficiency of projects, hypotheses on these relationships are raised.

In summary, this research provides a comprehensive perspective on managing variety-induced complexity. It pleads for exchanging the paradigm of isolated optimization concepts in literature for a holistic complexity management. Moreover, it illustrates the powerful role of enabling factors and, on the activity side, the importance of transparency creation and proactive complexity integration in decision-making for products.

7.2 Recommendations for management practice

This research is derived from managerial problems observed at manufacturing companies and is therefore meant for the purpose of extracting applicable research results. The conceptual model can serve as a management model revealing the importance of enabling factors and their interdependence with specific activity areas. To implement complexity management as more than another short-term optimization initiative, a holistic system needs to be established as a basis.

The recommendations for managers are clustered into three sets which are explained to facilitate adaptation by manufacturing companies. The first set of recommendations is given to provide orientation for the mandatory preconditions of complexity management:

- The organizational basics such as anchoring in the existing corporate strategy, engagement of top management and an involvement of knowledge of different departments are sometimes regarded as common sense in strategic initiatives. However, as observed in multiple discussions with eleven companies, these are, in fact, determining factors for successful complexity management. These basics cannot be furnished by complexity managers, but require the support of top managers across departments.

- The organizations observed run their complexity management with a broad, three-dimensional scope covering: Product portfolio, product architectures and value-chain processes. Although some originally started by focusing on a particular area, they realized over time that complexity can only be holistically optimized by means of a broad scope.

- Companies need to engage the entire organization to get the effort required to cover this broad scope. However, achieving this engagement is not just another exhausting task after numerous other optimization efforts, it is an opportunity to improve the content of complexity management. There is deep knowledge distributed throughout the various functional areas which can be used to optimize complexity. Positive communication indicating that ideas, experiences, methods and tools by the departments are being integrated in the initiative supports its reach and implementation.

The second set of recommendations is formulated to improve the creation of transparency on variety-induced complexity in view of the fact that this is a crucial element throughout all stages of the initiative:

- To reveal the effects of a broad-scope complexity management, certain projects should be undertaken at the beginning of the initiative. These “lighthouse projects” should reflect the overall complexity management approach. Positive and negative results can act as a role model for the organization which facilitates the roll-out of complexity management across the entire company. They confirm the feasibility of the approach which is then implemented across product lines and business segments.

- The most prominent evaluation approach in complexity management is the calculation of complexity cost. However, companies often experience difficulties in its implementation and daily use. This study therefore suggests considering the implementation of non-monetary approaches. In fact, it is a good alternative to costing approaches because they are, if set up correctly, more reliable and involve less effort. Case study analyses reveal that the implementation of complexity-related indicators enriches other monitoring techniques (existing performance-/ KPI-systems) and enables tracking of complexity management actions.

Finally, the third set of recommendations indicates that companies need to change their paradigm from targeting complexity reactive to a proactive control:

- Companies run various complexity management approaches which target complexity after it has occurred in products and processes. Concepts such as product modularization and late differentiation in processes are, to a large extent, reactive. The study shows that the most effective complexity management initiatives have at some point moved towards a proactive approach. In these initiatives, the point of complexity origin and the opportunity to control complexity at this point have been examined. The objective for managers should be not to let unnecessary complexity enter the internal product creation processes.

- Reasoning and processes of decision-making in early phases have been identified as an appropriate "control point". The study shows that complexity-related criteria (non-monetary criteria and complexity cost estimations) are capable of improving decision-making for products and product variants. By this, unnecessary complexity is avoided and "positive" complexity is permitted to enter the company's processes.

These recommendations are accompanied by applications each developed in close cooperation with one manufacturing company. In particular, a coherent evaluation concept for production plant complexity supports the understanding of the impact of complexity at production plant level. As emphasized in the recommendations, the second practical application explains the procedure for the integration of a complexity perspective in the business case template and the adjustment of processes in early decision-making. Although not validated in a number of case studies, these applications are fostering thinking about innovative approaches in complexity management. They can serve as a solid basis for specific adaptations of the applications and development of custom management tools.

7.3 Limitations and directions for further research

Although this research provides new insights on complexity management theory, answers the original research question and provides guidance for practical applications, some issues will need further scientific and empirical investigations. Also, new issues which could not yet be treated in depth arose during the research process. Most of these issues are a result of the limitations of the research at hand. For future reference, research limitations and suggestions for research are presented together. The research results imply some limitations resulting in three main directions for future research:

1. Investigate longer term effects and environmental dynamics: Some of the effects of complexity management are not visible within the first years due to the development time for new products and product lines. The initiatives observed are quite young and long-term effects could not yet be observed by this research. Therefore, a longitudinal study of complexity management is advisable. Also, complexity is not static, i.e. it evolves over time due to changes in the environment. It would be an outstanding contribution if researchers were to investigate the interdependencies of complexity management initiatives and the dynamics of the environment.

2. Develop science-based management tools and investigate feasibility: Although two practical applications have been developed in this research, its nature is conceptual. A number of directed management tools would enhance the capability of initiatives in practice. Future research should contribute not only to the development of these tools in close cooperation with practitioners but also investigate its feasibility in the implementation of complexity management.

3. Investigate cultural differences in complexity management initiatives: Owing to the interest of manufacturing companies located in Europe and the US, the approaches investigated are characterized by these cultures. Future research should therefore draw on complexity management in other regions such as Asia, South America and Africa, which may have a different approach to complexity management issues. A comparison of these with approaches in Europe and the US might lead to interesting insights. It fact, such a study could enable a transfer of knowledge on successful complexity management elements.

In conclusion, this research is highly relevant to management practice, as shown in the long-term cooperation with manufacturing companies in this study, as well as to management theory by providing new complexity management perspectives such as the conceptual model and research hypotheses. This research can serve as a starting point for scientists in the near future working towards higher effectiveness and efficiency of manufacturing companies by implementing holistic complexity management.

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Appendix A: Survey questionnaire

SECTION A - Information about your company (division) and markets

General information about your company/division

A1. Please indicate how many employees your company has.

○ up to 500 ○ 501-2'000 ○ 2'001-5'000 ○ 5'001-20'000 ○ over 20'000

A2. Please indicate the division for which you are completing this questionnaire (if applicable).

Division name:

Number of employees:

Please complete all following questions for your company or, if applicable, for your division.

A3. Please indicate the industry in which your company (division) operates.

☐ Automotive	☐ Food & Beverages	☐ Optics & Precision Mechanics
☐ Building & Construction	☐ Furniture	☐ Pharmaceuticals
☐ Chemical	☐ Heavy Industry	☐ Semiconductors
☐ Consumer Goods	☐ Information Technology	☐ Steel & Steel Products
☐ Electronics	☐ Luxury Goods	☐ Textile
☐ Engineering Services	☐ Machinery & Equipment	☐ Telecommunication Equipment

Other, please specify:

A4. Please indicate your company's (division's) position in the value-chain. (multiple answers possible)

☐ Original Equipment Manufacturer (OEM) ☐ Tier-1 Supplier ☐ Tier-2/Tier-3 Supplier

A5. Please indicate which processes your company (division) performs in-house.

☐ Research	☐ Logistics	☐ Distribution	☐ Sales
☐ Development	☐ Manufacturing	☐ Marketing	☐ After-Sales

Other, please specify

A6. Please indicate the importance of the following competitive priorities for your company (division) to win orders.

	Not important (1)				*Extremely important (5)*
Lower selling prices	1 ○	2 ○	3 ○	4 ○	5 ○
Superior product design and quality	1 ○	2 ○	3 ○	4 ○	5 ○
Superior conformance to customer specifications	1 ○	2 ○	3 ○	4 ○	5 ○
Reliable deliveries	1 ○	2 ○	3 ○	4 ○	5 ○
Faster deliveries	1 ○	2 ○	3 ○	4 ○	5 ○
Superior customer service (after-sales and/or technical support)	1 ○	2 ○	3 ○	4 ○	5 ○
Wider product range	1 ○	2 ○	3 ○	4 ○	5 ○
Offer new products more frequently	1 ○	2 ○	3 ○	4 ○	5 ○
Offer products that are more innovative	1 ○	2 ○	3 ○	4 ○	5 ○
Greater order size flexibility	1 ○	2 ○	3 ○	4 ○	5 ○

A7. Please estimate the proportion of your company's (division's) customer orders. (percentages should add up to 100 %)

Designed/engineered to order	Manufactured to order	Assembled to order	Producted to stock	Total
%	%	%	%	100 %

A8. Please estimate the proportion of the following process types (% of volume) in your company (division). (percentages should add up to 100%)

One of a kind production	Batch production	Mass production	Total
%	%	%	100 %

A9. Please indicate to which extent these statements regarding the role of complexity apply to your company (division).

	Strongly disagree (1)				*Strongly agree (5)*
We consider the level of complexity of our product portfolio as a differentiating factor in the market.	1 ○	2 ○	3 ○	4 ○	5 ○
We consider complexity management as important in order to achieve and sustain a competitive advantage.	1 ○	2 ○	3 ○	4 ○	5 ○

Market dynamics & variety management

A10. Please characterize the business environment of your company (division).

Business type:	☐ Business-to-Customer	☐ Business-to-Business	☐ Business-to-Government
Average duration of product life cycle:	○ less than 1 year ○ 7-15 years	○ 1-3 years ○ more than 15 years	○ 3-7 years
Regions served:	○ Regional/national market	○ Continental market (e.g. Europe)	○ Global market
Maturity of main market:	○ Introduction/development ○ Maturity	○ Strong growth (> 5% per year) ○ Decline	○ Weak growth (< 5% per year)

A11. Please indicate the development/change of company's (division's) product variety over the last three years?

	decreased more than 20%	decreased 5%-20%	constant -5%/+5%	increased 5%-20%	increased more than 20%
How has the number of product variants developed in the last three years?	○	○	○	○	○
How has the number of new products developed in the last three years?	○	○	○	○	○
How has the number of active parts developed in the last three years?	○	○	○	○	○

A12. Please estimate the trigger/origin of product variants in your company (division). (percentages should add up to 100 %)

Triggered by internal push (departments/employees)	Triggered by external pull (market/customers)	**Total**
____ %	____ %	**100 %**

SECTION B - Managing complexity in your business

Complexity drivers

B1. Please indicate the main drivers of complexity on your company's (division's) value-chain processes.

	Not relevant (1)				*Extremely relevant (5)*
Globalization of customer base	1 ○	2 ○	3 ○	4 ○	5 ○
Product requirements by customers	1 ○	2 ○	3 ○	4 ○	5 ○
Size of customer base	1 ○	2 ○	3 ○	4 ○	5 ○
Demand variability	1 ○	2 ○	3 ○	4 ○	5 ○
Actions of competitors	1 ○	2 ○	3 ○	4 ○	5 ○
Standards and regulations	1 ○	2 ○	3 ○	4 ○	5 ○
Globalization of supplier base	1 ○	2 ○	3 ○	4 ○	5 ○
Supplier unreliability	1 ○	2 ○	3 ○	4 ○	5 ○
Level of vertical integration	1 ○	2 ○	3 ○	4 ○	5 ○
Length of product life cycle	1 ○	2 ○	3 ○	4 ○	5 ○
Size of supplier base	1 ○	2 ○	3 ○	4 ○	5 ○
Product mix	1 ○	2 ○	3 ○	4 ○	5 ○
Product architecture	1 ○	2 ○	3 ○	4 ○	5 ○
Production structure	1 ○	2 ○	3 ○	4 ○	5 ○
Organizational structure	1 ○	2 ○	3 ○	4 ○	5 ○
Company culture	1 ○	2 ○	3 ○	4 ○	5 ○

Other, please specify: ____________________

Complexity management

B2. Please indicate to which extent these statements regarding your complexity management apply to your company (division).

	Strongly disagree (1)				*Strongly agree (5)*
Complexity management is successfully implemented.	1 ○	2 ○	3 ○	4 ○	5 ○
There has been a substantial improvement in performance since we implemented complexity management.	1 ○	2 ○	3 ○	4 ○	5 ○

B3. Please indicate the main strategic priorities of your company's (division's) complexity management. (multiple answers possible)

☐ Reduce complexity ☐ Avoid complexity ☐ Control complexity

B4. Please indicate the responsibility of company's (divisions's) complexity management.

○ Product development ○ Product management ○ Special department in the division

○ Special department in the company ○ Permanent cross-functional team ○ Temporary cross-functional team

Other, please specify: ______

B5. Please indicate the complexity fields you have already addressed in your complexity optimization projects (multiple answers possible)

☐ Product architecture ☐ Production ☐ End-to-end value-chain ☐ Markets / segments

☐ Product portfolio ☐ Supply chain network ☐ Organization ☐ We did not run any projects

Other, please specify: ______

SECTION C - Managing complexity in your product management

Decision-making for new products and variants

C1. Please indicate the stakeholders which typically take active part in your decision-making of a ... (multiple answers in each row possible)

	...new products (innovation)	...new product variants (existing product)	...face-lifts (mid-generational refresh)	...phase-outs of product (end of life cycle)
Research	☐	☐	☐	☐
Development	☐	☐	☐	☐
Procurement	☐	☐	☐	☐
Manufacturing	☐	☐	☐	☐
Logistics	☐	☐	☐	☐
Sales	☐	☐	☐	☐
Business development	☐	☐	☐	☐
Marketing	☐	☐	☐	☐
Product management	☐	☐	☐	☐
Aftersales	☐	☐	☐	☐
Finance/controlling	☐	☐	☐	☐
Corporate strategy (department)	☐	☐	☐	☐
Top management / senior executives	☐	☐	☐	☐
Other please specify:	☐	☐	☐	☐

C2. Please state the final responsibility of your decision for ...

	...new products (innovation)	...new product variants (existing product)	...face-lifts (mid-generational refresh)	...phase-outs of product (end of life cycle)
Responsible department /function:				

C3. Please indicate to which extent these statements regarding the decision-making for new products and product variants apply to your company (division).

	Strongly disagree (1)				*Strongly agree (5)*
Our decisions are dominated by financial figures (e.g. ROI, NPV, PBP*)	1 ○	2 ○	3 ○	4 ○	5 ○
Our decisions are dominated by interests of persons or departments.	1 ○	2 ○	3 ○	4 ○	5 ○
Intuition and gut feeling by decision makers significantly influence our decisions.	1 ○	2 ○	3 ○	4 ○	5 ○
Our decisions are mainly based on criteria pre-defined in a template or tool (e.g. business case).	1 ○	2 ○	3 ○	4 ○	5 ○
Our decisions are mainly based on cross-functional discussions.	1 ○	2 ○	3 ○	4 ○	5 ○
We consider our main complexity drivers in our decisions.	1 ○	2 ○	3 ○	4 ○	5 ○
We integrate lessons learned from past decisions/projects actively in new decisions.	1 ○	2 ○	3 ○	4 ○	5 ○

*ROI = Return on Invest; NPV = Net Present Value; PBP = Payback Period

C4. Please indicate to which extend the following mechanisms regarding your decision-making for … are applied in your company (division).

	…new products (innovation)					…new product variants (existing product)					…face-lifts (mid-generational refresh)					…phase-outs of product (end of life cycle)				
	0% applied (1)				*100% applied (5)*	*0% applied (1)*				*100% applied (5)*	*0% applied (1)*				*100% applied (5)*	*0% applied (1)*				*100% applied (5)*
	1				5	1				5	1				5	1				5
Rules, standards & guidelines	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
Established, standard process (e.g. stage gate model)	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
Formal meetings	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
Informal discussions and communication	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
Permanent cross-functional teams	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
Temporary cross-functional teams	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
Liasion roles (i.e. people in charge of ensuring coordination)	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
"Express lane" for the decision	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
Categorization regarding the level of complexity	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○

C5. Please indicate to which extent these statements regarding the decision impact apply to your ..

	… new products (innovation)					… new product variants (existing product)				
	Strongly disagree (1)				*Strongly agree (5)*	*Strongly disagree (1)*				*Strongly agree (5)*
The effort/cost induced in the value-chain as a result of the decision is transparent.	1 ○	2 ○	3 ○	4 ○	5 ○	1 ○	2 ○	3 ○	4 ○	5 ○
The value generated as a result of the decision is transparent.	1 ○	2 ○	3 ○	4 ○	5 ○	1 ○	2 ○	3 ○	4 ○	5 ○
We integrate criteria in our decisions which show the impact on complexity in value-chain processes.	1 ○	2 ○	3 ○	4 ○	5 ○	1 ○	2 ○	3 ○	4 ○	5 ○

C6. Please indicate the <u>most important criteria used in your early decision-making</u> for ...

	... new products (innovation)					... new product variants (existing product)				
	Not important (1)				*Extremely important (5)*	*Not important (1)*				*Extremely important (5)*
Alignment of project with business strategy	1 ○	2 ○	3 ○	4 ○	5 ○	1 ○	2 ○	3 ○	4 ○	5 ○
Impact on the business	1 ○	2 ○	3 ○	4 ○	5 ○	1 ○	2 ○	3 ○	4 ○	5 ○
Market size	1 ○	2 ○	3 ○	4 ○	5 ○	1 ○	2 ○	3 ○	4 ○	5 ○
Market growth and future potential	1 ○	2 ○	3 ○	4 ○	5 ○	1 ○	2 ○	3 ○	4 ○	5 ○
Intensity of competition	1 ○	2 ○	3 ○	4 ○	5 ○	1 ○	2 ○	3 ○	4 ○	5 ○
Degree of product innovation	1 ○	2 ○	3 ○	4 ○	5 ○	1 ○	2 ○	3 ○	4 ○	5 ○
Financial return (e.g. ROI, NPV, PBP*)	1 ○	2 ○	3 ○	4 ○	5 ○	1 ○	2 ○	3 ○	4 ○	5 ○
Impact on value-chain processes	1 ○	2 ○	3 ○	4 ○	5 ○	1 ○	2 ○	3 ○	4 ○	5 ○
Level of financial risk	1 ○	2 ○	3 ○	4 ○	5 ○	1 ○	2 ○	3 ○	4 ○	5 ○
Total project cost until market introduction	1 ○	2 ○	3 ○	4 ○	5 ○	1 ○	2 ○	3 ○	4 ○	5 ○
Product maintenance cost after market introduction	1 ○	2 ○	3 ○	4 ○	5 ○	1 ○	2 ○	3 ○	4 ○	5 ○
Market risk(e.g. sales, price)	1 ○	2 ○	3 ○	4 ○	5 ○	1 ○	2 ○	3 ○	4 ○	5 ○
Project risk (e.g. time to market)	1 ○	2 ○	3 ○	4 ○	5 ○	1 ○	2 ○	3 ○	4 ○	5 ○
Technical risk (e.g. familiarity of technologies)	1 ○	2 ○	3 ○	4 ○	5 ○	1 ○	2 ○	3 ○	4 ○	5 ○
Value of product provided to the customer	1 ○	2 ○	3 ○	4 ○	5 ○	1 ○	2 ○	3 ○	4 ○	5 ○
Other please specify:	1 ○	2 ○	3 ○	4 ○	5 ○	1 ○	2 ○	3 ○	4 ○	5 ○
Other please specify:	1 ○	2 ○	3 ○	4 ○	5 ○	1 ○	2 ○	3 ○	4 ○	5 ○
Other please specify:	1 ○	2 ○	3 ○	4 ○	5 ○	1 ○	2 ○	3 ○	4 ○	5 ○

*ROI = Return On Investment; NPV = Net Present Value; PBP = Payback Period

C7. Please indicate the criteria which are from your perspective <u>not reliable</u> in your <u>early</u> decision-making for new products and product variants.

☐ Market growth	☐ Project risk	☐ Project costs
☐ Market risk	☐ Financial risk	☐ Technical risk
Other please specify:	Other please specify:	Other please specify:

C8. Please state the three main criteria you use to <u>integrate the impact on process complexity</u> in your decision-making for products and product variants.

Criteria #1:	Criteria #2:	Criteria #3:

Product structure and portfolio

C9. Please indicate to which extent these statements regarding <u>product portfolio managemement</u> apply to your company (division).

	Strongly disagree (1)				*Strongly agree (5)*
We assess the complexity of our product portfolio.	1 ○	2 ○	3 ○	4 ○	5 ○
We know the impact of additional complexity of our product portfolio on value-chain processes.	1 ○	2 ○	3 ○	4 ○	5 ○
We have specific key performance indicators (KPIs) to steer product complexity.	1 ○	2 ○	3 ○	4 ○	5 ○
We determine the complexity of our product portfolio with a fully comparable baseline metric.	1 ○	2 ○	3 ○	4 ○	5 ○
We have specific KPIs to steer complexity of our product portfolio.	1 ○	2 ○	3 ○	4 ○	5 ○

SECTION D - Managing complexity in your processes

Complexity transparency

D1. Please indicate to which extent these statements regarding process complexity management apply to your company (division).

	Strongly disagree (1)				*Strongly agree (5)*
Our value-chain processes have a high degree of flexibility to cope with complexity.	1 ○	2 ○	3 ○	4 ○	5 ○
We know the process with the main burden of complexity in our value-chain.	1 ○	2 ○	3 ○	4 ○	5 ○

D2. Please estimate the additional effort (as a percentage) required for the creation of a product variant on average compared to the creation of a standard product. (Example: standard product from product line = baseline; typical customized product variant = baseline+X%)

+ [   ] **%**

D3. Please indicate to which extent these statements regarding complexity transparency apply to your company (division).

	Strongly disagree (1)				*Strongly agree (5)*
We make complexity in our products transparent (e.g. variant tree).	1 ○	2 ○	3 ○	4 ○	5 ○
We have methods and tools to visualize complexity in processes.	1 ○	2 ○	3 ○	4 ○	5 ○
We document and map complexity drivers.	1 ○	2 ○	3 ○	4 ○	5 ○
Complexity in our value-chain processes is made transparent on a regular basis.	1 ○	2 ○	3 ○	4 ○	5 ○
Complexity optimization projects are based on this complexity transparency.	1 ○	2 ○	3 ○	4 ○	5 ○

Complexity measurement

D4. Please indicate to which extent these statements regarding complexity transparency apply to your company (division).

	Strongly disagree (1)				*Strongly agree (5)*
We quantify the impact of complexity on value-chain processes due to new products and variants.	1 ○	2 ○	3 ○	4 ○	5 ○
We determine the complexity in our processes with a fully comparable baseline metric (e.g. complexity index).	1 ○	2 ○	3 ○	4 ○	5 ○
We have defined complexity indicators/KPIs for single value-chain processes (e.g. manufacturing).	1 ○	2 ○	3 ○	4 ○	5 ○
We evaluate the impact of complexity on value-chain processes by calculating complexity cost.	1 ○	2 ○	3 ○	4 ○	5 ○
Our evaluation of process complexity is based on process-related indicators (e.g. number of additional stock keeping units for a new product variant).	1 ○	2 ○	3 ○	4 ○	5 ○

D5. Please state your complexity indicators used along your company's (division's) value-chain.

	Complexity indicator(s) available	Name/specify indicator(s)
Research	☐ Yes	
Development	☐ Yes	
Procurement	☐ Yes	
Manufacturing	☐ Yes	
Inbound logistics	☐ Yes	
Manufacturing	☐ Yes	
Outbound logistics	☐ Yes	
Marketing	☐ Yes	
Sales	☐ Yes	
Aftersales	☐ Yes	
Other please specify:	☐ Yes	

D6. Please indicate to which extent these statements regarding complexity costs apply to your company (division).

	Strongly disagree (1)				Strongly agree (5)
Individual complexity costs for products and product variants are made transparent.	1 ○	2 ○	3 ○	4 ○	5 ○
We have implemented an evaluation method for complexity costs.	1 ○	2 ○	3 ○	4 ○	5 ○
We transfer complexity levels into monetary figures (e.g. mark-up on project costs).	1 ○	2 ○	3 ○	4 ○	5 ○
We do not allocate overhead costs to products and product variants.	1 ○	2 ○	3 ○	4 ○	5 ○
Rules of thumb for average cost of a customer order, a stock-keeping unit, etc. are implemented.	1 ○	2 ○	3 ○	4 ○	5 ○
Complexity costs are considered in the pricing of products and product variants.	1 ○	2 ○	3 ○	4 ○	5 ○

D7. Please indicate the costs/activities which are considered in calculating complexity costs in your company (division).

☐ Research/design cost	☐ Purchasing cost	☐ Quality control cost
☐ Development cost	☐ Supplier qualification cost	☐ Information technology cost
☐ Inventory cost	☐ Product maintenance cost	☐ Marketing cost
☐ Inbound logistics cost	☐ Spare parts cost	☐ Training cost
☐ Outbound logistics cost	☐ Tooling cost	☐ Overhead cost
☐ Sales cost	☐ Start-up/launch cost	Other please specify:
☐ Order processing cost	☐ Production planning cost	Other please specify:

SECTION E - Performance & competitive advantage

E1. Please indicate the development/change of your company's (division's) overall financial performance over the last three years.

	deteriorated more than 5%	stayed about the same -5%/+5%	improved 10%-30%	improved 30%-50%	improved more than 50%
Sales	○	○	○	○	○
Market share	○	○	○	○	○
EBIT (Earnings before interests and taxes)	○	○	○	○	○
ROI (Return on Investment)	○	○	○	○	○

E2. Please indicate the achievement of objectives (as a percentage of all projects) for new products and for product variants in your company (division).

	For new products (innovation)					For new product variants (existing product)				
	<50%		65-80%		>95%	<50%		65-80%		>95%
The intended date for the market introduction / delivery is met.	1 ○	2 ○	3 ○	4 ○	5 ○	1 ○	2 ○	3 ○	4 ○	5 ○
The intended quality requirements are met.	1 ○	2 ○	3 ○	4 ○	5 ○	1 ○	2 ○	3 ○	4 ○	5 ○
The desired customer satisfaction is met.	1 ○	2 ○	3 ○	4 ○	5 ○	1 ○	2 ○	3 ○	4 ○	5 ○
The planned project costs are met (with less than +/-10% from initial plan).	1 ○	2 ○	3 ○	4 ○	5 ○	1 ○	2 ○	3 ○	4 ○	5 ○
The planned target sales volume is met.	1 ○	2 ○	3 ○	4 ○	5 ○	1 ○	2 ○	3 ○	4 ○	5 ○
The intended creation of a competitive advantage in the market is realized.	1 ○	2 ○	3 ○	4 ○	5 ○	1 ○	2 ○	3 ○	4 ○	5 ○

Please describe (in a few words) your successful practices with regard to complexity management.

Thank you very much for your participation!

Please submit this completed questionnaire by pushing the button to send it via EMAIL (matthias.goetzfried@unisg.ch)

or print it and sent it via FAX: +41 71 224 73 11 or MAIL (see address on cover page)

Appendix B: Interview guideline

Company environment & complexity drivers

- How would you characterize your company's environment?
- What are your main complexity drivers?
- What impact does complexity have on your business and processes?

Complexity management in general

- Is there a formal complexity management in your company?
- How is complexity management organized in your company?
- What is the focus of your complexity management?

Transparency on product portfolio and product architecture complexity

- How do you evaluate the complexity of your product portfolio?
- What are the indicators used in this evaluation?
- What are the most relevant tools and methods you use in this evaluation?
- How do you evaluate the complexity of product architectures?
- What are the indicators used in this evaluation?
- What are the most relevant tools and methods you use in this evaluation?

Transparency on value-chain processes complexity

- How do you evaluate the complexity of your value-chain processes?
- Do you evaluate the complexity of single processes (e.g. manufacturing) or the entire value-chain?
- What are the indicators used in this evaluation?
- Who is involved in this evaluation?
- What are the most relevant tools and methods you use in this evaluation?
- Do you calculate complexity cost? How?
- How is the awareness of decision-makers regarding the consequences of their decision on the execution in the value-chain processes?

Decision-making for products and the integration of a complexity perspective

- What is the process structure (trigger, phases, activities, milestones) of your decision-making for new products and product variants?
- Do you organize for decision-making in teams? How?
- How is the go/no-go decision at the milestones made?
- What are the main determinants of decisions? (rationality, intuition by decision-makers or political behavior by stakeholders)
- What are the dominant criteria for decision-making?
- How do you gather the required data for the criteria used for decision-making?
- How would you characterize the reliability of your decision criteria?
- How is induced complexity (value and effort) considered in your decision-making processes?
- Do you use complexity criteria or complexity cost estimations in your decisions?

Curriculum Vitae

Name:	Matthias Götzfried
Date of birth:	May 24th, 1982
Place of birth:	Heilbronn-Neckargartach/Germany

Professional Experience

2012 – today	**Freudenberg Sealing Technologies,** Weinheim/Germany Strategic Board Projects, Executive Assistant to the Board
2009 – 2012	**Institute of Technology Management,** St. Gallen/Switzerland Group Coordinator and Research Associate
2008 – 2009	**Porsche Consulting GmbH**, Bietigheim-Bissingen/Germany Diploma thesis (Dipl.-Ing.) in the division "Lean Development"
2008	**Fraunhofer IAO**, Stuttgart/Germany Master thesis (M.Sc.) in the division "R&D Management"
2006 – 2007	**AUDI AG**, Neckarsulm/Germany Intern at the department of quality management
2002	**ThyssenKrupp Elevator**, Neuhausen/Germany Intern at the department of manufacturing

Education

2009 – 2012	**University of St.Gallen (HSG)**, St. Gallen/Switzerland Doctoral programme "Management - Business Innovation" (Dr. oec.)
2007 – 2009	**Rose-Hulman Institute of Technology**, Terre Haute/USA Master of Science in Engineering Management (M.Sc.)
2002 – 2009	**University of Stuttgart**, Stuttgart/Germany Diploma degree in Technology Management (Dipl.-Ing.)
1992 – 2001	**Hohenstaufen-Gymnasium**, Bad Wimpfen/Germany High-school studies ("Abitur")