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# Complexity drivers in product development: A comparison between literature and empirical research

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## ABSTRACT

Companies in high-technology marketplaces are confronted with social, market-specific, technological and economical changes such as technology innovation, changing customer requirements, globalization of markets and competitions as well as market uncertainty. Manufacturing companies cannot escape these trends. For company´s success, it is fundamental to bring new and high quality products quickly and with customer´s individual settings to market. Product development is one of the most complex tasks and uncertain processes in the company. Complexity in product development comes from a variety of internal and external sources, so called complexity drivers. In literature, 108 complexity drivers in product development are described by several authors. To compare literature´s information about complexity drivers in product development and their effects with the practice, an empirical study is needed. Currently, an empirical research regarding complexity drivers in product development in manufacturing companies and their effects does not exist. Covering this research gap is this paper's purpose. For this empirical study, a six stage systematic approach from Flynn et al. was applied, starting with the determination of the theoretical foundation and the research design as well as the selection of the data collection method. The data was collected in different fields of the German manufacturing industry through standardized questionnaires, which were sent by e-mail to 3,086 companies between 2015 and 2016. In total, 295 questionnaires were answered completely. The data was analyzed by using statistical methods. The empirical results regarding complexity drivers were compared with literature to identify communalities and differences. In literature, 108 complexity drivers and 18 effects are described. In contrast, 30 complexity drivers and 4 effects were mentioned by experts. Based on a factor analysis, the complexity drivers were aggregated to 7 factors, which reflect the complexity drivers.

**KEYWORDS:** Complexity · Complexity management · Complexity drivers · Product development · Empirical research

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## 1 INTRODUCTION

*"I think the next (21st) century will be the century of complexity"* [66]. This statement by Stephen W. Hawking [66] from the year 2000 describes the current situation in science and practice. Maguire, Allen and McKelvey [92] describe that "*complexity is one of the fastest growing topics*" in scientific research. In practice, the same situation can be observed. Complexity in manufacturing companies and especially in product development has continuously increased in many industries within the last years [44, 83, 89, 149, 132]. The reasons are social, market-specific, technological and economical changes, such as more and more demanding customers, market's globalization, dynamic market environment, technology innovation and uncertainty. Manufacturing companies have to face these trends and cannot escape [102, 103, 112, 144]. Increasing global competition and customer´s individual needs force companies to offer a diversified product portfolio in the market, by developing different product variants [3, 32, 45, 65, 35]. A diversified product portfolio with many different product variants causes an increase in complexity [26], especially in products and in processes [8]. Other reasons for increasing complexity in product development are the increasing number of product launches in the market, shorter product lifecycles and customer´s demands

for new and innovative products [32]. According to Schaefer [119] and Chapman and Hyland [33], product development and innovation is an important key factor for business success. For company´s strategy, product development became a central importance [36, 39, 63]. Increasing complexity is one of the biggest tasks that manufacturing companies have to face and to handle today [44]. According to Warnecke and Puhl [147], company´s complexity can only be managed if it is identified. Thus, complexity understanding becomes more and more important in manufacturing companies [69].

According to Warnecke [146], complexity can be seen as a phenomenon and evolutionary process, which is challenging especially for science and engineering. Complexity is intensified through innovations in products and processes [146]. In scientific research, there is no general understanding as well as explicit, universal and widely accepted definition of the term complexity [26, 44, 118]. Complexity is "*in the eye of the beholder*" [100] and depends on individual´s experience and knowledge [41]. The origin of the term *complexity* comes from the Latin words "*complexus"* and *"complecti"*, which means "*extensive, interrelated, confusing, entwined or twisted together*" [44, 54, 60, 113]. The term *"complexity"* is therefore often used synonymously with the term *"complicated"* [44, 54], but the terms have specific characteristics and different meanings.

Within a company, product development is one of the most complex tasks and uncertain processes [12, 39] and has the biggest influence on a company's complexity [83]. For a new global economy's success, product development is the core process according to Ragatz et al. [116]. Product development´s objective is "*to translate an idea into a tangible physical asset"* [39]. The time for product development of industrial goods has strongly reduced during the last years due to increasing globalization, customer's behavior change and hardly predictable market fluctuations [83]. Product development process is often the longest part of bringing a product to market [57] and is confronted with several factors such as demand variety, uncertain objectives, dynamics, high time pressure and restricted resources [151]. Generally, complexity in product development comes from a variety of internal and external sources [40], called complexity drivers. Complexity drivers play a significant role for complexity management. They describe the complexity in a system and help to evaluate and handle it [142]. For managing a system's complexity, an optimum fit between internal and external complexity is needed [130, 141]. The management of complexity is a strategic issue for companies to be competitive [102]. For an effective and target oriented complexity management, information is needed [39].

Based on scientific research, information can be gathered by conducting literature research or empirical studies. To verify existing knowledge or theories and to identify communalities and differences, the results from literature and the real world are compared. In literature, several empirical studies regarding complexity management in various fields of industries and regions/countries already exist. They are focused on different fields in the company and along the value chain and were conducted in the time period between 1999 and 2015 (see chapter 2.3). There are also empirical studies regarding complexity management in the field product development and have been done by Li et al. [88], Kim and Wilemon [78], Newman [106], Chronéer and Bergquist [34], Kim and Wilemon [79] and Grussenmeyer and Blecker [62]. The data collection was conducted in China, United States of America, Sweden, Italy and Germany and in 14 different fields of industries (e.g. engineering, electrical, medical industry, chemical & pharmaceutical, clothing, etc.). Based on these studies, the impact of environmental complexity and the choice of management control systems and their effects on product development and their processes are investigated. Furthermore, the sources, which cause complexity and the consequences when complexity arises in new product development and especially in development projects, are identified and analyzed to increase transparency and understanding for an effective complexity management. In addition, the complexity level in new product development is analyzed and the question of how complexity can be reduced through standardization and modularization is discussed.

For an effective complexity management, it is necessary to identify the complexity sources, called complexity drivers, and their effects first [142]. None of the previous empirical studies regarding complexity management in product development is concerned with the identification and analysis of complexity drivers and their effects. Furthermore, no comparison between the empirical findings and literature has been done in the previous empirical studies.

The purpose of this paper is to close this research gap by an empirical research regarding complexity drivers and their effects to verify scientific findings and to compare the literature and the empirical results to identify similarities and differences. The perception between science and practice and their discrepancy is described and processed. A further contribution of this empirical study is to develop additional knowledge (scientific based – practice driven) according to complexity in product development for science and practice within a systematical and target-oriented data collection and the succeeding comparison of the literature with the empirical results.

From *scientific perspective*, this empirical research establishes a connection between scientific research and the real world by answering the research questions (see chapter 2) within the systematical gained empirical data. It closes a currently existing gap in scientific literature by comparing the literature and empirical results to identify similarities and differences and to verify scientific findings. In addition to the comparison between the theoretical and the empirical results, the theoretical findings can also be confirmed, advanced or progressed within this empirical research. This study presents a theoretical overview about complexity drivers in product development and the existing empirical researches and gives the researcher an overview about what is already known in practice about these issues and practice´s tendencies (empirical findings). Furthermore, the researcher gains some detail information about the research and data collection methodology, the objectives and the sample description to increase transparency. This enables the researcher to reproduce the findings. Based on this study, researchers can build new ideas, theories and hypotheses for their own research. Within this research, the gaps for future research are pointed out.

From *practical perspective*, this empirical study gives the practitioner an overview about complexity perception in product development by other practitioners. Furthermore, the practitioner receives a differentiated overview of complexity in product development, which is perceived in different fields of industries. This study also answers the following manager´s questions “What complexity sources (drivers) have a high influence on product development´s complexity and thus are relevant for the company?” and “What effects do high complexity within the company have on product development?”, by providing an overview about the main and relevant complexity drivers, which were assigned by the respondents with a strong or very strong influence on product development´s complexity. Beyond, the practitioner gets an overview about the main topics and properties in product development with high complexity, which have a strong or very strong influence on product development’s performance as said so by the respondents. This overview can increase transparency for the practitioner.

As already mentioned, different complexity drivers, focused on product development, are described in literature by several authors. To compare literature´s findings with the practice, this empirical research was conducted. This research paper is structured as follows: In section 2, the paper gives a literature overview about the complexity drivers in product development and their effects on company´s complexity. Furthermore, an overview of existing empirical research in the field of complexity management is described. The research methodology and objectives, questionnaires´ design as well as the data collection methodology and sample description are presented in section 3. The empirical findings are described in section 4. Furthermore, the results are compared with literature to identify commonalities and differences. Section 5 concludes the paper with implications for future research and presents this research´s limitations.

## 2 LITERATURE REVIEW

### 2.1 Research methodology and boundary definition

This paper´s purpose is to compare literature´s findings regarding specific complexity drivers and their effects on company´s complexity, especially in product development, with the real world to increase transparency and knowledge for science and practice by identifying similarities and differences. Furthermore, an overview about existing empirical studies in the field complexity management is presented. The empirical study was conducted in the manufacturing industry of Germany.

Before starting an empirical research, the existing literature regarding the complexity drivers and their effects as well as the previous empirical studies must be reviewed. The following chapter presents a literature review in these 3 issues. For this literature review, we used the methodology of Fink [48] and defined 2 research questions:

*RQ1:* What complexity drivers currently occur in the field product development in manufacturing companies in scientific literature? What effects do complexity drivers generally have on company´s complexity?

*RQ2:* What empirical studies in the field complexity management currently exist in scientific literature? What objectives do they have and what research methodologies are applied? What empirical studies concern with specific complexity drivers and their effects?

Next, we defined the search terms and databases by following the methodology of Vogel and Lasch [142] and Vogel [143]. The search terms are formulated based on the research questions. For search terms´ formulation, we used a particular grammar and logic, and combined the key words with specific Boolean operators (AND, OR and NEAR) analogously. The finalized search terms are created through an iterative process in order to identify all important literature sources. To extend the amount of relevant literature, the literature search was performed in English- and German-language literature and 8 different databases, which are specialized in science and economics: EBSCOhost, Emerald, GENIOS/WISO, Google Scholar, IEEE Xplore, JSTOR, ScienceDirect and SpringerLink. Most of the databases are connected with other databases. For example, EBSCOhost and Google Scholar are connected with the databases Emerald, IEEE Xplore, ScienceDirect and SpringerLink. Since we want to compare our empirical findings with the existing literature in the same time period, the time period of our literature research was restricted between 1900/01/01 and 2015/12/31, because our empirical study was performed in the years 2015 and 2016. The literature search resulted in a certain amount of literature sources (complexity drivers and their effects: 911 literature sources; previous empirical studies in the field complexity management: 26,699 literature sources) and comprises research papers from journals, conference proceedings, books, essays and PhD theses. Several literature sources were found more than once.

Answering the first and second research question, the existing literature was analyzed, evaluated and synthesized based on the research questions by using qualitative data analysis techniques to identify the relevant literature sources. Literature research always accumulates many publications, but only a few are relevant for scientific research [48]. Synthesizing the results of the literature research is therefore necessary to identify the relevant literature sources. For the qualitative data analysis, we used the methodology of Vogel and Lasch [142], which is described in detail in their publication. In the following subchapters 2.2 and 2.3, the results of our literature research are described.

### 2.2 Complexity drivers in product development and their effects on company´s complexity

The result of our literature research is a systematic, explicit and reproducible literature review about complexity drivers in manufacturing companies and along the value chain, published by Vogel and Lasch. In their literature review, Vogel and Lasch identified different definitions about complexity drivers and generated a more general definition of complexity drivers [142]. Further, they described a variety of methods for complexity driver´s identification, operationalization, and visualization and presented several different complexity drivers, which occur in manufacturing companies and along the value chain, including the field product development. Based on literature, complexity drivers have a direct influence on the company and the total value chain [130]. The knowledge about complexity drivers is necessary to develop an effective complexity strategy [135]. As already mentioned, product development has the biggest influence on a company's complexity [83]. The first step in developing and implementing a target oriented complexity management in a company and finally in product development is to identify the corresponding complexity drivers [49, 53, 112]. Keuper [76] followed this argumentation and described that the handling of company´s complexity depends on the complexity drivers. In their literature review, Vogel and Lasch [142] defined complexity drivers as "*factors, which influence a system´s complexity and company´s target achievement. They are responsible for increasing system´s complexity level and help to define the characteristics or the phenomenon of a system´s complexity. Complexity drivers are influenced by one another that is by internal or external drivers, and cannot be reduced completely to another one*".

According to their origin, complexity drivers can be separated in internal and external drivers [13, 74, 154]. Furthermore, internal complexity drivers can be differentiated in correlated and autonomous complexity drivers [15]. Correlated complexity drivers have a direct correlation to external complexity and are influenced by it. Autonomous complexity drivers are not influenced by external factors and the company itself determines them. Internal and external complexity drivers are connected directly and induce system´s complexity [9, 38, 56, 58, 59]. They cannot be separated selectively and they cannot be operationalized [18, 56, 123, 129].

In the literature review from Vogel and Lasch [142], 17 publications regarding complexity drivers in product development were found between 1998 and 2015. No publications are found before 1998. Sixty-five percent of the publications were published between 2010 and 2015. This trend shows an increased interest throughout the last years and it can be derived that complexity drivers in product development become more and more important in scientific research.

Furthermore, 107 different complexity drivers in product development were found in the literature review from Vogel and Lasch [142]. The identified complexity drivers were clustered in different main complexity driver categories depending on their origin, characteristics and influence on other drivers. The classification system consists of *3 main groups* (external complexity, internal complexity and general complexity), *4 subcategories* (society complexity, market complexity, internal correlated complexity and internal autonomous complexity) and *22 main complexity driver categories* (society, demand, competitive, supply, technological external, target, customer, product & product portfolio, technological internal, product development, supply process, service, remanufacturing, organizational, process, production, planning, control & information, resource, logistics, sales & distribution, general complexity). As a result of complexity drivers´ clustering, 28 external (26%), 30 internal correlated (28%) and 49 internal autonomous complexity drivers (46%) were found and identified in literature. Most of the identified complexity drivers were assigned to the main group internal complexity. Thus, this group is mostly influenced by complexity and must be handled first [142].

Table 1 presents the identified complexity drivers in the field product development and their literature occurrence. The most referred complexity drivers are *organizational complexity* (N: 6), *process complexity* (N: 5) and *product structure/ design* (N: 5). As also seen in Table 1, some authors appointed more complexity drivers than other authors in the field product development. The amount of complexity drivers in a system, especially in product development, reflects the level of difficulty in managing a system`s complexity, because complexity drivers have a high influence on a system´s complexity. The number of identified complexity drivers in product development ranges from 2 up to 38 (see Table 1) and depends on the situation and the eye of the beholder. In the complexity driver categories *supply complexity*, *supply process complexity*, *service complexity* and *remanufacturing complexity*, no specific complexity drivers were appointed by the authors. It seems that these categories are not so relevant for product development from literature's point of view. Based on these results, in practice, the same or other complexity drivers can occur from our point of view. For example, the category remanufacturing complexity could be relevant for product development´s complexity, because in product development, product's structure, materials and functions are defined and these are relevant for product´s remanufacturing. Thus, an empirical research must be performed to identify new complexity drivers or to confirm the existing drivers.

In the end, the empirical results are compared with the results from literature to identify communalities and differences. For designing the questionnaire of our empirial research, only the literature sources, which were published before 2015 were considered, because the empirical research started already in 2014 with the pretest. After the pretest, the final questionnaire started at the beginning of the year 2015. The publications from Bosch-Rekveldt et al. [19] and Oyama, Learmonth and Chao [109] were not yet published at the time the questionnaire started and thus their findings were not implemented in questionnaire's design.

*Table 1: Overview of the main complexity drivers in the field product development and their literature occurrence*

**Explanation:**
* Complexity drivers, which are out of focus according to questionnaire´s design, because they were published after the year 2014 (Focus for questionaire´s design: complexity drivers, which were published between 1998 – 2014)

| Origin | | Complexity driver category and its drivers | Komorek [82] | Wangenheim [145] | Kim and Wilemon [77] | Dehnen [40] | Giannopoulos [53] | Krause, Franke and Gausemeier [83] | Grussenmeyer and Blecker [61] | Eigner, Anderl and Stark [43] | ElMaraghy *et al.* [44] | Schömann [127] | Zhang and Yang [155] | Budde and Golovatchev [28] | Jensen, Bekdik and Thuesen [72] | Lucae, Rebentisch and Oehmen [90] | Thiebes and Plankert [139] | Bosch-Rekveldt *et al.* [19] | Oyama, Learmonth and Chao [109] | **Literature occurrence (Total)** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **External complexity** | **Society complexity** | • Social framework * | | | | | | | | | | | | | | | | ● | | **1** |
| | | • Value change & value awareness | | | | | | ● | | | | | | | | | | | | **1** |
| | | • Environmental complexity (general) | | | | ● | | | | | | | ● | | | ● | | | | **3** |
| | | • Dynamic & change of company´s environment * | | | | | | | | | | | | | | | | ● | | **1** |
| | | • Ecological conditions / factors | | | | | | ● | | | | | | | | | | | | **1** |
| | | • Legal factors | | | | | | ● | | | | | | | | | | | | **1** |
| | | • Political framework conditions | | | | | | | | | | | ● | | | | | ● | | **2** |
| | | • Country-specific requirements * | | | | | | | | | | | | | | | | ● | | **1** |
| | | • Change of populations structure | | | | | | ● | | | | | | | | | | | | **1** |
| | | • Standards and regulations | | | | | | ● | | | | | | | | | | | | **1** |
| | | • Turbulences in company´s environment | | | | | | | | | | | ● | | | | | | | **1** |
| | | • Uncertainty in company´s environment * | | | | | | | | | | | | | | | | ● | | **1** |
| | | • Interdependencies between environmental factors | | | | | | | | | | | ● | | | | | ● | | **2** |
| | **Market complexity** | **General market-related complexity** | | | | | | | | | | | | | | | | | | |
| | | • Market complexity (general) | | | ● | | | | ● | | ● | | | | | | | | | **3** |
| | | • Market´s change | | | | | | ● | | | | | | | | | | | | **1** |
| | | • Market´s globalization | | | | | | ● | | | | | | | | | | | | **1** |
| | | • Market´s dynamics | | | | | | | | | | | ● | | | | | | | **1** |
| | | • Market´s protectionism | | | | | | ● | | | | | | | | | | | | **1** |
| | | **Demand complexity** | | | | | | | | | | | | | | | | | | |
| | | • Demand complexity (general) | | | | ● | | | | | | ● | | | | | | | | **2** |
| | | • Individuality of customer demands | | | | | | ● | | | | | | | | | | | | **1** |
| | | **Competitive complexity** | | | | | | | | | | | | | | | | | | |
| | | • Competitive complexity (general) | | | | ● | | | | | | ● | | | | | | | | **2** |
| | | • Number and strength of competitors | | | | | | | | | | | ● | | | | | ● | | **2** |
| | | • Competitive pressure | | | | | | ● | | | | | | | | | | | | **1** |
| | | **Supply complexity** | | | | | | | | | | | | | | | | | | |
| | | **Technological complexity (external)** | | | | | | | | | | | | | | | | | | |
| | | • External technological complexity (general) | | | | ● | | | | | | | | | | | | | | **1** |
| | | • Technological progress | | | | | | ● | | | | | ● | | | | | | | **2** |
| | | • Technological innovations & availability | | | | | | ● | | | | | | | | | | | | **1** |
| | | • New technologies and materials | | | | | | ● | | | | | | | | | | | | **1** |

**Explanation:**
* Complexity drivers, which are out of focus according to questionnaire´s design, because they were published after the year 2014 (Focus for questionaire´s design: complexity drivers, which were published between 1998 – 2014)

| Origin | | Complexity driver category and its drivers | Komorek [82] | Wangenheim [145] | Kim and Wilemon [77] | Dehnen [40] | Giannopoulos [53] | Krause, Franke and Gausemeier [83] | Grussenmeyer and Blecker [61] | Eigner, Anderl and Stark [43] | ElMaraghy *et al.* [44] | Schömann [127] | Zhang and Yang [155] | Budde and Golovatchev [28] | Jensen, Bekdik and Thuesen [72] | Lucae, Rebentisch and Oehmen [90] | Thiebes and Plankert [139] | Bosch-Rekveldt *et al.* [19] | Oyama, Learmonth and Chao [109] | **Literature occurrence (Total)** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Internal complexity (Part I)** | **Internal correlated complexity** | **Target complexity** | | | | | | | | | | | | | | | | | | |
| | | • Target complexity (general) | | | | • | | | | | | • | | | | | | | | **2** |
| | | • Amount of different targets * | | | | | | | | | | | | | | | | • | | **1** |
| | | • Conflict between different targets * | | | | | | | | | | | | | | | | • | | **1** |
| | | • Ambiguity of targets * | | | | | | | | | | | | | | | | • | | **1** |
| | | **Customer complexity** | | | | | | | | | | | | | | | | | | |
| | | • Customer structure | | | | | | | | | | • | | | | | | | | **1** |
| | | **Product & product portfolio complexity** | | | | | | | | | | | | | | | | | | |
| | | • Product complexity (general) | | | | | | | | | • | • | • | | | | • | | | **4** |
| | | • Product portfolio complexity (general) | | | | | | | | | | • | | | | • | | | | **2** |
| | | • Product variety | | • | | | | • | | • | | | | | | | • | | | **4** |
| | | • Product range / portfolio | | • | | | | • | | • | | | | | | | • | | | **4** |
| | | • Product structure / design | | • | | • | | | | • | | | • | | • | | | | | **5** |
| | | • Product technology | • | | | | | | | | | | | | | | | | | **1** |
| | | • Component type | | | | | • | | | | | | | | | | | | | **1** |
| | | • Variety and property of parts and modules | • | • | | | • | | | | | | | | | | | | • | **4** |
| | | • Variety and property of the applied materials | • | | | | | | | | | | | | | | | | | **1** |
| | | • Quality standards * | | | | | | | | | | | | | | | | • | | **1** |
| | | • Conflicts between different standards * | | | | | | | | | | | | | | | | • | | **1** |
| | | **Technological complexity (internal)** | | | | | | | | | | | | | | | | | | |
| | | • Technology complexity (general) | | | • | | | | • | | | | • | | | • | | | | **4** |
| | | • Technology change / innovation | | | | | | | | | | | | | | | • | | | **1** |
| | | • New technologies * | | | | | | | | | | | | | | | | • | | **1** |
| | | • Number of different applied technologies | | • | | | | | | | | | | | | | | | | **1** |
| | | • Technological uncertainty * | | | | | | | | | | | | | | | | • | | **1** |
| | | • Hardware and software complexity (general) | | | | | • | | | | | | | | | | | | | **1** |
| | | • Type of data medium | | | | | • | | | | | | | | | | | | | **1** |
| | | • Size of data medium | | | | | • | | | | | | | | | | | | | **1** |
| | | • Type of interfaces | | | | | • | | | | | | | | | | | | | **1** |
| | | • Amount of interfaces | | | | | • | | | | | | | | | | | | | **1** |
| | | • Criteria of hardware and software tests | | | | | • | | | | | | | | | | | | | **1** |
| | | **Product development complexity** | | | | | | | | | | | | | | | | | | |
| | | • Development complexity (general) | | | • | | | | • | | | | | | | | | | | **2** |
| | | • Development program´s complexity | | | | • | | | | | | | | | | | | | | **1** |
| | | • Applied methods or instruments | | | | | | • | | | | | | | | | | | | **1** |
| | | **Supply process complexity** | | | | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | | | | | |
| | | **Service complexity** | | | | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | | | | | |
| | | **Remanufacturing complexity** | | | | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | | | | | |

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|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Internal complexity (Part II)** | **Internal autonomous complexity** | **Organizational complexity** | | | | | | | | | | | | | | | | | | |
| | | • Organizational complexity (general) | | | ● | | | | ● | | ● | ● | ● | | | ● | | | | **6** |
| | | • Organization´s structure | | | ● | | | ● | | | | | | | | | | | | **2** |
| | | • Deficits in organization structure * | | | | | | | | | | | | | | | | ● | | **1** |
| | | • Organization´s / Company´s size | | | | | | | | | | | | | | | ● | | | **1** |
| | | • Company´s location * | | | | | | | | | | | | | | | | ● | | **1** |
| | | • Company´s management * | | | | | | | | | | | | | | | | ● | | **1** |
| | | • Business segment / industrial sector | | | | | | | | | | | | | | | ● | | | **1** |
| | | • Company´s strategy (strategical complexity) | | | | | | ● | | | | | ● | | | ● | | | | **3** |
| | | • Complexity between cooperation partners | | | | | | ● | ● | | | | | | | | | | | **2** |
| | | • Force within the company * | | | | | | | | | | | | | | | | ● | | **1** |
| | | • Handling of risks, uncertainty and incidence * | | | | | | | | | | | | | | | | ● | | **1** |
| | | • Employee complexity (general) | | | | | | ● | | | | | | | | ● | | | | **2** |
| | | • Employee experience * | | | | | | | | | | | | | | | | ● | | **1** |
| | | • Employee qualification * | | | | | | | | | | | | | | | | ● | | **1** |
| | | • Employee behavior * | | | | | | | | | | | | | | | | | ● | **1** |
| | | • Number of tasks * | | | | | | | | | | | | | | | | ● | | **1** |
| | | • Task´s variety * | | | | | | | | | | | | | | | | ● | | **1** |
| | | • Dependencies between different tasks * | | | | | | | | | | | | | | | | ● | | **1** |
| | | • Number of different languages in the company * | | | | | | | | | | | | | | | | ● | | **1** |
| | | • Number of different nationalities in the company * | | | | | | | | | | | | | | | | ● | | **1** |
| | | • Number of different time zones * | | | | | | | | | | | | | | | | ● | | **1** |
| | | • Number of joint-ventures * | | | | | | | | | | | | | | | | ● | | **1** |
| | | • Number of contractual partner * | | | | | | | | | | | | | | | | ● | | **1** |
| | | • Number of different financial sources * | | | | | | | | | | | | | | | | ● | | **1** |
| | | • Confidence in contractual partners * | | | | | | | | | | | | | | | | ● | | **1** |
| | | • Lack of transparency (general) | | | | | | ● | | | | | | | | | | | | **1** |
| | | • Lack of cost transparency | | | | | | ● | | | | | | | | | | | | **1** |
| | | • Lack in consistency of activities | | | | | | ● | | | | | | | | | | | | **1** |
| | | **Process complexity** | | | | | | | | | | | | | | | | | | |
| | | • Process complexity (general) | | | | ● | | | | | ● | ● | ● | | | ● | | | | **5** |
| | | • Variety of processes | | | | | | | ● | | | | | | | | | | | **1** |
| | | • Number of process interfaces * | | | | | | | | | | | | | | | | ● | | **1** |
| | | **Production complexity** | | | | | | | | | | | | | | | | | | |
| | | • Production complexity (general) | ● | | | | | | | | | ● | | | | | | | | **2** |
| | | • Production structure | | | | | | | | | | | | | ● | | | | | **1** |
| | | • Number of production locations * | | | | | | | | | | | | | | | | ● | | **1** |
| | | • Manufacturing technology | ● | | | | | | | | | | | | | | | | | **1** |
| | | • Uncertainties in production methods * | | | | | | | | | | | | | | | | ● | | **1** |
| | | • Maintenance complexity (general) | ● | | | | | | | | | | | | | | | | | **1** |
| | | **Planning, control and information complexity** | | | | | | | | | | | | | | | | | | |
| | | • Planning, control and information complexity (general) | | | | | | | | | | ● | | | | | | | | **1** |
| | | • Project time * | | | | | | | | | | | | | | | | ● | | **1** |
| | | • Time pressure in project planning * | | | | | | | | | | | | | | | | ● | | **1** |
| | | • Project team * | | | | | | | | | | | | | | | | ● | | **1** |
| | | • Lack in strategic planning | | | | | | ● | | | | | | | | | | | | **1** |
| | | • Organization´s information technology systems | | | | | | ● | | | | | | | | | | | | **1** |
| | | **Resource complexity** | | | | | | | | | | | | | | | | | | |
| | | • Resources shortage * | | | | | | | | | | | | | | | | ● | | **1** |
| | | **Logistics complexity** | | | | | | | | | | | | | | | | | | |
| | | • Supply chain complexity (general) | | | | | | | | ● | | | | | | | | | | **1** |
| | | **Sales & distribution complexity** | | | | | | | | | | | | | | | | | | |
| | | • Distribution complexity (general) | ● | | | | | | | | | | | | | | | | | **1** |
| | | • Marketing complexity (general) | | | ● | | | | ● | | | | | | | | | | | **2** |
| **General complexity** | | • Variety / Multiplicity | | | | | | | | | | | | ● | | | | | | **1** |
| | | • Dynamics | | | | | | | | | | | | ● | | | | | | **1** |
| | | **Total amount of complexity drivers cited in literature source:** | 7 | 5 | 6 | 8 | 8 | 25 | 7 | 4 | 4 | 10 | 13 | 2 | 2 | 7 | 6 | 38 | 2 | |

For a complexity management, it is necessary to identify and analyze the effects of high complexity and its origin within the company [73]. In literature, the authors describe several effects of high complexity. Furthermore, effects of high complexity are divided in different categories, although the differentiation in 2 categories is preferred in literature.

For example, Meyer [101] divides the effects of high complexity in 2 categories: general effects and effects on company´s cost level. Keuper [76] specifies the effects into cost effects and divides them also in 2 categories: direct costs (e.g. costs for product development or prototype testing) and time-delayed costs (e.g. cost for employees or data processing). Schuh and Schwenk [129], Schuh [130] and Thiebes and Plankert [139] divide the effects of high complexity also in the 2 categories *direct effects* (e.g. costs for product and product development process or quality management) and *indirect effects* (e.g. product cannibalization or distributions system´s effectiveness). However, the divisions made by the already mentioned authors are fairly equal to Keuper´s classification. In contrast, Gießmann [54] divides the effects of high complexity into 4 main categories: *time* (e.g. time for quality checks or process time), *quality* (e.g. process balance or adherence to deadlines), *costs* (e.g. direct costs or indirect costs), and *flexibility* (e.g. design flexibility or process flexibility). Furthermore, Meyer [101] divides the effects of high complexity into 11 main categories: *procurement* (e.g. inventory or resource planning), *research and development* (e.g. development process of new products or product tests), *costs* (e.g. development costs or coordination costs), *logistic* (e.g. inventory or amount of required resources), *marketing* (e.g. pricing or product reclamation), *product* (e.g. product design), *production* (e.g. amount of required tools or controlling effort), *process* (e.g. process planning and controlling or coordination effort), *total company* (e.g. quality or efficiency), *management and controlling* (e.g. calculation effort or economy) and *other parts* (e.g. delivery time or supplied goods or resource variety). Wildemann [151], Benett [10], Schuh and Schwenk [129] and Schuh [130] assign the complexity effects based on variety to the specific parts of the value chain and describe therefore 7 categories: *supplier* (e.g. outsourcing complexity), *research and development* (e.g. effort for product development or product tests), *procurement and logistics* (e.g. stocks or material staging), *production* (e.g. quality or preproduction costs), *distribution* (e.g. marketing costs or coordination effort), *distribution channel* (e.g. costs for product handling or forecast´s accuracy) and *after-sales service* (e.g. stockpiling of spare parts or training for staff members).

For effect´s classification, we analyzed the specific effects from different authors and created intersections between the mentioned complexity effects. In general, we found out that most of the mentioned complexity effects can be aggregated in 4 main categories. Keuper [76], Schuh and Schwenk [129], Thiebes and Plankert [139], Gießmann [54], Meyer [101], Wildemann [151], Benett [10] and Schuh [130] assigned complexity effects under the categories time, quality and costs. Gießmann [54] extended the main categories by adding the category flexibility. In our general framework, we defined 4 main categories for the complexity effects, based on literature: time, quality, costs and flexibility.

Based on the already mentioned categories from different parts of the value chain, which were found in literature, we defined a more general framework for identification, analyzing and evaluation of the complexity effects along the value chain. In general, the value chain is separated in 7 different fields, according to Vogel and Lasch [142]: product development, procurement/purchasing, logistics, production, order processing/distribution/sale, internal supply chain and remanufacturing (see Fig. 1).

This framework is the basis for identification, analysis and evaluation of the complexity effects in product development within our empirical study, because the field product development is also a part of the value chain.

## 2.3 Overview of existing empirical researches

For a researcher, it is important to review existing empirical studies in the same or a similar scientific area before starting an empirical research, because it allows him to get an overview about their objectives, research methodologies and findings [91]. Theories and statements in literature and practice can change over time, so it is important to determine and to review the practical side by an empirical research [71].

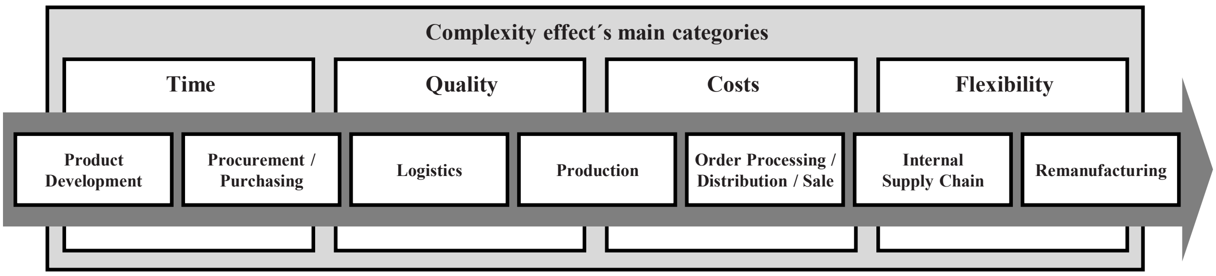


*Figure 1: General framework for identification, analysis and evaluation of the complexity effects in the company and along the value chain*

Following Madu [91], another literature research was performed analogously to the literature research about complexity drivers and their effects (see chapter 2.2). The objective was to identify all existing empirical researches concerning complexity management in manufacturing companies and focusing on complexity drivers and their effects on company´s complexity during the last years. The literature research resulted in 72 different empirical studies in the time period between 1999 and 2015, which are focused on complexity management. These studies were analyzed and synthesized regarding their content, research objectives, focus, field of industry, region/country, research period and applied data collection methodology.

The conducted empirical researches analyzed company's complexity with different objectives, data collection methodologies and focuses. Table 2 presents the results of our literature analysis.

The empirical studies are focused on 8 different fields: *general in manufacturing companies* (N: 32; 44%), *product development* (N: 6; 8%), *production* (N: 3; 4%), *logistics* (N: 5; 7%), *order processing / distribution / sale* (N: 4; 6%), *internal supply chain* (N: 16; 22%), *remanufacturing* (N: 2; 3%) and *other fields* (N: 4; 6%) (see Table 2). Most of the empirical studies are focused on the fields *general in manufacturing industries* and *internal supply chain*. The most applied data collection methodologies are *questionnaires* (N: 37) and *expert interviews* (N: 41).

During our literature analysis, we identified 13 different empirical studies, which are focused on complexity drivers, in the fields general in manufacturing companies (N: 3), production (N: 2), logistics (N: 2), order processing, distribution and sale (N: 2), internal supply chain (N: 2) and remanufacturing (N: 2). However, no empirical study regarding complexity drivers and their effects in product development exists in literature.

Table 2 shows that previous empirical studies regarding product development have been done by the following 6 authors: Li et al. [88], Kim and Wilemon [78, 79], Newman [106], Chronéer and Bergquist [34] and Grussenmeyer and Blecker [62]. The empirical studies were conducted in different countries and fields of industries between the time period 2005 and 2013. In these studies, the authors pursued also different objectives.

In their empirical study, *Li et al.* [88] analyzed the impact of environmental complexity on the choice of management control systems and their effects on product development and process decisions. The study was conducted in China in the year 2002 by using questionnaires and comprises 9 different fields of industries: Engineering, electrical, metal & materials, chemical & pharmaceutical, food, clothing & textile, telecommunication, commercial products and other fields of industries.

*Kim and Wilemon* [78, 79] published 2 papers with results from their empirical researches. In their first study, they identified and analyzed the conditions, which cause complexity in new product development to increase the understanding of an effective complexity management. Furthermore, they identified and analyzed methods for complexity handling. The second study was done with the objective to increase the understanding of the consequences in new product development projects when complexity arises and the competitive advantages for companies, which manage complexity effectively. The 2 studies were conducted in the USA, especially in the states of New York and Connecticut and comprised 5 different fields of industries: Engineering, electrical, industrial photographic paper, medical industry, heating and ventilating as well as air conditioning industry. In their empirical studies, the methodology expert interviews was used for data collection. None information regarding the research period was mentioned in the publications and no complexity drivers were identified.

*Newman* [106] analyzed the complexity of a global new product development process and discussed the question how complexity can be reduced through component´s standardization and modularization. The study was done by using expert interviews. Regarding research period, field of industries and region, no information was given.

*Chronéer and Bergquist* [34] identified and analyzed the complexity regarding research and development projects. The study was conducted in Sweden and comprised 6 different fields of industries: Metal, rubber & plastics, chemical, papers, mining and food & dairy. For data collection, they combined the 3 methodologies expert interviews, case studies and observations. None information regarding the research period was mentioned in literature.

Another empirical study in the field of product development was done by *Grussenmeyer and Blecker* [62]. The study was conducted in Germany and Italy in the year 2011. The objective of their study was the analysis of project´s complexity level in new product development and the evaluation of a specific complexity management in product development. In their research, Grussenmeyer and Blecker [62] used questionnaires for data collection. Regarding the fields of industries, none information was mentioned in literature.

Table 3 summarizes the results of our analysis according to the previous empirical researches regarding complexity management in the field product development. The table shows a list of current existing empirical studies and gives an overview of their specific research period, region, field of industries and applied data collection methodologies. Furthermore, the existing empirical studies are analyzed and evaluated in comparison with the objectives of our empirical study regarding complexity management in product development. The evaluation is based on the following 3 criteria: fulfilled (+ +), partial fulfilled (+) and not fulfilled (-).

*Table 2: Overview about empirical researches in the field of complexity management between 1999 and 2015*

**Explanation according to focus and occurrence in literature:**

| | | |
|---|---|---|
| G | General in manufacturing companies | (N: 32) |
| PD | Product Development | (N: 6) |
| PR | Production | (N: 3) |
| L | Logistics | (N: 5) |
| OPD | Order Processing / Distribution / Sale | (N: 4) |
| SC | Supply Chain internal | (N: 16) |
| R | Remanufacturing | (N: 2) |
| OF | Other Field | (N: 4) |

**Explanation according to field of industry, region/country, research´s period and sample size:**

| | |
|---|---|
| - - - | None information referred |
| X | Applied, but no sample size referred |
| X X | No data collection method and sample size referred |

| Author(s) | Research objectives | Focus | Field of industry | Region / Country | Research´s period (mm/yyyy) | Applied data collection method, sample size and amount of received data: Questionnaire | Expert interviews | Workshop(s) | Case study | Observation | Documentary analysis | Not specified |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Ashmos, Duchon and McDaniel [5] | Identification of organizational responses to environmental complexity. | G | Medical Industry | State of Texas, USA | 1990 | 710 (back 164) | | | 8 | 2 | | |
| Beutin [11] | Identification of product complexity's influence on customer´s benefit. | G | Engineering / Electrical / Metal / Petroleum & Plastics / Chemical / Leather, Glas, Ceramic, Pit & Quarry / Transport | USA, Germany | 03/1998 - 07/1998 | 4,800 (back 981) | | | | | | |
| Maune [95] | Analysis of complexity in the automotive industry. | G | Automotive / Engineering | Germany | - - - | 1,300 (back 126) | | | | | | |
| Novak and Eppinger [108] | Analysis of the connection between product complexity and vertical integration. | G | Automotive | USA, Europe, Japan | - - - | | More than 1,000 | | | | | |
| Chapman and Hyland [33] | Identification and analysis of the aspects of complexity regarding product, process, technological and customer interface. | G | - - - | Sweden, Ireland, Italy, Netherlands, UK and Australia | - - - | 70 (back - - -) | | 70 | 70 | | | |
| Purle [114] | Identification of the influences on complexity and resources induced by company growth. | G | Information Technology / Biotechnology / Material Industry | Germany | 12/2001 - 12/2002 | | 20 | | 3 | | | |
| Eichen *et al.* [42] | Analysis of complexity in the company. | G | - - - | - - - | - - - | | More than 50 | | | | | |
| PricewaterhouseCoopers (2006) [cited in 127] | Identification of management´s complexity perception in the company. | G | - - - | Worldwide | - - - | | | | | | | X X |
| Scheiter, Scheel and Klink [121] | Analysis of the question how much complexity really costs. | G | - - - | - - - | - - - | | | | | | | X X |
| Schuh *et al.* [131] | Analysis of complexity in the automotive industry. | G | Automotive | - - - | - - - | | X | | | | | |
| Closs *et al.* [37] | Identification and analysis of the significant dimensions of product portfolio complexity. | G | Automotive / Engineering / Optics / Computer Industry / Telecommunication / Aircraft | USA | 2005 - 2006 | | 63 | | 6 | 6 | | |
| Maylor, Vidgen and Carver [98] | Identification and analysis of project managers´ perceptions regarding managerial complexity and what makes a project complex to manage. | G | - - - | - - - | - - - | 128 (back - - -) | | 1 | | | | |
| Bayer [7] | Identification of complexity factors and their influences in different company divisions during new product development. | G | - - - | Germany | - - - | 125 (back 107) | | | | | | |
| Gießmann and Lasch [55] | Analysis of company's complexity and demonstration of the relevance for organizations. | G | Engineering | Germany | - - - | 1,496 (back 236) | | | | | | |
| Palmisano [110] | Analysis of capitalizing based on complexity, its increase and effective handling. | G | 33 Industries in the sectors: public, communications, industrial, distribution, financial services | Worldwide (in 60 countries) | 09/2009 – 01/2010 | | 1,541 | | | | | |
| Schoenherr *et al.* [125] | Identification and analysis of enterprise systems complexity. | G | Engineering | Germany | - - - | | More than 36 | | 18 | | | |
| Bosch-Rekveldt *et al.* [20] | Identification of the elements, which contribute to project complexity. | G | Process Engineering | Europe, Asia, Middle-America | - - - | | 18 | | | | | |

**Explanation according to focus and occurrence in literature:**

| | | |
|---|---|---|
| G | General in manufacturing companies | (N: 32) |
| PD | Product Development | (N: 6) |
| PR | Production | (N: 3) |
| L | Logistics | (N: 5) |
| OPD | Order Processing / Distribution / Sale | (N: 4) |
| SC | Supply Chain internal | (N: 16) |
| R | Remanufacturing | (N: 2) |
| OF | Other Field | (N: 4) |

**Explanation according to field of industry, region/country, research´s period and sample size:**

| | |
|---|---|
| - - - | None information referred |
| X | Applied, but no sample size referred |
| X X | No data collection method and sample size referred |

| Author(s) | Research objectives | Focus | Field of industry | Region / Country | Research´s period (mm/yyyy) | Applied data collection method, sample size and amount of received data: Questionnaire | Expert interviews | Workshop(s) | Case study | Observation | Documentary analysis | Not specified |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Parry, Purchase and Mills [111] | Analysis of the nature of complexity and the factors that arise in high value contracts between large organizations. | G | Engineering Service Industry | - - - | 2008 | | 28 | | | | | |
| Wildemann and Voigt [150] | Identification of complexity drivers, their influences and approaches for complexity management in manufacturing companies. | G | Automotive / Engineering / Metal / Plastics / Medical Industry | Germany | 2010-2011 | 2,132 (back 248) | 26 | 4 | 27 | | | |
| Brexendorf [25] | Identification and analysis of complexity in co-operations. | G | Automotive / Engineering / Electrical / Chemical & Pharmaceutical / Others | Germany, Switzerland, Luxembourg, Netherlands, Hungary | 06/2006 - 09/2006 | 405 (back 60) | | | | | | |
| Collinson and Jay [38] | Identification of complexity drivers and their influences on company's performance. | G | Pharmaceutical / Banking / Insurance | Worldwide | 2005 - 2010 | | 200 | 200 | 200 | | 200 | |
| Schey and Roesgen [122] | Identification and analysis of management´s perception regarding complexity in their company. | G | Chemical & Pharmaceutical / Consumer Goods | Europe | - - - | | | | | | | X X |
| Schömann [127] | Identification and analysis of complexity perception in the automotive industry. | G | Automotive | - - - | - - - | | | | | | | X X |
| VDI (2012) [In 22] | Analysis of the complexity perception in the company. | G | - - - | Germany | 05/2012 | n.n. | X | | | | | |
| Götzfried [56] | Analysis and evaluation of company´s complexity induced by product variety. | G | Automotive / Engineering / Consumer Goods | - - - | - - - | 175 (back - - -) | 49 | 21 | 17 | | | |
| Hanisch and Wald [64] | Identification of complexity drivers in project management. | G | Automotive / Engineering / Electrical / Chemical & Pharmaceutical / Information Technology / Telecommunicaton / Puplic Administration / Finance / Provider | Germany, Austria, Switzerland | - - - | X (back 218) | | | | | | |
| Schuh, Froitzheim and Sommer [133] | Analysis of management´s perception regarding complexity in company´s processes. | G | - - - | - - - | - - - | | | | | | | 228 |
| Jäger *et al.* [70] | Identification and analysis regarding complexity in value networks. | G | - - - | - - - | - - - | | 190 | 190 | | | | |
| Schatz, Schöllhammer and Jäger [120] | Analysis of management´s perception regarding complexity in their company. | G | Automotive / Engineering / Electrical / Others | Germany | Spring 2013 | 200 (back - - -) | | | | | | |
| Schöllhammer, Jäger and Bauernhansl [126] | Identification and analysis of company´s complexity level, the complexity perception in the company and the current applied strategies and approaches for complexity handling. | G | Automotive / Engineering / Electrical / Plastics / Chemical / Food / Printing / Aircraft / Information Technology / Service / Consumer Goods / Packaging Industry | Germany | 07/2014 – 10/2014 | 192 (back - - -) | | | | | | |
| Wölfling [152] | Analysis of different kinds of complexity and the application of complexity management strategies and approaches. | G | Engineering / Electrical / Petroleum & Gas / Chemical / Automation / Energy / Traffic & Infrastructure / Telecommunication / Others | Germany | - - - | 65 (back 41) | | | | | | |

**Explanation according to focus and occurrence in literature:**

| | | |
|---|---|---|
| G | General in manufacturing companies | (N: 32) |
| PD | Product Development | (N: 6) |
| PR | Production | (N: 3) |
| L | Logistics | (N: 5) |
| OPD | Order Processing / Distribution / Sale | (N: 4) |
| SC | Supply Chain internal | (N: 16) |
| R | Remanufacturing | (N: 2) |
| OF | Other Field | (N: 4) |

**Explanation according to field of industry, region/country, research´s period and sample size:**

| | |
|---|---|
| - - - | None information referred |
| X | Applied, but no sample size referred |
| X X | No data collection method and sample size referred |

| Author(s) | Research objectives | Focus | Field of industry | Region / Country | Research´s period (mm/yyyy) | Applied data collection method, sample size and amount of received data: Questionnaire | Expert interviews | Workshop(s) | Case study | Observation | Documentary analysis | Not specified |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Tresselt [140] | Investigation of the question how current standards of project management address complexity, and how complex products can be handled adequately. | G | - - - | Germany | 09/2013 - 06/2014 | 4,900 (back 176) | 36 | | | | | |
| Li *et al.* [88] | Analysis of the impact of environmental complexity on the choice of management control systems and their effects on product development and process decisions. | PD | Engineering / Electrical / Metal & Materials / Chemical & Pharmaceutical / Food / Clothing & Textile / Telecommunication / Commercial Products / Others | China | 11/2002 | 850 (back 607) | | | | | | |
| Kim and Wilemon [78] | Identification and analysis of the conditions, which cause complexity in new product development to increase the understanding of an effective complexity management and methods for complexity handling. | PD | Engineering / Electrical / Industrial Photographic Paper / Medical Industry / Heating, Ventilating & Air Conditioning Industry | States of New York and Conneticut, USA | - - - | | 32 | | | | | |
| Newman [106] | Analysis of the complexity of global new product development and discussion of the question how complexity can be reduced through standardization and component modularization. | PD | - - - | - - - | - - - | | 16 | | | | X | |
| Chronéer and Bergquist [34] | Identification and analysis of complexity regarding R&D projects. | PD | Metal / Rubber & Plastics / Chemical / Papers / Mining / Food & Dairy | Sweden | - - - | | 71 | | 50 | 50 | | |
| Kim and Wilemon [79] | Increasing the understanding of the consequences in new product development projects when complexity arises and the competitive advantages for companies that effectively manage complexity. | PD | Engineering / Electrical / Industrial Photographic Paper / Medical Industry / Heating, Ventilating & Air Conditioning Industry | States of New York and Conneticut, USA | - - - | | 32 | | | | | |
| Grussenmeyer and Blecker [62] | Analysis of project's complexity level in the new product development and evaluation of a specific complexity management. | PD | - - - | Germany, Italy | 01/2011 - 06/2011 | 23 (back - - -) | | | | | | |
| Größler, Grübner and Milling [59] | Identification of complexity drivers in production. | PR | Engineering | Europe, South America, Asian Pacific Area | 2002 | 558 (back - - -) | | | | | | |
| Grübner [60] | Identification of complexity drivers and their influences in production in the metal and electrical industry. | PR | Engineering / Electrical & Optics / Metal | Worldwide | 2003 | 558 (back - - -) | | | | | | |
| Fässberg *et al.* [46] | Identification and analysis of production complexity from the perspective of different functions or roles within the production system. | PR | Automotive / Electrical | Sweden | 09/2010 - 12/2010 | | X | X | | 3 | | |
| Westphal [148] | Analysis of complexity in manufacturing logistics. | L | Engineering / Metal | Germany | 1995 - 1997 | 380 (back 66) | | | | | | |
| Mayer [96] | Identification of complexity drivers and applied management methods in logistics. | L | Automotive / Engineering / Furniture / Safety | Germany | - - - | | 5 | | | 5 | | |
| Meyer [101] | Analysis of logistics' complexity, identification of complexity drivers and their influences. | L | Automotive / Medical Industry / Logistics Service Industry | - - - | 11/2005 - 04/2006 | 22 (back - - -) | 8 | 25 | | | | |

**Explanation according to focus and occurrence in literature:**

| | | |
|---|---|---|
| G | General in manufacturing companies | (N: 32) |
| PD | Product Development | (N: 6) |
| PR | Production | (N: 3) |
| L | Logistics | (N: 5) |
| OPD | Order Processing / Distribution / Sale | (N: 4) |
| SC | Supply Chain internal | (N: 16) |
| R | Remanufacturing | (N: 2) |
| OF | Other Field | (N: 4) |

**Explanation according to field of industry, region/country, research´s period and sample size:**

| | |
|---|---|
| - - - | None information referred |
| X | Applied, but no sample size referred |
| X X | No data collection method and sample size referred |

| Author(s) | Research objectives | Focus | Field of industry | Region / Country | Research´s period (mm/yyyy) | Applied data collection method, sample size and amount of received data: Questionnaire | Expert interviews | Workshop(s) | Case study | Observation | Documentary analysis | Not specified |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Gießmann [54] | Analysis of complexity and its perception in procurement logistics. | L | Automotive / Engineering / Electrical / Metal / Plastics / Chemical & Pharmaceutical / Glas, Ceramic, Pit & Quarry / Food / Lumber, Papers & Furniture / Clothing & Textile / Aircraft / Others | Germany | 2008 | 1,496 (back 236) | | | | | | |
| BVL [30] | Analysis of the current status regarding complexity management and its handling in the field of logistics. | L | Manufacturing Industry / Trading / Logistics Service Industry | Germany | Summer 2014 | 104 (back - - -) | | | | | | |
| Raufeisen [117] | Evaluation of complexity in the field order processing. | OPD | Engineering / Metal | - - - | - - - | | X | | 3 | | X | |
| Buob [29] | Analysis and evaluation of order processing complexity. | OPD | Insurance | Switzerland | - - - | 2,680 (back 341) | 17 | | | | | |
| Kersten, Lammers and Skirde [75] | Analysis of complexity perception in the field of distribution, identification of complexity drivers and development of approaches for complexity improvement. | OPD | - - - | Germany | 06/2010 - 10/2011 | | 8 | 3 | 8 | | | |
| Lammers [85] | Analysis of complexity perception in the field of distribution, identification of complexity drivers and development of approaches for complexity improvement. | OPD | Chemical / Medical Industry / Safety Equipment / Wholesale / Service Industry / Transport / Maritime Industry | Germany | 06/2010 - 10/2011 | | 8 | 3 | 8 | | | |
| Miragliotta, Perona and Portioli-Staudacher [102] | Analysis of supply chain complexity in the Italian household appliance industry. | SC | Household Appliance Industry | Italy | - - - | | X | | 13 | | | |
| Perona and Miragliotta [112] | Investigation of the question how complexity can affect manufacturing company’s performances and its supply chain. | SC | Household Appliance Industry | Italy | - - - | X | X | | 14 | | | |
| Geimer [51] | Analysis of supply chain complexity. | SC | Automotive / Engineering / Electrical / Chemical / Telecommunication / Life Sciences / Consumer Goods | Europe | 06/2004 - 10/2004 | 45 (back - - -) | 45 | | | | | |
| Wu, Frizelle and Efstathiou [153] | Identification and analysis of the relationship between costs and supply chain complexity indices. | SC | Engineering / Chemical | UK | - - - | | X | | 2 | X | | |
| Abdelkafi [1] | Analysis of supply chain complexity and identification of the main influencing variables. | SC | Medical Industry | Germany | - - - | | X | | 1 | X | | |
| Bozarth *et al.* [21] | Analysis and evaluation of supply chain complexity. | SC | Engineering / Electrical / Transport | Austria, Finland, Japan, Germany, Sweden, USA, South Korea | 2005 - 2007 | 4,807 (back - - -) | | | | | | |
| Carbonara and Giannoccaro [31] | Evaluation of supply chain complexity by measuring a set of supply chain features. | SC | Furniture Industry / Clothing & Textile | Italy | - - - | X | X | | 2 | | X | |
| Caridi, Pero and Sianesi [32] | Analysis of the question how innovations affect supply chain management decisions and supply chain complexity. | SC | Automotive / Furniture Industry / Tractor / Household Appliances / Aircraft / Medical Industry | Italy | - - - | X | X | | 20 | | X | |

| Explanation according to focus and occurrence in literature: | | | Explanation according to field of industry, region/country, research´s period and sample size: | | | Applied data collection method, sample size and amount of received data | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| G General in manufacturing companies (N: 32)<br>PD Product Development (N: 6)<br>PR Production (N: 3)<br>L Logistics (N: 5)<br>OPD Order Processing / Distribution / Sale (N: 4)<br>SC Supply Chain internal (N: 16)<br>R Remanufacturing (N: 2)<br>OF Other Field (N: 4) | | | - - - None information referred<br>X Applied, but no sample size referred<br>X X No data collection method and sample size referred | | | | | | | | | |
| **Author(s)** | **Research objectives** | **Focus** | **Field of industry** | **Region / Country** | **Research´s period (mm/yyyy)** | **Questionnaire** | **Expert interviews** | **Workshop(s)** | **Case study** | **Observation** | **Documentary analysis** | **Not specified** |
| Klagge and Blank [81] | Analysis of supply chain complexity and identification of the complexity drivers. | SC | - - - | Germany | 2011 | | 40 | | | | | |
| Manuj and Sahin [93] | Analysis of the supply chain and the supply chain decision-making complexity. | SC | - - - | - - - | - - - | | 11 | | | | | |
| Alflayyeh [2] | Investigation of the question how companies can manage complexity´s challenges through effective network practices and how supply chain complexity can be measured. | SC | Engineering / Service Industry | USA | - - - | 1,500 (back 193) | | | | | | |
| Gerschberger and Hohensinn [52] | Analysis of the development of supply chain complexity within the 4 perspectives market, process, product, and organization. | SC | Engineering | Austria | - - - | | 24 | 1 | 1 | | | |
| Leeuw, Grotenhuis and Goor [87] | Identification of complexity drivers in the supply chain. | SC | Wholesale | Netherlands | - - - | X | X | | 5 | | | |
| Subramanian and Rahman [137] | Analysis of supply chain complexity and development of appropriate supply chain strategies based on material flow and contractual relationships. | SC | Automotive | Worldwide | - - - | | | | 1 | | | |
| Brandon-Jones, Squire and Rossenberg [23] | Analysis of the dimensions regarding supply base complexity, the effects and its management. | SC | Engineering | UK | - - - | 1,200 (back 264) | | | | | | |
| Subramanian, Rahman and Abdulrahman [138] | Identification of tangible and intangible factors regarding sourcing complexity and investigation of the question how well the companies currently handle those elements. | SC | Automotive / Electrical / Metal / Plastics / Papers / Textile | China | 10/2011 - 05/2012 | 600 (back 101) | | | | | | |
| Haumann *et al.* [65] | Identification and evaluation of complexity drivers and their influences in the field of remanufacturing. | R | - - - | - - - | - - - | | X | | | | | |
| Seifert *et al.* [134] | Identification and evaluation of complexity drivers and their influences in the field remanufacturing. | R | - - - | - - - | - - - | X | X | X | | | X | |
| Blockus [16] | Analysis of complexity in the service industry. | OF | Banking / Insurance / Telecommunication | Switzerland | - - - | | 21 | | 6 | | | |
| He *et al.* [67] | Evaluation of project complexity by identifying the key factors. | OF | - - - | - - - | - - - | X | X | | | | | |
| Braun [24] | Examination of an effective model based on internal service complexity. | OF | - - - | Germany | Summer 2014 | 946 (back 710) | | | | | | |
| Maturity [94] | Analysis of management´s perception regarding information technology complexity. | OF | Automotive / Engineering / Electrical / Chemical & Pharmaceutical / Food / Finance & Insurance / Building Industry / Biotechnology / Medical Industry / Information Technology / Consumer Goods / Transport & Logistics / Administration & Civil Service | Europe | May 2015 | | | | | | | X X |

*Table 3: List of existing empirical researches focused on product development and their content*

| Author(s) | | Li et al. [88] | Kim and Wilemon [78] | Newman [106] | Chronéer and Bergquist [34] | Kim and Wilemon [79] | Grussenmeyer and Blecker [62] |
|---|---|---|---|---|---|---|---|
| **Research period** | | 2002 | - - - | - - - | - - - | - - - | 2011 |
| **Region / Country** | | China | USA | - - - | Sweden | USA | Germany, Italy |
| **Field of Industries** | Automotive | | | | | | |
| | Engineering | ● | ● | | | ● | |
| | Electrical & Optics | ● | ● | | | ● | |
| | Metal | ● | | | ● | | |
| | Petroleum & Plastics | | | | ● | | |
| | Chemical & Pharmaceutical | ● | | | ● | | |
| | Glas, Ceramic, Pit & Quarry | | | | ● | | |
| | Food, Forage & Tobacco | ● | | | ● | | |
| | Lumber, Papers, Printing & Furniture | | ● | | ● | ● | |
| | Clothing & Textile | ● | | | | | |
| | Others | ● | ● | | | ● | |
| **Data collection methodology** | Questionnaire | ● | | | | | ● |
| | Expert interviews | | ● | ● | ● | ● | |
| | Workshop(s) | | | | | | |
| | Case study | | | | ● | | |
| | Observation | | | | ● | | |
| | Documentary analysis | | | ● | | | |
| **Main research objectives** | Complexity driver´s identification and analysis | - | + | - | - | - | - |
| | Identification and analysis of complexity driver´s effects | - | - | - | - | - | - |

**Evaluation criteria:**

| | | |
|---|---|---|
| fulfilled | (+ +) | Specific complexity drivers and their effects are described in detail. |
| partial fulfilled | (+) | Complexity drivers and their effects are only mentioned but not described in detail. |
| not fulfilled | (-) | No information regarding complexity drivers and their effects is referred to. |

Analyzing the existing empirical studies regarding complexity in product development (see Table 3) as well as other fields (e.g. general in manufacturing companies, production, logistics, etc.), we come to the conclusion that no empirical research focusing on complexity management in product development in manufacturing companies in Germany, including the identification and analysis of complexity drivers and their effects exists yet. By presenting a systematic, explicit and reproducible empirical research regarding product development in manufacturing companies in Germany, we want to close the aforementioned literature gap.

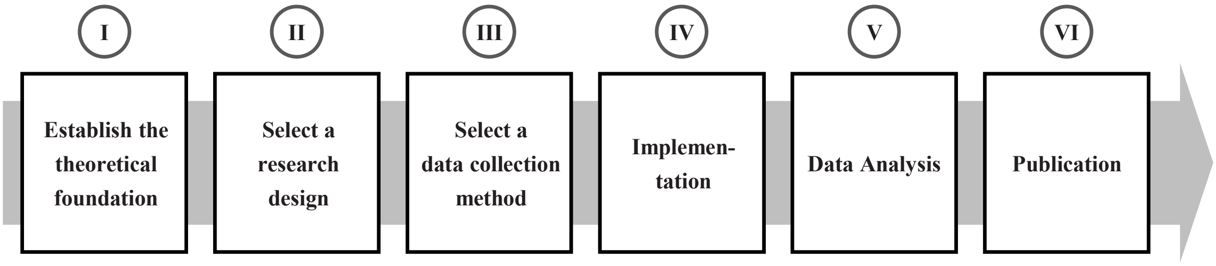


*Figure 2: Six stage systematic approach for empirical research*

## 3 EMPIRICAL RESEARCH

### 3.1 Research methodology and objectives

In this empirical research, we followed the methodology of Flynn et al. [50]. Based on social sciences, Flynn *et al.* [50] developed a 6 stage systematic approach for conducting an empirical research (see Fig. 2). This helps the researcher describing what happens in the real world [105]. The approach starts with the determination of the theoretical foundation (stage I) and the research design, which is applied to the research problem and the theoretical foundation (stage II). In stage III, the data collection method is selected. Data collection is an important part of an empirical research [71]. Several methods are described in literature and can be combined for better results [50, 71]. The data collection method, which is mostly used, is the questionnaire. It is a useful technique for single and multiple case studies as well as panel studies and focus groups. Next, the data collection methods and sample description for research´s implementation are selected in stage IV. Before preparing the research report for publication (stage VI), the collected data is processed and analyzed in stage V [50].

The first step in performing an empirical research is to define the research questions and objectives. Empirical research can be used to document the state-of-the-art in different fields of research [50]. In this paper, we use an empirical research to document the current state in practice regarding the complexity drivers and their effects in the field of product development in the manufacturing industry of Germany. A further objective is to compare literature findings with the results from our empirical research to identify commonalities and differences. Based on our introduction, the literature review and the identified research gap, we determined 4 further research questions, focused on our empiricism (called empirical research question) to close the research gap:

*RQ 3:* How is the product development of the participating companies characterized regarding product and variant range; length of product life cycle and product development process; amount of applied components, materials, technologies and processes; the height of the own value adding percentage as well as organization´s influence on product development´s complexity?

*RQ 4:* What are the main complexity drivers in product development and what interdependencies exist between them? Can the complexity drivers be aggregated to factors?

*RQ 5:* What influences have high complexity and especially the complexity drivers on product development's complexity?

*RQ 6:* What are the significant differences and commonalities between the literature and practical (empirical) results?

Regarding the limitations of our research approach, we decided to limit the scope of our empirical research by analyzing only the German manufacturing industry, because the German manufacturing industry and its product development is one of the most leading industries in the world compared to other countries and/or field of industries. Furthermore, by our limitation we want to ensure that this research is manageable. In addition, we had only data from the German manufacturing industry available for our empirical research. Data from other countries and/or field of industries was not available at the time our research was conducted.

### 3.2 Questionnaire´s design, data collection methodology, sample description and statistical analysis

The implementation of an empirical research starts with the selection of the data collection method and the sample description [50]. For data collection, a standardized questionnaire with 15 questions and a fixed response possibility was applied in this research, because the questionnaire is the most used data collection method in scientific research and provides the best results regarding reliability, validity and generalization [50].

The data was collected from a stratified random sample. The sample was taken out of a given population of 17,862 manufacturing companies, located in Germany with more than 50 employees. The research was conducted in 2015 and 2016. At the beginning of our empirical study in 2015, the population of 17,862 manufacturing companies was determined based on the Amadeus database. In the Amadeus database, all manufacturing companies of Germany are documented. In our research, we selected only companies with more than 50 employees, because the complexity phenomenon primarily occurs in bigger companies rather than in smaller.

As already mentioned, we used a standardized questionnaire for data collection. The questionnaire was sent in 2 stages by e-mail to 3,086 companies, exclusive of service and printing companies. According to Mayer [97], we use a 2 stage empirical research to increase the amount of responded questionnaires and thus the research´s quality. To increase answer´s significance, the companies were asked in the cover letter to send the questionnaire to an experienced employee from the product development department. However, this is no guarantee that the questionnaire is send to the right person within the company and/or product development department. In this research, we assume that the responded questionnaires were answered by the right persons. All participants were assured that only aggregated data would be presented. The stratified random sample size (n = 1,565) is calculated based on the methodology of Mayer [97] and Raab, Poost and Eichhorn [115]. The input parameters are the population (N = 17,862); a safety factor (t = 2); the proportion of the elements within the random sample, which fulfills the feature characteristic (p = 0.5); and the sampling error (d = 0.05). The population comprises the amount of documented companies in the Amadeus database and the safety factor depends on respondents´ level of significance.

For questionnaire´s design, the questions with the same focus are clustered in main categories to increase understanding and transparency [84]. The questionnaire in this study was structured in 3 main parts: *general information regarding the respondents* (company size, field of industry and respondent´s position in the company); *general information about product developments characteristics* (dimension of product and variant range; length of product life cycle and product development process; amount of applied components, materials, technologies and processes; as well as the height of the own value adding percentage) and *information about the complexity drivers and their effects*.

The questions were formulated based on the research questions. To ensure representative results, the questions must be formulated explicit and easily [84]. In the questionnaire, the scale items were designed as statements and the interviewees were asked about their assessment. For measurement, we used nominal scales (yes / no) and ordinal scales (1 – no influence; 2 – small influence; …; 5 – strong influence; 6 – very strong influence) to increase reliability, validity and comparability. Other scale items such as interval or rational are not used in this research, because these scales have another focus and are not applicable in this research.

Before starting the empirical research, a first version of the questionnaire was pretested to identify and remove systematic gaps and inconsistencies [68]. In 2014, our questionnaire was pretested by 40 experts from the potential target group. The objective was to check and refine the wording, understanding, relevance as well as the measurement instrument. Furthermore, the questionnaire length and the time for questionnaire´s responding was checked. Based on pretest´s results and comments from the experts, the questionnaire was revised and checked again by a smaller group of experts.

According to Flynn et al. [50] and Moody [105], a questionnaire has to be analyzed by using statistical methods. Several data analysis techniques or statistical tests for statistical analysis exist in scientific literature and can be used by a researcher, although there is no general rule to select a particular approach [91]. Montoya-Weiss and Calantone [104] classified the data analysis techniques into 4 groups: *descriptive statistics* (e.g. means, frequencies and proportions); *tests of differences or similarities* (e.g. t-test); *measures of dimensionalities* (e.g. factor analysis) and *statistical interpretation of parametes* (e.g. correlation analysis). For answering the empirical research questions, we analyzed the empirical findings by using several different data analysis techniques without a limitation. However, some of the results were not significant. In summary, we used the data analysis techniques from the groups *descriptive statistics*, *measures of dimensionalities* and *statistical interpretation of parameters*. The group *tests of differences or similarities* was not applied in this research, because the data analysis techniques from these group are used for testing hypotheses. Since we did not propose hypotheses or did an experiment in our research, we did not use these data analysis techniques.

## 4 ANALYSIS OF EMPIRICAL RESEARCH AND FINDINGS

### 4.1 Sample results and data validation

For data collection, 3,086 manufacturing companies with more than 50 employees, located in Germany, were questioned. The questionnaire was sent by e-mail to them. The Amadeus-Database lists mostly general email-addresses of companies. Therefore, the inquiry emails sent to those addresses, included the request to forward the email to an experienced employee in the department of product development.

Next, the net sample size was calculated by reducing the total sample size based on the amount of e-mails that were undeliverable or rejected by the companies. The net sample size is needed for response rate's counting [54]. In our research, the final sample size consisted of 2,817 companies. In total, 295 questionnaires were answered completely and resulted in a response rate of 10.5 percent, which is an acceptable response rate according to Meffert [99]. Industry's range contained

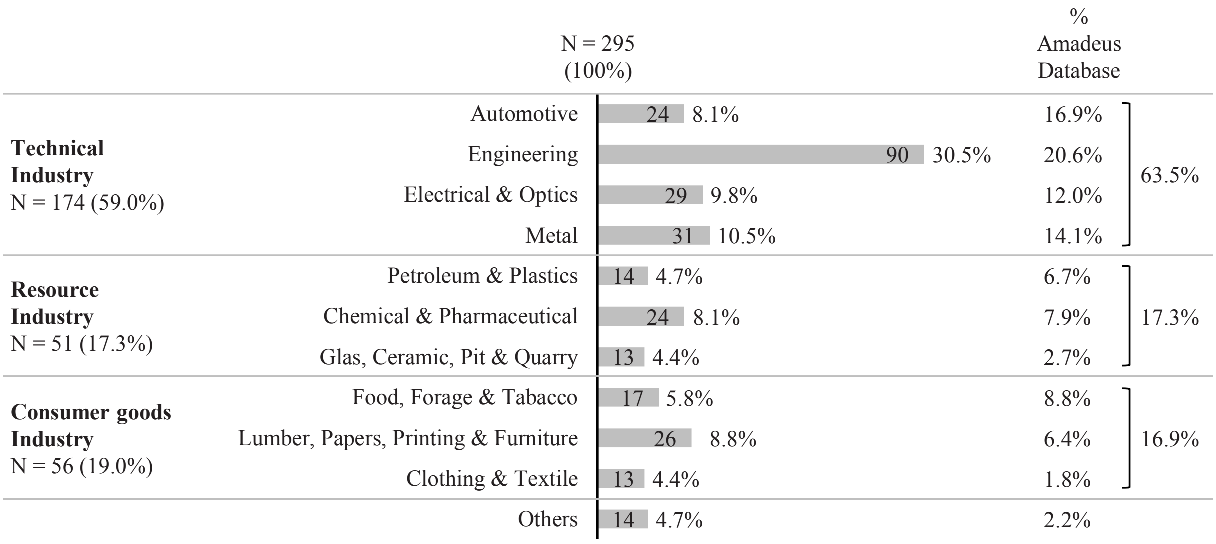


*Figure 3: Frequency of received questionnaires according to industry and comparison of results and database's percentage*

11 different fields of industry. According to their characteristics, the identified industry branches were clustered in 4 industry clusters: Technical industries, resource industries, consumer goods industry and others. The technical industry is the largest industry cluster and comprises about 60 percent of the respondents: engineering (30.5%), metal (10.5%), electrical and optics (9.8%), automotive (8.1%) (see Fig. 3). Based on the Amadeus database, the technical industry is traditionally Germany's major field of industry with a percentage of 63.5 percent. For result's validation, the percentage of the empirical research was compared with the percentage of the database to identify differences and communalities. In our research, the percentage of empirical research and database are very close in all industry clusters. The empirical findings are therefore representative and can be generalized.

In the next step, the number of employees and the position profile of the respondents were analyzed (see Fig. 4). With 61.8 percent, the small and middle-sized companies formed the biggest group in our empirical research. Larger companies with more than 250 employees represent 38.2 percent. Based on these results, it can be concluded that small and middle-sized companies are highly interested in empirical studies regarding complexity management and especially in product development.

The analysis of the respondent's position profile shows that 80 percent of the respondents can be assigned to the category upper management (see Fig. 4). This category comprises the following 3 groups: Presidents, CEOs and COOs (18.0%); directors and division managers (26.1%); senior managers and department managers (35.9%). This result shows that complexity in product development is an important issue for company´s management.

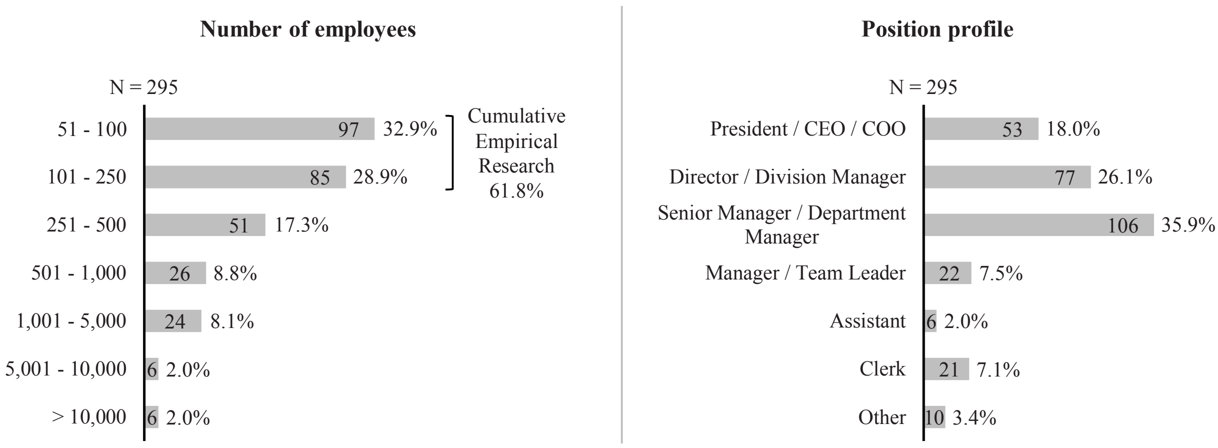


*Figure 4: Overview about the number of employees and the position profile of the respondents*

To answer RQ3 and for analyzing the product development characteristic in general of the participating companies, we requested the following properties in 10 different questions (Q4 – Q13): Dimensions of product range and variant range; length of product life cycle and product development process; amount of applied components, materials, technologies and process; height of the own value adding percentage and organization´s influence on product development´s complexity. The results are described in Figure 5. Approximately 75 percent of the companies are characterized by a medium and big product (Q4) and variant range (Q5). Based on the analysis of questions 6 and 7, more than 50 percent of the developed products have a life cycle length of more than 72 months (Q6), but approximately 70 percent of the respondents specified that the length of product development process is less than 25 months (Q7). Furthermore, the majority of companies indicate that their products consist of many different components (Q8), materials (Q9) as well as technologies (Q10) and the product development process consists of many different processes (Q11). Furthermore, the percentage of the own value adding activity in product development was analyzed. However, there was no explicit tendency recognizable (Q12). In literature, organizational complexity and value added complexity are general complexity drivers in the company [142]. To analyze organization's influence on product development´s complexity, the respondents were questioned about their evaluation. More than 75 percent of the respondents specified that the organization has no negative influence on product development´s complexity (Q13). Comparing this result with literature, there is a discrepancy, especially regarding the complexity drivers in product development, which are described in chapter 2.2. In literature, 9 authors described 28 different organizational complexity drivers, which are responsible for increasing complexity in the company and especially in product development. It would be interesting to investigate the reasons for this discrepancy wihin a further empirical research (e.g. investigation through expert interviews).

## 4.2 Complexity drivers and their effects on company´s complexity

We started our pretest by using the complexity drivers in product development which are already mentioned in literature and published before 2015 (N: 72) (see chapter 2.2). Furthermore, we added additional complexity drivers from other fields along the value chain to extend the amount of complexity drivers in total, because product development has an influence on all parts of the value chain (N: 44). The complexity drivers originate in the following fields: *General in manufacturing companies* [14, 15, 124], *procurement and purchasing* [55], *logistics* [54, 86], *production* [44, 128], *order processing, distribution and sales* [29] as well as *internal supply chain* [135] and *remanufacturing* [65]. In total, the collection of the complexity drivers used in our pretest comprises 116 different complexity drivers. One of the objectives of doing the pretest was to ask the experts about the relevance of the different complexity drivers, because we wanted to reduce the number of drivers for the final questionnaire to the truly relevant drivers. As a result of our pretest, from the expert´s view, only 59 complexity drivers of the total amount of 116 are relevant and should be used in the final questionnaire and empirical research. Furthermore, they mentioned additional important and relevant complexity drivers that we added to our questionnaire (N: 5). The final questionnaire comprises 64 complexity drivers in total. Another surprising result is that the internal complexity drivers *product complexity (general)*, *product portfolio complexity (general)*, *technological complexity (general)* and *development complexity (general)* are not relevant from expert´s view, although these drivers are fundamentally connected to the product development process (see Table 4). One reason is that these drivers are general drivers and are already known and handled by the experts. Another reason is that the experts want to have some further information about specific complexity drivers, which are important for complexity management in product development. Thus, these general drivers do not need further analysis.

Table 4 presents an overview about the different complexity drivers, which are mentioned in literature in product development and the other fields along the value chain as well as the results of expert´s evaluation regarding the relevance of the different drivers.

Answering the forth research question, we used different statistical methods for analyzing the questionnaire results. The main complexity drivers in product development in each driver category were identified by using the descriptive statistics. In this research, 64 different complexity drivers were evaluated by the respondents within an ordinal scale (1-no influence; 2-small influence;…; 5-strong influence; 6-very strong influence) according to their influence on product development´s complexity. The complexity drivers, which are evaluated by more than 50 percent of the respondents with a *strong* or *very strong* influence on product development's complexity are identified as the main complexity drivers. As already mentioned, 64 complexity drivers were included in the questionnaire, but only 30 drivers were regarded by the respondents in different fields of industry as drivers that have a strong or very strong influence in principle (see Table 4, reference No. 4 in the field explanation). Table 4 presents the identified main complexity drivers in product development in the different fields of industry, which are identified in our empirical research. As a result of our research, some industries are influenced by more complexity drivers than other industries. For example, the following fields of industries are influenced by 12 main complexity drivers: Automotive, petroleum & plastics as well as food, forage & tobacco. In contrast, the electrical & optics industry or the chemical & pharmaceutical industry are influenced by only 6 drivers.

A further result of our empirical research is that some complexity drivers are more important than other drivers, because these drivers occur in most fields of industries. These include the following complexity drivers: *Market´s economic factors*, *individuality of customer demands*, *number and strength of competitors*, *product range/portfolio* and *amount of simultaneous projects*. The driver *variety of customer requirements* influence every field of industry (see Table 4). Furthermore, product development's complexity is influenced to the same extend by external as well as internal complexity drivers (14 external drivers vs. 16 internal drivers). Comparing this result with literature (see chapter 2.2), most of the described complexity drivers in literature belong to the main category internal complexity drivers (28 external drivers vs. 79 internal drivers). Thus, there is also a discrepancy between literature and practice. These results draw to the conclusion that internal complexity drivers can be handled by the company itself so they are not considered as problems whereas external complexity drivers cannot be handled easily and are therefore regarded more as problems. Thus, less internal complexity drivers are described by the respondents in our research as drivers with a high influence than it would be expected when looking at the findings in literature.

As also seen in Table 4, the different fields of industries are influenced by individual main complexity drivers. The *technical industries* are characterized by 6 main complexity drivers: *Market´s economic factors*, *variety of customer requirements*, *individuality of customer demands*, *number and strength of competitors*, *product range/portfolio* and *amount of simultaneous projects*.

The *resource industries* and the consumer goods industry are also characterized by *variety of customer requirement* and *individuality of customer demands*. Furthermore, the resource industries are influenced by the 3 complexity drivers *political framework conditions*, *demand´s dynamics* as well as *technological progress* and the consumer goods industry is characterized by *market´s economic factors*, *number and strength of competitors* as well as *product range/portfolio*.

In summary, the external complexity driver categories *general market-related complexity*, *demand complexity* and *competitive complexity* and their specific drivers are most important for complexity management in product development. In contrast, the complexity drivers from the categories *society complexity*, *technological complexity (external and internal), supply complexity*, *target complexity*, *customer complexity*, *product and product portfolio complexity*, *product development complexity*, *organizational complexity*, *production complexity*, *process complexity*, *planning, control and information complexity* as well as *logistics complexity*, *sales and distribution complexity* and the *general complexity drivers* have mostly no strong or very strong influence on product development´s complexity and do not seem to be so important for complexity management in product development.

It was surprising that the complexity driver categories *technological complexity (external and internal), product and product portfolio complexity as well as product development complexity* and their specific drivers did not have a strong or very strong influence on product development´s complexity in total, although product development is characterized by these categories.

The comparison between literature´s complexity drivers and the complexity drivers identified in this empirical research is shown in chapter 4.3.

Next, a *correlations analysis* was conducted to test the bivariate relationships and interdependences between the 64 different complexity drivers. The results are documented in the appendix (Table 9 Part A – C). Based on the correlations analysis, 29 strong (correlation coefficient $0.6 < x \leq 0.8$) and 3 very strong correlations (correlation coefficient $0.8 < x \leq 1.0$) were identified and clustered according to their origin and the literature's main complexity driver categories (see Table 5). Strong correlations between different complexity drivers occur in the following categories: *Society complexity*, *demand complexity*, *general market-related complexity*, *technological complexity* (external and internal), *supply complexity*, *target complexity*, *customer complexity*, *product and product portfolio complexity*, *product development complexity*, *production complexity*, *process complexity* as well as *planning, control and information complexity* and *organizational complexity*. Beyond, in the 2 categories *process complexity* and *planning, control and information complexity*, very strong correlations occur between the different complexity drivers *process degree of cross-linking* and *amount of process interfaces*, *information flow's dynamics and variety* as well as *company's control level of detail* and *requirements of company's control*. Overall, the correlations analysis provides 2,080 correlations, however 88.9 percent are weak correlations (correlation coefficient $0.2 < x \leq 0.4$). Only 6.5 percent are about medium correlations (correlation coefficient $0.4 < x \leq 0.6$) and 1.4 percent strong correlations.

Based on the correlation analysis, a *factor analysis* with *varimax rotation* was applied for complexity driver's aggregation. We used the statistic software SPSS 21 to perform the factor analysis and to list the eigenvalues associated with each linear component (factor) before extraction, after extraction and after rotation (see Table 10 appendix). Before extraction, 64 linear components (factors) are identified within the data set. In this case, the amount of eigenvectors are the same as variables and so there will be as many factors as variables. The eigenvalues are associated with each factor and represent the variance, which is explained by that particular linear component [47]. In our study, factor 1 explains 25,276 percent of total variance. To identify the relevant amount of factors, which explains cumulative more than 50 percent, we extract only factors with eigenvalues greater than 2. All factors with eigenvalues of 2 and less are ignored. For optimizing the factor structure, we used the varimax rotation. As a result of our factor analysis, we identified 7 factors, reflecting the complexity drivers. The identified factors clarify 51 percent of the 64 complexity drivers, thus these factors are important for a company´s complexity management. The first factor describes a company`s complexity. Product and technology complexity load onto the second factor. The third and fourth factor reflects the customer complexity and the market complexity. Supply complexity loads onto the fifth factor. The sixth factor describes environmental and society and the seventh factor describes company`s target complexity. Table 6 presents an overview about the identified factors und their factor load's ranges.

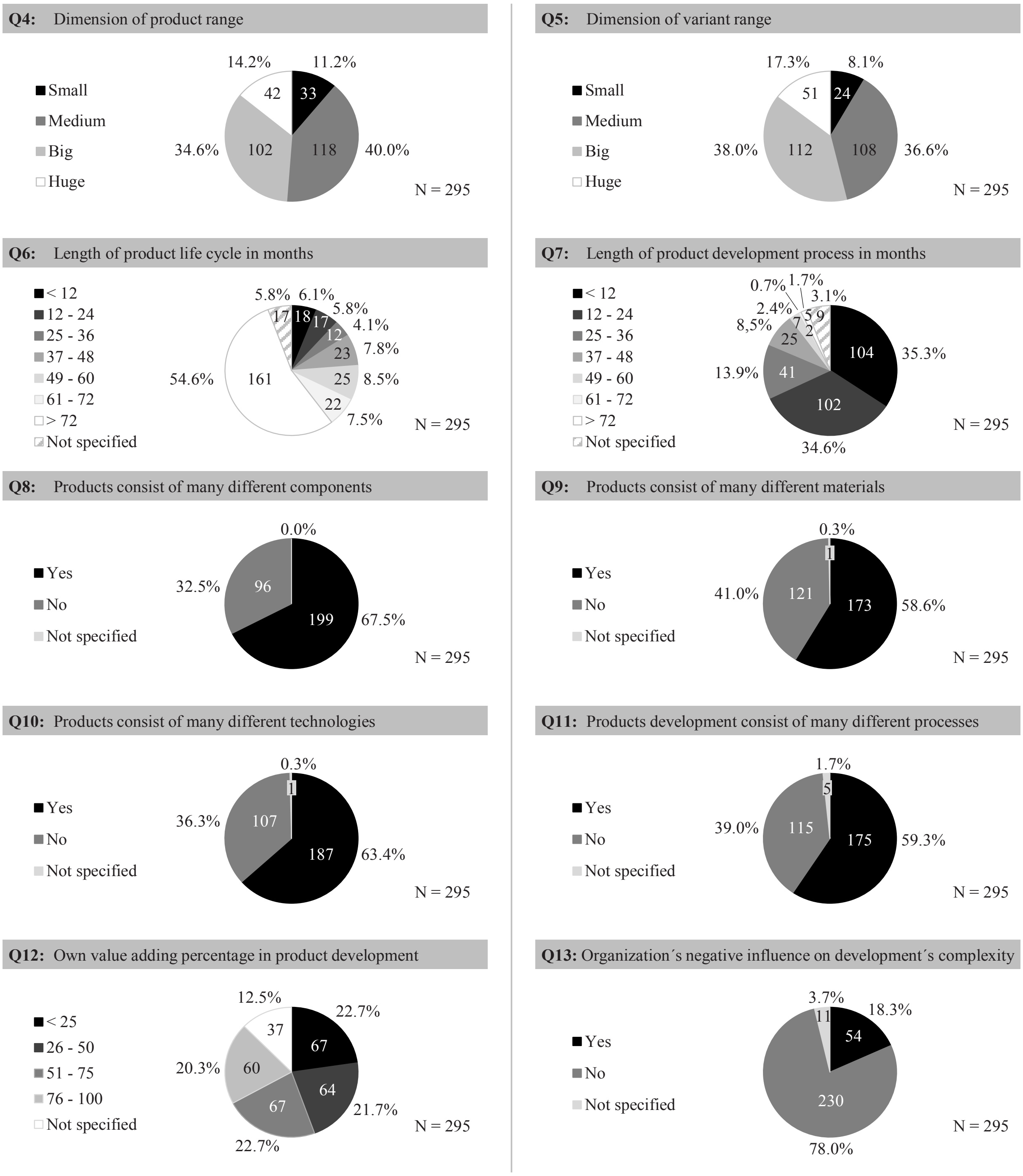


*Figure 5: Analysis results regarding the product development characteristic of the participating companies*

*Table 4: Overview about the complexity drivers, which are evaluated by the respondents with a strong and very strong influence on product development*

**Explanation:**

[1] Complexity drivers, which are documented in the literature review, focused on product development (see chapter 2.2) (N: 72)

[2] Complexity drivers, which are documented in literature in other fields along the value chain and general in manufacturing companies (N: 44)

[3] Additional complexity drivers, mentioned by the practice during expert interviews (N: 5)

[4] Complexity drivers, which were regarded by the respondents as drivers that have a strong or very strong influence (N: 30)

RfQ Relevant (R) for questionnaire based on the results of our pretest and several expert interviews (N: 64)

| | | | **Field of Industries** | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Technical Industries | | | | Resource Industry | | | Consumer goods Industry | | | | |
| **Origin** | **Specific complexity drivers in each category** | **RfQ** | Automotive | Engineering | Electrical & Optics | Metal | Petroleum & Plastics | Chemical & Pharmaceutical | Glas, Ceramic, Pit & Quarry | Food, Forage & Tobacco | Lumber, Papers, Printing & Furniture | Clothing & Textile | Others | **Total** |
| **External complexity** | **Society complexity** | | | | | | | | | | | | | |
| | Environmental complexity (general) [1] | | | | | | | | | | | | | |
| | Value change & value awareness [1, 4] | R | | | | | ● | | | | | | | **1** |
| | Environmental awareness in population [2] | R | | | | | | | | | | | | |
| | Ecological conditions / factors [1] | R | | | | | | | | | | | | |
| | Political framework conditions [1, 4] | R | | | | | ● | | ● | | | | | **2** |
| | Legal factors [1, 4] | R | | | | | | ● | | ● | | | ● | **3** |
| | Change of populations structure [1] | | | | | | | | | | | | | |
| | Standards and regulations [1] | | | | | | | | | | | | | |
| | Turbulences in company´s environment [1] | | | | | | | | | | | | | |
| | Interdependencies between environmental factors [1] | | | | | | | | | | | | | |
| | **General market-related complexity** | | | | | | | | | | | | | |
| | Market complexity (general) [1] | | | | | | | | | | | | | |
| | Market´s infrastructure [3] | R | | | | | | | | | | | | |
| | Market´s economic factors [2, 4] | R | ● | ● | ● | ● | ● | | | | ● | ● | | **7** |
| | Variety of customer requirements [2, 4] | R | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | **11** |
| | Market´s change [1, 4] | R | ● | | | ● | | | | | | ● | | **3** |
| | Market´s globalization [1, 4] | R | ● | ● | | | ● | | | | | ● | ● | **5** |
| | Market´s dynamics [1] | | | | | | | | | | | | | |
| | Market´s protectionism [1] | | | | | | | | | | | | | |
| | **Demand complexity** | | | | | | | | | | | | | |
| | Demand complexity (general) [1] | | | | | | | | | | | | | |
| | Individuality of customer demands [1, 4] | R | ● | ● | ● | | ● | | ● | ● | ● | ● | ● | **9** |
| | Demand´s dynamics [2, 4] | R | | | | | ● | | ● | ● | | ● | ● | **5** |
| | **Competitive complexity** | | | | | | | | | | | | | |
| | Competitive complexity (general) [1] | | | | | | | | | | | | | |
| | Number and strength of competitors [1, 4] | R | ● | ● | ● | ● | | | ● | ● | | ● | ● | **8** |
| | Competitor´s dynamics [2, 4] | R | | | | | | ● | | ● | | | ● | **3** |
| | Competitive pressure [1] | | | | | | | | | | | | | |
| | **Technological complexity (external)** | | | | | | | | | | | | | |
| | External technological complexity (general) [1] | | | | | | | | | | | | | |
| | Technological progress [1, 4] | R | ● | | | | ● | ● | ● | | | | ● | **5** |
| | Technological innovations & availability [1, 4] | R | | | | | | | | | | | ● | **1** |
| | New technologies and materials [1] | | | | | | | | | | | | | |
| | **Supply complexity** | | | | | | | | | | | | | |
| | Variety of supplied goods [2] | R | | | | | | | | | | | | |
| | Amount of suppliers [2] | R | | | | | | | | | | | | |
| | Supply strategy or concept [2, 4] | R | | | | | | | | | | | ● | **1** |
| | Quality uncertainty of delivered goods [2] | R | | | | | | | | | | | | |
| | Uncertainty of delivery date [2] | R | | | | | | | | | | | | |
| | | **Total:** | **7** | **5** | **4** | **4** | **8** | **4** | **6** | **6** | **3** | **7** | **10** | |

**Explanation:**

1 Complexity drivers, which are documented in the literature review, focused on product development (see chapter 2.2) (N: 72)

2 Complexity drivers, which are documented in literature in other fields along the value chain and general in manufacturing companies (N: 44)

3 Additional complexity drivers, mentioned by the practice during expert interviews (N: 5)

4 Complexity drivers, which were regarded by the respondents as drivers that have a strong or very strong influence (N: 30)

RfQ Relevant (R) for questionnaire based on the results of our pretest and several expert interviews (N: 64)

| | | | Field of Industries | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Technical Industries | | | | Resource Industry | | | Consumer goods Industry | | | | |
| **Origin** | **Specific complexity drivers in each category** | **RfQ** | Automotive | Engineering | Electrical & Optics | Metal | Petroleum & Plastics | Chemical & Pharmaceutical | Glas, Ceramic, Pit & Quarry | Food, Forage & Tobacco | Lumber, Papers, Printing & Furniture | Clothing & Textile | Others | **Total** |
| **Internal correlated complexity** | **Target complexity** | | | | | | | | | | | | | |
| | Target complexity (general) [1] | | | | | | | | | | | | | |
| | Amount of different targets [1] | R | | | | | | | | | | | | |
| | Business objective´s change frequency [2] | R | | | | | | | | | | | | |
| | Business objective´s time pattern [2] | R | | | | | | | | | | | | |
| | **Customer complexity** | | | | | | | | | | | | | |
| | Customer´s amount [2, 4] | R | | | | | | | | | | | ● | **1** |
| | Customer structure [1, 4] | R | | | | | ● | | | | | | ● | **2** |
| | Customer´s participation [2, 4] | R | ● | | | ● | | | | | | | | **2** |
| | **Product & product portfolio complexity** | | | | | | | | | | | | | |
| | Product complexity (general) [1] | | | | | | | | | | | | | |
| | Product portfolio complexity (general) [1] | | | | | | | | | | | | | |
| | Product variety [1, 2, 4] | R | | | | | | | ● | | | | ● | **2** |
| | Product range / portfolio [1, 4] | R | ● | ● | ● | | ● | | | ● | ● | | | **6** |
| | Product portfolio change frequency [2] | R | | | | | | | | | | | | |
| | New product launch´s frequency [2] | R | | | | | | | | | | | | |
| | Product life cycle length [2] | R | | | | | | | | | | | | |
| | Product structure / design [1] | R | | | | | | | | | | | | |
| | Product technology [1, 2] | | | | | | | | | | | | | |
| | Component type [1] | | | | | | | | | | | | | |
| | Variety of parts and modules [1] | R | | | | | | | | | | | | |
| | Variety of the applied materials [1] | R | | | | | | | | | | | | |
| | Variance in product design [2] | R | | | | | | | | | | | | |
| | Availability of materials or components [3] | R | | | | | | | | | | | | |
| | Properties of modules or materials [1, 4] | R | | | | | ● | | | ● | | | | **2** |
| | Product´s degree of innovation [2, 4] | R | ● | | | | | ● | | ● | | | | **3** |
| | Product life cycle length [2, 4] | R | ● | | | | | | | | | | | **1** |
| | **Technological complexity (internal)** | | | | | | | | | | | | | |
| | Technology complexity (general) [1] | | | | | | | | | | | | | |
| | Technology change / innovation [1] | R | | | | | | | | | | | | |
| | Number of different applied technologies [1] | R | | | | | | | | | | | | |
| | Hardware and software complexity (general) [1] | | | | | | | | | | | | | |
| | Type of data medium [1] | | | | | | | | | | | | | |
| | Size of data medium [1] | | | | | | | | | | | | | |
| | Type of interfaces [1] | | | | | | | | | | | | | |
| | Amount of interfaces [1] | | | | | | | | | | | | | |
| | Criteria of hardware and software tests [1] | | | | | | | | | | | | | |
| | Technology´s complicacy [3] | R | | | | | | | | | | | | |
| | Technology´s combination [2] | R | | | | | | | | | | | | |
| | Technology life cycle length [2] | R | | | | | | | | | | | | |
| | **Product development complexity** | | | | | | | | | | | | | |
| | Development complexity (general) [1] | | | | | | | | | | | | | |
| | Development program´s complexity [1] | | | | | | | | | | | | | |
| | Applied methods or instruments [1] | | | | | | | | | | | | | |
| | Product software [2, 4] | R | | ● | | | | | | | | | | **1** |
| | Data processing system [2] | R | | | | | | | | | | | | |
| | | **Total:** | **4** | **2** | **1** | **1** | **3** | **1** | **1** | **3** | **1** | **0** | **3** | |

**Explanation:**

[1] Complexity drivers, which are documented in the literature review, focused on product development (see chapter 2.2) (N: 72)
[2] Complexity drivers, which are documented in literature in other fields along the value chain and general in manufacturing companies (N: 44)
[3] Additional complexity drivers, mentioned by the practice during expert interviews (N: 5)
[4] Complexity drivers, which were regarded by the respondents as drivers that have a strong or very strong influence (N: 30)
RfQ Relevant (R) for questionnaire based on the results of our pretest and several expert interviews (N: 64)

| | | | **Field of Industries** | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Technical Industries | | | | Resource Industry | | | Consumer goods Industry | | | | |
| **Origin** | **Specific complexity drivers in each category** | **RfQ** | Automotive | Engineering | Electrical & Optics | Metal | Petroleum & Plastics | Chemical & Pharmaceutical | Glas, Ceramic, Pit & Quarry | Food, Forage & Tobacco | Lumber, Papers, Printing & Furniture | Clothing & Textile | Others | **Total** |
| **Internal autonomous complexity** | **Organizational complexity** | | | | | | | | | | | | | |
| | Organizational complexity (general) [1] | | | | | | | | | | | | | |
| | Organization´s structure [1] | | | | | | | | | | | | | |
| | Organization´s / Company´s size [1] | R | | | | | | | | | | | | |
| | Amount of hierarchical levels [2] | R | | | | | | | | | | | | |
| | Degree of centralization [2] | R | | | | | | | | | | | | |
| | Business segment / industrial sector [1] | | | | | | | | | | | | | |
| | Company´s strategy (strategical complexity) [1, 2] | | | | | | | | | | | | | |
| | Complexity between cooperation partners [1] | | | | | | | | | | | | | |
| | Employee complexity (general) [1] | | | | | | | | | | | | | |
| | Amount of employees [2] | R | | | | | | | | | | | | |
| | Lack of transparency (general) [1] | | | | | | | | | | | | | |
| | Lack of cost transparency [1] | | | | | | | | | | | | | |
| | Lack in consistency of activities [1] | | | | | | | | | | | | | |
| | Amount of simultaneous projects [3, 4] | R | • | • | • | | | • | | • | | | • | **6** |
| | Amount of simultaneous processes [3] | R | | | | | | | | | | | | |
| | **Production complexity** | | | | | | | | | | | | | |
| | Production complexity (general) [1] | | | | | | | | | | | | | |
| | Vertical range of manufacture [2] | R | | | | | | | | | | | | |
| | Production system [2, 4] | R | | | | | | | | | | | • | **1** |
| | Production structure [1] | | | | | | | | | | | | | |
| | Manufacturing technology [1] | | | | | | | | | | | | | |
| | Maintenance complexity (general) [1] | | | | | | | | | | | | | |
| | **Process complexity** | | | | | | | | | | | | | |
| | Process complexity (general) [1] | | | | | | | | | | | | | |
| | Variety of processes [1, 2, 4] | R | | | | | | | • | | | | | **1** |
| | Amount of process interfaces [2] | R | | | | | | | | | | | | |
| | Process degree of cross-linking [2, 4] | R | | | | | | | | | | | • | **1** |
| | Process standardization [2, 4] | R | | | | | | | | | | | • | **1** |
| | **Planning, control and information complexity** | | | | | | | | | | | | | |
| | Planning, control & information complexity [1, 2] | | | | | | | | | | | | | |
| | Lack in strategic planning [1] | | | | | | | | | | | | | |
| | Organization´s information technology systems [1] | | | | | | | | | | | | | |
| | Information flow´s variety [2, 4] | R | | | | | | | | • | | | • | **2** |
| | Information flow´s dynamic [2, 4] | R | | | | | • | | | • | | | | **2** |
| | Requirements of company´s control [2] | R | | | | | | | | | | | | |
| | Company´s control level of detail [2] | R | | | | | | | | | | | | |
| | Company´s communication system [2] | R | | | | | | | | | | | | |
| | **Logistics complexity** | | | | | | | | | | | | | |
| | Supply chain complexity (general) [1, 2] | | | | | | | | | | | | | |
| | **Sales & distribution complexity** | | | | | | | | | | | | | |
| | Distribution complexity (general) [1] | | | | | | | | | | | | | |
| | Marketing complexity (general) [1] | | | | | | | | | | | | | |
| **General complexity** | Variety / Multiplicity [1] | | | | | | | | | | | | | |
| | Dynamics [1] | | | | | | | | | | | | | |
| | | **Total:** | **1** | **1** | **1** | **0** | **1** | **1** | **1** | **3** | **0** | **0** | **5** | |

Factor loadings are required for factor's interpretation. The factor loadings are described in detail in the appendix (Table 11).

For a target oriented complexity management, the complexity drivers and their influences have to be identified. In literature, complexity drivers have a direct influence on the company and the total value chain [130] and are responsible for high complexity in the company. Furthermore, they have an influence on a company's performance, especially on product development. To respond to RQ5, we developed a framework for identification, analysis and evaluation of the complexity effects in product development in our empirical research. The framework is developed based on the general framework, presented in Fig. 1, and the different examples, which are described in literature (see chapter 2.2). In this research, 18 different effects on product development, which are clustered in the 4 categories *time*, *quality*, *costs* and *flexibility*, were evaluated by the respondents with an ordinal scale (1-no effect; 2-small effect;…; 5-strong effect; 6-very strong effect). The effects, which are evaluated by more than 50 percent of the respondents with a *strong* or *very strong* impact on product development's performance, were identified as the main effects.

Table 7 presents the identified main effects in product development, the amount of respondents in the different fields of industry ($N_{resp}$) and the amount of respondents of our survey that evaluated these effects as strong or very strong in the different fields of industry (N). As a result of our empirical research and based on the evaluation results in the different fields of industries, high complexity has mostly a strong or very strong effect on the following 4 attributes (see Table 7): *product development time* (N: 155; 53%), *adherence to deadlines in product development* (N: 128; 43%), *product quality* (N: 95; 32%) and *product development's costs in general* (N: 123; 42%). High complexity has a strong effect on the development time in nearly all industry branches. Furthermore,

*Table 5: Overview about the strong and very strong correlations between different complexity drivers*

| Correlations between the specific complexity drivers | | | Correlation | Main complexity driver categories |
|---|---|---|---|---|
| Ecological conditions / factors | ↔ | Environmental awareness in population | strong | Society complexity |
| Individuality of customer demands | ↔ | Variety of customer requirements | strong | Demand complexity & General market-related complexity |
| Technological innovations & availability | ↔ | Technological progress | strong | Technological complexity (external) |
| Amount of suppliers | ↔ | Variety of supplied goods | strong | Supply complexity |
| Supply strategy or concept | ↔ | Amount of suppliers | strong | Supply complexity |
| Uncertainty of delivery date | ↔ | Quality uncertainty of delivered goods | strong | Supply complexity |
| Business objective's change frequency | ↔ | Amount of different targets | strong | Target complexity |
| Customer structure | ↔ | Customer's amount | strong | Customer complexity |
| Product variety | ↔ | Product range / Portfolio | strong | Product & product portfolio complexity |
| New product launch's frequency | ↔ | Product portfolio change frequency | strong | Product & product portfolio complexity |
| Variety of parts and modules | ↔ | Product structure / design | strong | Product & product portfolio complexity |
| Variety of the applied materials | ↔ | Variety of parts and modules | strong | Product & product portfolio complexity |
| Properties of modules and materials | ↔ | Availability of materials or components | strong | Product & product portfolio complexity |
| Technology's complicacy | ↔ | Number of different applied technologies | strong | Technological complexity (internal) |
| Technology's combination | ↔ | Number of different applied technologies | strong | Technological complexity (internal) |
| Technology's combination | ↔ | Technology's complicacy | strong | Technological complexity (internal) |
| Technology life cycle length | ↔ | Technology's combination | strong | Technological complexity (internal) |
| Data processing system | ↔ | Product software | strong | Product development complexity |
| Production system | ↔ | Vertical range of manufacture | strong | Production complexity |
| Amount of process interfaces | ↔ | Variety of processes | strong | Process complexity |
| Process degree of cross-linking | ↔ | Variety of processes | strong | Process complexity |
| Process standardization | ↔ | Process degree of cross-linking | strong | Process complexity |
| Information flow's variety | ↔ | Process degree of cross-linking | strong | Planning, control, information complexity & Process complexity |
| Information flow's variety | ↔ | Process' standardization | strong | Planning, control, information complexity & Process complexity |
| Information flow's dynamics | | Process degree of cross-linking | strong | Planning, control, information complexity & Process complexity |
| Organization´s / Company´s size | ↔ | Amount of hierarchical levels | strong | Organizational complexity |
| Amount of simultaneous processes | ↔ | Amount of simultaneous projects | strong | Organizational complexity |
| Process degree of cross-linking | ↔ | Amount of process interfaces | very strong | Process complexity |
| Information flow's dynamics | ↔ | Information flow's variety | very strong | Planning, control and information complexity |
| Company's control level of detail | ↔ | Requirements of company's control | very strong | Planning, control and information complexity |

*Table 6: Overview about the identified factors, factor load's range and the amount of aggregated complexity drivers*

| Factor | Reflecting complexity driver | % of Variance (Initial Eigenvalues) | Factor load's range | Amount of aggregated complexity drivers |
|---|---|---|---|---|
| #1 | Company's complexity | 25.276 | 0.76 – 0.54 | 15 |
| #2 | Product and technology complexity | 6.021 | 0.67 – 0.42 | 16 |
| #3 | Customer's complexity | 4.809 | 0.71 – 0.44 | 8 |
| #4 | Market complexity | 4.375 | 0.69 – 0.35 | 9 |
| #5 | Supply complexity | 3.718 | 0.75 – 0.66 | 5 |
| #6 | Environmental and society complexity | 3.438 | 0.84 – 0.37 | 6 |
| #7 | Target complexity | 3.397 | 0.69 – 0.45 | 5 |
| Total: | | 51.034 | | 64 |

high complexity has more effects in technical industries than in other fields of industry. The most important attributes in technical industries are *product development time*, *adherence to deadlines in product development, product quality, product development's direct costs* and *product development's costs in general*. In the resource industries, high complexity has a strong or very strong effect on the attributes *product development time* and *adherence to deadlines in product development* and thus these attributes are most important for complexity management. In the consumer goods industries, only 1 attribute is highly influenced by complexity and important for complexity management: *product development time*.

To answer the fifth research question, a correlation analysis between the complexity drivers and the effects was conducted. Based on the results, only weak correlations were identified. Thus, the results were not taken into account.

### 4.3 Comparison of literature results with empirical results

Answering the sixth research question, the empirical findings about complexity drivers in product development are compared with the literature findings to identify differences and commonalities. The objective is to confirm or to refine existing scientific knowledge or theories and to identify further research gaps.

In literature, 108 different complexity drivers in product development are described in total between 1998 and 2015 ($N_{Lit.\,T}$) (see Fig. 6 and Table 1). In our research, only the complexity drivers, published before 2015, were considered ($N_{Lit.\,1998\text{-}2014}$), because the empirical research started already in 2014. For comparing the literature and empirical results, the complexity drivers, published in 2015 ($N_{Lit.\,2015}$), were also considered. For the pretest ($N_{Pretest\,T}$), we used the complexity drivers, which were already mentioned in literature before 2015 and added additional drivers from other fields along the value chain ($N_{VC}$). Our pretest resulted in 59 complexity drivers, which were considered truly relevant by the pretesters ($N_{rel.}$). Furthermore, the experts mentioned 5 additional important and relevant complexity drivers ($N_{Experts}$). Thus, our final questionnaire comprised 64 complexity drivers in total ($N_{Questionnaire\,T}$). As a result of our empirical research, the respondents regarded 30 different complexity drivers as drives that have a strong or very strong influence in principle ($N_{eval.}$). Based on these drivers, different main complexity drivers in the different fields of industry are identified (see Table 4). Furthermore, some industries are influenced by more complexity drivers than other industries.

In summary, 108 different complexity drivers are described in literature (see Fig. 6). In contrast, 30 complexity drivers with a strong or very strong influence on product development were mentioned by experts. These drivers can be separated in 14 external, 9 internal correlated and 7 internal autonomous drivers. Furthermore, 6 main complexity drivers were identified. No further complexity drivers were mentioned in our final empirical research. The different complexity drivers, which were mentioned by the experts are described in Table 4 (see chapter 4.2).

In literature, the main complexity drivers are mostly related to internal complexity (see Table 1). Thus, the origin of complexity is seen mainly inside the company itself. In contrast, the identified complexity drivers from the empirical research are mostly related to external complexity. In practice, complexity is regarded as a condition, which is mostly influenced from outside. The reason may be that companies can influence and handle internal complexity actively, thus we come to the conclustion that the companies are aware of it. Contrary to internal complexity, external complexity cannot or nearly cannot be influenced by the company itself and is often unknown. Thus, the respondents consider the complexity phenomenon as an external source and want to receive additional

*Table 7: Overview of the identified main complexity effects in product development and in different fields of industry*

| | | Technical Industries | | | | | | | | Resource Industries | | | | | | Consumer Goods Industries | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Automotive | | Engineering | | Electrical & Optics | | Metal | | Petroleum & Plastics | | Chemical & Pharmaceutical | | Glas, Ceramic, Pit & Quarry | | Food, Forage & Tobacco | | Lumber, Papers, Printing & Furniture | | Clothing & Textile | | Others | | **Total** | |
| High complexity in product development has a **strong or very strong** effect on... | | $N_{resp}$: 24 | | $N_{resp}$: 90 | | $N_{resp}$: 29 | | $N_{resp}$: 31 | | $N_{resp}$: 14 | | $N_{resp}$: 24 | | $N_{resp}$: 13 | | $N_{resp}$: 17 | | $N_{resp}$: 26 | | $N_{resp}$: 13 | | $N_{resp}$: 14 | | $N_T$: 295 | |
| | | **N** | % | **N** | % | **N** | % | **N** | % | **N** | % | **N** | % | **N** | % | **N** | % | **N** | % | **N** | % | **N** | % | **N** | % |
| **Time** | product development time | **15** | 63% | **53** | 59% | **21** | 72% | **19** | 61% | | | **14** | 58% | **9** | 69% | **9** | 53% | **15** | 58% | | | | | **155** | 53% |
| | adherence to deadlines in product development | **13** | 54% | **57** | 63% | **19** | 66% | **19** | 61% | | | **12** | 50% | **8** | 62% | | | | | | | | | **128** | 43% |
| | delivery time of supplied goods | **12** | 50% | | | | | | | | | | | | | | | | | | | | | **12** | 4% |
| | time for product's validation | **13** | 54% | | | | | | | | | | | | | | | | | | | | | **13** | 4% |
| **Quality** | product quality | **14** | 58% | **45** | 50% | **16** | 55% | | | | | | | **8** | 62% | **11** | 65% | | | | | | | **94** | 32% |
| | process' balance | | | | | | | | | | | | | | | | | | | | | | | | |
| | process planning and controlling | | | | | | | | | | | | | | | | | | | | | | | | |
| | process size for quality check | | | | | | | | | | | | | | | | | | | | | | | | |
| **Costs** | product development's direct costs | **15** | 63% | | | **15** | 52% | **17** | 55% | **8** | 57% | | | | | | | **14** | 54% | | | | | **69** | 23% |
| | product development's indirect costs | **12** | 50% | | | | | | | | | | | **7** | 54% | | | | | | | | | **19** | 6% |
| | product development's costs in general | **18** | 75% | **55** | 61% | **23** | 79% | | | **10** | 71% | | | **8** | 62% | | | | | | | **9** | 64% | **123** | 42% |
| | product costs | **12** | 50% | | | **15** | 52% | | | **7** | 50% | | | **7** | 54% | | | | | **7** | 54% | | | **48** | 16% |
| | coordination costs | **12** | 50% | | | | | | | | | | | | | | | | | | | | | **12** | 4% |
| | inventory costs | **15** | 63% | | | | | | | | | | | | | | | | | | | | | **15** | 5% |
| **Flexi-bility** | product design flexibility | | | | | | | | | | | | | | | | | | | | | | | | |
| | product development process flexibility | **12** | 50% | | | | | | | | | | | | | | | | | | | | | **12** | 4% |
| | temporal flexibility on product development content | **13** | 54% | | | | | | | | | | | | | | | | | | | | | **13** | 4% |
| | resource management's flexibility | | | | | | | | | | | | | | | | | | | **7** | 54% | | | **7** | 2% |
| **Total amount of effects based on complexity:** | | 13 | | 4 | | 6 | | 3 | | 3 | | 2 | | 6 | | 2 | | 2 | | 2 | | 1 | | 14 | |

information regarding external complexity drivers to increase their knowledge.

There were some major differences between our research and literature regarding specific complexity drivers as well as driver categories and their influence on company's complexity. In literature, organizational complexity is described as an important driver for company´s complexity (see Table 1, chapter 2.2). In our empirical research we found out that the organization and its complexity does not have a major influence on company´s complexity (see Fig. 5, chapter 4.1). The same could be found regarding the complexity driver categories *technological complexity (external and internal), product and product portfolio complexity* as well as *product development complexity* and their specific drivers (see Table 1, chapter 2.2). In literature, these categories and their specific drivers are also described as important sources for company´s complexity. However, in our research, the respondents classified these categories and their specific drivers not as important and relevant sources for managing company's complexity (see Table 4, chapter 4.2).

From scientific perspective, this comparison allows a concentration on the most important complexity drivers (see Table 4). Futhermore, the differences between literature and practice regarding specific drivers and driver categories are pointed out. From practical perspective, this comparison allows not only an insight about the drivers known in literature but also about the drivers that are considered important by

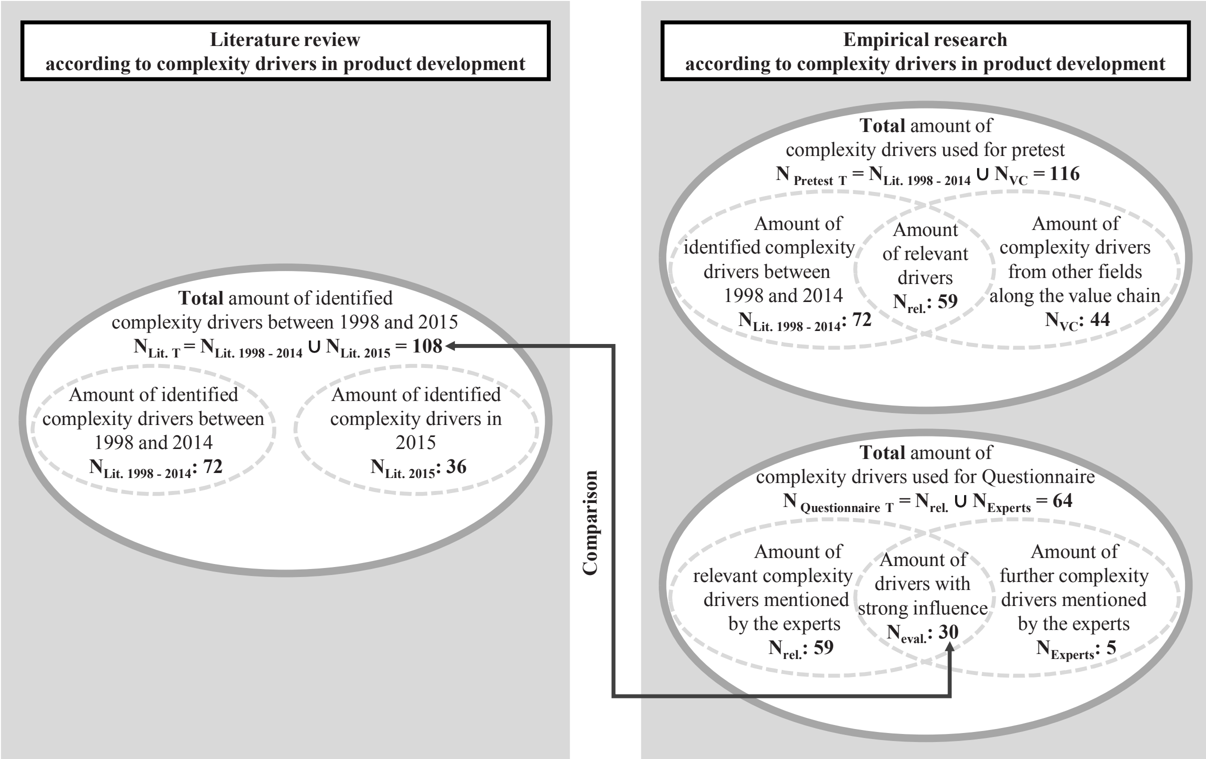


*Figure 6: Comparison of literature findings versus empirical findings regarding complexity drivers in product development*

other practitioners from other fields of industry. This overview increases transparency for the practitioner.

Further research should analyze the differences between theory and practice more in detail and the empirical findings should be used for further discussions und evaluations in literature. In addition, the companies should compare and evaluate their complexity drivers with those described in literature to question their own identified complexity drivers.

## 5 CONCLUSION, OUTLOOK AND LIMITATIONS

The objective of this empirical research paper is to develop additional knowledge for science and practice by identifying and analyzing existing complexity drivers in science and practice in the field of product development. Furthermore, the results are compared to identify communalities and differences and to identify further research gaps.

In the first step before starting our empirical study, we reviewed the literature regarding complexity drivers and their effects (see chapter 2.2). Next, we searched for previously existing empirical studies regarding complexity management and gaps in literature (see chapter 2.3). Our literature search resulted in 72 empirical studies regarding complexity management. As a result of analyzing all previous empirical studies, only 6 studies are focused on product development. Furthermore, we found out that an empirical research in the field product development in manufacturing companies in Germany, including the identification and analysis of complexity drivers and their effects does not exist yet. In this paper, we want to close this gap.

For our empirical research, we used the methodology of Flynn *et al.* [50]. In the third chapter, the research methodology, the objectives, the sample description and the methods for statistical analysis are described. For data collection, a standardized questionnaire consisting of 15 questions and a fixed response possibility was sent in 2 stages by e-mail to 3,086 companies in 2015 and 2016. Only companies with more than 50 employees and located in Germany are selected. In total, 295 questionnaires were completed. The response rate resulted in 10.5 percent. Industry´s range contained 11 different fields of industry. For this empirical research, we determined 4 research questions, which were answered as follows.

Answering the first empirical research question *(RQ3)*, product development´s characteristics of the participating companies are analyzed regarding product and variant range; length of product life cycle and product development process; amount of applied components, materials, technologies and processes; the height of the own value adding percentage as well as organization´s influence on product development´s complexity. The results are described in detail in chapter 4.1.

For answering the second empirical research question (*RQ4*), the empirical data regarding complexity drivers was analyzed and evaluated. Complexity drivers have an influence on a company's complexity and are the basis for a target oriented complexity management. Based on the statistical analysis, some industries are influenced by more complexity drivers than other industries. For example, the automotive industry is influenced by 12 complexity drivers. In contrast, the chemical & pharmaceutical industry is influenced by only 6 drivers. Furthermore, some complexity drivers are more important than other drivers, because these drivers occur in most fields of industries. These include the complexity drivers *market´s economic factors*, *variety of customer requirements, individuality of customer demands*, *number and strength of competitors*, *product range/portfolio* and *amount of simultaneous projects* (see Table 4).

As a further result, complexity in product development is mostly influenced by external complexity drivers. We also found out that different fields of industries are influenced by individual main complexity drivers. For example, the *technical industries* are characterized by the 6 main complexity drivers *market´s economic factors*, *variety of customer requirements*, *individuality of customer demands*, *number and strength of competitors*, *product range/portfolio* and *amount of simultaneous projects*. In contrast, the resource industries are influenced by the 5 complexity drivers: *variety of customer requirements, individuality of customer demands, political framework conditions*, *demand´s dynamics* as well as *technological progress*. It was surprising that the respondents did not evaluate the complexity driver categories *technological complexity (external and internal), product and product portfolio complexity as well as product development complexity* and their specific drivers with a strong or very strong influence on product development´s complexity, although product development is characterized by these categories.

To identify the relationships and interdependences between the different complexity drivers, a correlation analysis was conducted. As a result of this analysis, strong correlations between different complexity drivers occur in the categories *society complexity*, *demand complexity*, *general market-related complexity*, *technological complexity* (external and internal), *supply complexity*, *target complexity*, *customer complexity*, *product and product portfolio complexity*, *product development complexity*, *production complexity*, *process complexity* as well as *planning, control and information complexity* and *organizational complexity*. Beyond, very strong correlations occur between the 2 categories *process complexity* and *planning, control and information complexity*. Based on the correlation analysis, a factor analysis with varimax rotation was used for complexity driver's aggregation. The factor analysis was performed by the statistic software SPSS 21. As a result of the factor analysis, 7 factors were identified, reflecting the complexity drivers: *Company´s complexity*, *product and technology complexity*, *customer´s complexity*, *market complexity*, *supply complexity*, *environmental and society complexity* as well as *target complexity*.

Next, complexity driver's influences on product development´s complexity in the 4 categories time, quality, costs and flexibility were analyzed (see Table 7) to answer the third empirical research question (*RQ5*). As a result of our empirical research, high complexity has mostly a strong or very strong effect on the 4 attributes *product development time*, *adherence to deadlines in product development, product quality* and *product development's costs in general*. Also, high complexity has a strong effect on the development time in nearly all industry branches. Furthermore, high complexity has a higher effect in technical industries than in others. In the technical industries (e.g. automotive or engineering), the most important attributes are *product development time*, *adherence to deadlines in product development, product quality, product development's direct costs* and *product development's costs in general*. In the resource industries (e.g. petroleum & plastics or glas, ceramic, pit & quarry), high complexity has a strong or very strong effect on the attributes *product development time* and *adherence to deadlines in product development* and is thus most important for complexity management. In the consumer goods industries (e.g. food, forage & tobacoo or clothing & textile), only 1 attribute is highly influenced by complexity and important for complexity management: *product development time.*

Answering the last empirical research question (*RQ6*), the empirical findings about the complexity drivers are compared with the literature findings to identify the significant differences and commonalities (see chapter 4.3). In literature, 108 different complexity drivers are described in total without prioritization by the authors. In contrast, in our empirical study only 30 complexity drivers with a strong or very strong influence on product development are mentioned and prioritized by experts.

Summarizing the results of our empirical research, we developed some additional knowledge regarding complexity management as well as its drivers and effects in product development for *science* and *practice*.

From *scientific perspective*, we connected scientific research with the real world by conducting a transparent, systematic, explicit and reproducible empirical research. Further, we compared the empirical results with the literature to identify communalities and differences and to close a currently existing gap in scientific literature, since no empirical research regarding complexity drivers and their effects in product development exists yet. In our empirical research we found out that 30 complexity drivers with a strong or very strong influence on product development and 4 effects of high complexity are mentioned by experts. In literature, 108 different drivers and 18 effects are described without priorization. Further, the experts stated that complexity in product development is mostly influenced by external complexity drivers. In literature, the complexity in product development is mostly influenced by internal drivers. This draws to the conclusion that internal drivers are not considered as problems, because these drivers can be handled by the company itself, whereas external complexity drivers cannot be influenced by the company itself and are therefore regarded more as problems. Thus, the practitioners need more and specific information about these drivers. Regarding organization`s influence on product development´s complexity, the authors in literature came to the conclusion that organization has a direct influence. In our research, the respondents specified that the organization has no negative influence on product development´s complexity. Based on these results, the researcher receive an overview about what is already known in practice and can confirm theoretical findings or can develop new ideas, theories or hypotheseses.

From *practical perspective*, the practioners receive an overview about complexity perception in product development by other practitioners and from other fields of industries. In our research we found out that product development´s characteristics in the different fields of the German manufacturing industry are characterized by a medium and big product and variant range with a product life cycle length of more than 72 months. In contrast, the length of product development process is less than 25 months. The products predominantly consist of many different components, materials and technologies and the product development process consists of many different processes. Relating to company´s own value adding percentage in product development, there was no explicit recognizable tendency.

Regarding the complexity drivers in product development we found out that some industries are influenced by more complexity drivers than other industries. For example, the industries *automotive*, *petroleum & plastics* and *food, forage & tobacco* are influenced by 12 different complexity drivers. In contrast, the electrical & optics industry or the chemical & pharmaceutical industry are influenced by only 6 drivers. Furthermore, the following drivers are identified as important drivers for product development´s complexity in most fields of industries: *market´s economic factors*, *variety of customer requirements, individuality of customer demands*, *number and strength of competitors*, *product range/portfolio* and *amount of simultaneous projects*. Seperating the results according to the different fields of industries it can be seen that the different industry clusters are characterized by a specific amount of important complexity drivers: Technical industries (N: 6), resource industry (N: 5) and consumer goods industry (N: 5). Based on a factor analysis, the complexity drivers were aggregated to 7 factors, which reflect the complexity drivers: *Company´s complexity*, *product and technology complexity*, *customer´s complexity*, *market complexity*, *supply complexity*, *environmental and society complexity* as well as *target complexity.* This aggregation helps the practitioner to focus their activities regarding complexity management in product development on this specific complexity sources within the company. Another purpose of this research was to analyze the effects of high complexity on product development, to give the practice a specific indication. In our research we identified 4 different effects in the categories time, quality and costs and over all fields of industries: *product development time*, *adherence to deadlines in product development*, *product quality* and *product development´s costs in general*. Within the different field of industries, the results can deviate. This overview increases transparency and helps the practioner to answer the questions "What complexity drivers have a high influence on product development´s complexity and are thus relevant for the company?" and "What effects do high complexity within the company have on product development?".

As already mentioned, further research is needed to analyze and explain the differences between literature and practice. Based on our empirical findings, further discussions und evaluations can be performed in literature. Our research was focused on the manufacturing industry in Germany in 2015 and 2016. Future research may also include other countries and sectors as well as companies with less than 50 employees. It would be interesting to compare the empirical results from our study with the results from a further study, which is conducted in other field of industry or country / region. Furthermore, the development of complexity drivers and their importance for a company over time would also be interesting. Therefore, the same empirical research should be repeated in the future (i.e. 5 to 10 years) to identify differences and commonalities of complexity driver's perception between now and the future.

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**CONFLICT OF INTEREST:**

The authors declare that they have no conflict of interest.

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## APPENDIX

*Table 8 General framework of literature collection, focused on empirical research in the field complexity management*

| Database | Search terms | Date | Results |
|---|---|---|---|
| **EBSCOhost** | (Komplexität N10 Management) AND (Studie OR Untersuchung OR Empir* OR Befrag* OR Interview) | 17/04/23 | 3 |
| | (complexity N10 management) AND (study OR survey OR empir* OR questioning OR interview) | 17/04/23 | 750 |
| **Emerald** | "Komplexität?" AND (Studie OR Untersuchung OR Empir? OR Befrag? OR Interview) | 17/03/24 | 4 |
| | ("complexity management" OR "management of complexity") AND (study OR survey OR empir? OR questioning OR interview) | 17/03/30 | 148 |
| **GENIOS / WISO** | Komplexität* ndj5 (Studie OR Untersuchung OR Empir* OR Befrag* OR Interview) | 17/03/02 | 600 |
| | complexity ndj5 (study OR survey OR empir* OR questioning OR interview) | 17/03/04 | 790 |
| **Google Scholar** | "Komplexität*" AND ("Studie" OR "Untersuchung" OR "Empir*" OR "Befrag*" OR "Interview") | 17/03/09 | 4,200 |
| | "complexity" AND ("study" OR "survey" OR "empir*" OR "questioning" OR "interview") | 17/03/12 | 14,910 |
| **IEEE Xplore** | Komplexität* NEAR/2 (Studie OR Untersuchung OR Empir* OR Befrag* OR Interview) | 17/03/18 | 4 |
| | complexity NEAR/2 (study OR survey OR empir* OR questioning OR interview) | 17/03/16 | 1,232 |
| **JSTOR** | ("Komplexität Management"~5) AND (Studie OR Untersuchung OR Empir* OR Befrag* OR Interview) | 17/04/17 | 27 |
| | ("complexity management"~5) AND (study OR survey OR empir* OR questioning OR interview) | 17/04/23 | 2,462 |
| **ScienceDirect** | Komplexität* AND (Studie OR Untersuchung OR Empir* OR Befrag* OR Interview) | 17/03/19 | 112 |
| | complexity AND (study OR survey OR empir* OR questioning OR interview) | 17/03/22 | 282 |
| **SpringerLink** | (Komplexität NEAR/5 Management) AND (Studie OR Untersuchung OR Empir* OR Befrag* OR Interview) | 17/04/06 | 728 |
| | (complexity NEAR/5 management) AND (study OR survey OR empir* OR questioning OR interview) | 17/04/12 | 447 |
| | | *Total:* | *26,699* |

*Table 9 – Part A: Intercorrelations between complexity drivers*

| Complexity drivers | ID | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | 25 | 26 | 27 | 28 | 29 | 30 | 31 | 32 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Value change & value awareness | 1 | 1 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Environmental awareness in population | 2 | .59** | 1 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Ecological conditions / factors | 3 | .42** | .78** | 1 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Political framework conditions | 4 | .25** | .37** | .42** | 1 | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Legal factors | 5 | .28** | .32** | .32** | .36** | 1 | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Market's infrastructure | 6 | .18** | .26** | .27** | .32** | .28** | 1 | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Market's economic factors | 7 | .15** | .14* | .21** | .18** | .12* | .32** | 1 | | | | | | | | | | | | | | | | | | | | | | | | | |
| Variety of customer requirements | 8 | .05 | .10 | .13* | .02 | .10 | .15* | .36** | 1 | | | | | | | | | | | | | | | | | | | | | | | | |
| Individuality of customer demands | 9 | .12* | .10 | .17** | -.05 | .03 | .16** | .33** | .64** | 1 | | | | | | | | | | | | | | | | | | | | | | | |
| Demand's dynamics | 10 | .23** | .25** | .21** | .13* | .04 | .24** | .35** | .35** | .50** | 1 | | | | | | | | | | | | | | | | | | | | | | |
| Number & strength of competitors | 11 | -.01 | .14* | .19** | .14* | -.03 | .14* | .26** | .13* | .18** | .31** | 1 | | | | | | | | | | | | | | | | | | | | | |
| Market's change | 12 | .13* | .19** | .25** | .19** | .14* | .23** | .31** | .28** | .28** | .35** | .42** | 1 | | | | | | | | | | | | | | | | | | | | |
| Competitor's dynamics | 13 | .14* | .17** | .20** | .17** | .09 | .20** | .29** | .23** | .22** | .32** | .55** | .43** | 1 | | | | | | | | | | | | | | | | | | | |
| Market´s globalization | 14 | .07 | .14* | .15* | .20** | .07 | .30** | .30** | .15* | .13* | .22** | .34** | .54** | .42** | 1 | | | | | | | | | | | | | | | | | | |
| Technological progress | 15 | .03 | .06 | .07 | .12* | .17** | .27** | .24** | .21** | .14* | .17** | .27** | .37** | .43** | .41** | 1 | | | | | | | | | | | | | | | | | |
| Technological innovations & availability | 16 | .08 | .06 | .07 | .09 | .13* | .24** | .25** | .17** | .15* | .18** | .24** | .29** | .41** | .31** | .73** | 1 | | | | | | | | | | | | | | | | |
| Variety of supplied goods | 17 | .17** | .16** | .17** | .19** | .18** | .22** | .22** | .08 | .05 | .22** | .12* | .22** | .32** | .17** | .19** | .27** | 1 | | | | | | | | | | | | | | | |
| Amount of suppliers | 18 | .08 | .12* | .09 | .23** | .14* | .18** | .13* | .05 | .02 | .19** | .14* | .18** | .27** | .24** | .21** | .23** | .67** | 1 | | | | | | | | | | | | | | |
| Supply strategy or concept | 19 | .06 | .12* | .10 | .16** | .10 | .20** | .11 | .05 | .05 | .15* | .12* | .21** | .24** | .21** | .19** | .25** | .53** | .67** | 1 | | | | | | | | | | | | | |
| Quality uncertainty of delivered goods | 20 | .12* | .11 | .08 | .07 | .13* | .19** | .16** | .05 | .03 | .13* | .07 | .13* | .17** | .20** | .23** | .18** | .38** | .40* | .53** | 1 | | | | | | | | | | | | |
| Uncertainty of delivery date | 21 | .08 | .10 | .07 | .09 | .06 | .23** | .14* | .10 | .05 | .16** | .07 | .17** | .17** | .21** | .20** | .13* | .33** | .39** | .47** | .73** | 1 | | | | | | | | | | | |
| Amount of different targets | 22 | .23** | .15** | .11 | .06 | .19** | .18** | .04 | .12* | .14* | .21** | .13* | .10 | .16** | .10 | .18** | .17** | .13* | .03 | .13* | .14* | .13* | 1 | | | | | | | | | | |
| Business objective's change frequency | 23 | .21** | .13* | .09 | .10 | .24** | .17** | .01 | .06 | .01 | .08 | .08 | .09 | .14* | .06 | .21** | .21** | .15** | .10 | .21** | .15** | .17** | .61** | 1 | | | | | | | | | |
| Business objective's time pattern | 24 | .06 | .10 | .80 | -.01 | .15* | .13* | .12* | .14* | .06 | .01 | .08 | .17** | .25** | .14* | .24** | .20** | .18** | .14* | .17** | .10 | .10 | .41** | .50** | 1 | | | | | | | | |
| Customer's amount | 25 | .02 | .05 | .06 | .04 | .09 | .12* | .14* | .32** | .25** | .28** | .18** | .26** | .28** | .24** | .33** | .22** | .20** | .21** | .24** | .20** | .18** | .16** | .14* | .18** | 1 | | | | | | | |
| Customer structure | 26 | .03 | .03 | .06 | .06 | .08 | .08 | .18** | .37** | .26** | .28** | .14* | .27** | .27** | .27** | .28** | .17** | .18** | .22** | .19** | .15** | .15** | .13* | .06 | .12* | .75** | 1 | | | | | | |
| Customer's participation | 27 | -.05 | .03 | .11 | .12* | .01 | .13* | .14* | .24** | .21** | .15* | .10 | .20** | .22** | .24** | .23** | .17** | .20** | .22** | .16** | .12* | .18** | -.06 | -.03 | .07 | .43** | .46** | 1 | | | | | |
| Product variety | 28 | .13* | .09 | .14* | .14* | .04 | .06 | .19** | .24** | .23** | .25** | .17** | .19** | .33** | .19** | .20** | .18** | .28** | .22** | .14* | .07 | .11 | .18** | .14* | .11 | .43** | .47** | .34** | 1 | | | | |
| Product range / Portfolio | 29 | .03 | .03 | .13* | .17** | .04 | .03 | .08 | .19** | .20** | .19** | .16** | .21** | .28** | .16** | .18** | .14* | .24** | .22** | .16** | .09 | .07 | .18** | .14* | .13* | .37** | .45** | .38** | .68** | 1 | | | |
| Product portfolio change frequency | 30 | .13* | .16** | .11 | .15* | .15* | .18** | .18** | .13* | .05 | .12* | .12* | .18** | .38** | .20** | .26** | .26** | .34** | .31** | .22** | .17** | .19** | .14* | .28** | .27** | .25** | .24** | .23** | .43** | .39** | 1 | | |
| New product launch's frequency | 31 | .22** | .23** | .22** | .12* | .21** | .21** | .14* | .19** | .17** | .19** | .14* | .20** | .36** | .17** | .25** | .21** | .30** | .24** | .26** | .19** | .21** | .28** | .27** | .31** | .25** | .23** | .16** | .39** | .32** | .64** | 1 | |
| Product life cycle length | 32 | .09 | .04 | .05 | .12* | .12* | .21** | .09 | .11 | .06 | .12* | .04 | .18** | .22** | .22** | .23** | .18** | .10 | .10 | .14* | .17** | .18** | .10 | .19** | .24** | .26** | .23** | .15** | .29** | .25** | .32** | .39** | 1 |

*Note:*
**= significant at the 0.01 level
* = significant at the 0.05 level
N = 295 companies

Explanation for intercorrelations:
■ Very strong correlations
■ Strong correlations
■ Medium correlations

*Table 9 – Part B: Intercorrelations between complexity drivers*

| Complexity drivers | ID | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | 25 | 26 | 27 | 28 | 29 | 30 | 31 | 32 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Product structure / design | 33 | .03 | .12* | .15* | .13* | .13* | .18** | .12* | .16** | .03 | .10 | .16** | .23** | .28** | .18** | .15** | .12* | .27** | .30** | .26** | .22** | .18** | .16** | .17** | .25** | .21** | .21** | .29** | .26** | .31** | .36** | .40** | .42** |
| Variety of parts and modules | 34 | .15** | .14* | .16** | .16** | .16** | .13* | .10 | .17** | .07 | .16** | .08 | .18** | .20** | .16** | .22** | .20** | .32** | .35** | .29** | .21** | .22** | .12* | .20** | .20** | .22** | .22** | .23** | .30** | .33** | .35** | .33** | .40** |
| Variety of the applied materials | 35 | .17** | .18** | .24** | .11 | .18** | .20** | .11 | .11 | .06 | .13* | .09 | .08 | .20** | .14* | .20** | .20** | .37** | .39** | .32** | .34** | .27** | .18** | .21** | .19** | .22** | .18** | .16** | .23** | .20** | .26** | .32** | .33** |
| Variance in product design | 36 | .13* | .13* | .08 | .05 | .06 | .22** | .11* | .18** | .21** | .14* | .09 | .15* | .20** | .16** | .21** | .23** | .26** | .27** | .26** | .17** | .16** | .19** | .20** | .23** | .15** | .14* | .15* | .21** | .13* | .29** | .39** | .28** |
| Availability of materials or components | 37 | .13* | .15** | .14* | .07 | .15* | .22** | .13* | .09 | .01 | .10 | .03 | .12* | .11 | .09 | .22** | .20** | .29** | .32** | .27** | .37** | .35** | .13* | .13* | .21** | .15* | .04 | .16** | .11 | .13* | .15** | .21** | .30** |
| Properties of modules and materials | 38 | .17** | .25** | .20** | .14* | .15** | .23** | .13* | -.10 | -.04 | .06 | .02 | .07 | .12* | .14* | .17** | .12* | .22** | .30** | .27** | .44** | .31** | .15* | .08 | .16** | .14* | .08 | .19** | .07 | .08 | .16** | .26** | .26** |
| Product's degree of innovation | 39 | .24** | .29** | .21** | .13* | .19** | .23** | .17** | .18** | .06 | .09 | .15* | .14* | .22** | .20** | .28** | .28** | .16** | .17** | .15** | .18** | .18** | .27** | .33** | .29** | .19** | .17** | .10 | .21** | .13* | .30** | .39** | .31** |
| Product life cycle length | 40 | .13* | .09 | .04 | .07 | .14* | .16** | .21** | .23** | .15** | .17** | .09 | .22** | .25** | .19** | .30** | .26** | .18** | .16** | .17** | .22** | .16** | .16** | .15* | .21** | .25** | .23** | .21** | .32** | .21** | .25** | .33** | .58** |
| Technology change / innovation | 41 | .09 | .16** | .10 | .07 | .13* | .25** | .22** | .20** | .12* | .12* | .13* | .26** | .24** | .26** | .42** | .41** | .19** | .21** | .26** | .28** | .23** | .23** | .18** | .26** | .22** | .20** | .16** | .21** | .18** | .32** | .35** | .33** |
| Number of different applied technologies | 42 | .08 | .17** | .17** | .19** | .27** | .26** | .20** | .17** | .09 | .12* | .08 | .26** | .16** | .27** | .39** | .37** | .26** | .28** | .31** | .28** | .20** | .21** | .23** | .23** | .21** | .16** | .22** | .22** | .22** | .36** | .41** | .35** |
| Technology's complicacy | 43 | .07 | .17* | .16** | .16** | .16** | .26** | .19** | .15** | .08 | .17** | .13* | .23** | .20** | .27** | .39** | .32** | .20** | .24** | .32** | .22** | .20** | .18** | .14* | .26** | .22** | .20** | .23** | .23** | .16** | .29** | .37** | .33** |
| Technology's combination | 44 | .10 | .18** | .20** | .21** | .20** | .27** | .15** | .15* | .04 | .11 | .09 | .24** | .17** | .26** | .34** | .28** | .20** | .19** | .24** | .18** | .20** | .20** | .16** | .18** | .20** | .15** | .17** | .17** | .17** | .30** | .35** | .30** |
| Technology life cycle length | 45 | .04 | .09 | .11 | .18** | .13* | .23** | .07 | .20** | .09 | .13* | .06 | .26** | .22** | .23** | .33** | .29** | .21** | .16** | .25** | .18** | .15* | .20** | .19** | .21** | .23** | .23** | .19** | .21** | .18** | .32** | .35** | .46** |
| Product software | 46 | .07 | .06 | .03 | .13* | .12* | .18** | .12* | .09 | .04 | .17** | .07 | .22** | .22** | .22** | .30** | .25** | .24** | .19** | .26** | .17** | .15** | .14* | .16** | .09 | .18** | .20** | .24** | .25** | .24** | .28** | .27** | .24** |
| Data processing system | 47 | .09 | .11 | .10 | .16** | .15** | .20** | .19** | .040 | -.01 | .13* | .04 | .26** | .17** | .28** | .30** | .20** | .23** | .23** | .27** | .24** | .24** | .11 | .16** | .17** | .12* | .16** | .20** | .17** | .19** | .26** | .23** | .18** |
| Vertical range of manufacture | 48 | .11 | .16** | .13* | .06 | .13* | .15** | .09 | .20** | .15* | .16** | .05 | .18** | .09 | .21** | .13* | .10 | .09 | .12* | .14* | .16** | .20** | .24** | .04 | .17** | .20** | .14* | .20** | .22** | .21** | .15* | .19** | .20** |
| Production system | 49 | .03 | .13* | .15* | .07 | .15** | .15** | .13* | .19** | .12* | .12* | .06 | .18** | .08 | .25** | .21** | .17** | .13* | .16** | .18** | .19** | .20** | .20** | .05 | .19** | .24** | .22** | .27** | .26** | .24** | .18** | .25** | .19** |
| Variety of processes | 50 | .11 | .14* | .16** | .14* | .19** | .18** | .21** | .23** | .14* | .16** | .12* | .22** | .14* | .26** | .23** | .12* | .11 | .16** | .19** | .18** | .17** | .28** | .17** | .23** | .22** | .24** | .15* | .26** | .25** | .19** | .20** | .26** |
| Amount of process interfaces | 51 | .12* | .20** | .20** | .20** | .19** | .21** | .22** | .25** | .16** | .18** | .13* | .19** | .13* | .28** | .25** | .17** | .12* | .15* | .20** | .09 | .10 | .30** | .21** | .23** | .23** | .24** | .15** | .28** | .27** | .20** | .24** | .24** |
| Process degree of cross-linking | 52 | .15** | .16** | .16** | .19** | .20** | .19** | .24** | .19** | .14* | .25** | .17** | .26** | .17** | .29** | .29** | .19** | .12* | .13* | .24** | .12* | .11 | .30** | .20** | .23** | .18** | .18** | .08 | .20** | .19** | .17** | .27** | .25** |
| Process standardization | 53 | .12* | .19** | .25** | .20** | .21** | .11 | .12* | .19** | .08 | .15** | .10 | .23** | .14* | .20** | .22** | .13* | .10 | .12* | .19** | .15** | .14* | .19** | .14* | .19** | .24** | .21** | .14* | .19** | .20** | .13* | .23** | .18** |
| Information flow's variety | 54 | .12* | .14* | .14* | .21** | .17** | .20** | .17** | .16** | .11 | .20** | .17** | .24** | .15* | .21** | .30** | .18** | .21** | .18** | .33** | .15* | .16** | .23** | .24** | .21** | .20** | .19** | .14* | .20** | .19** | .19** | .27** | .19** |
| Information flow's dynamics | 55 | .16** | .16** | .14* | .23** | .18** | .26** | .17** | .18** | .12* | .20** | .13* | .24** | .19** | .19** | .29** | .19** | .25** | .22** | .33** | .17** | .17** | .23** | .26** | .26** | .22** | .20** | .16** | .21** | .21** | .26** | .33** | .20** |
| Amount of hierarchical levels | 56 | .20** | .22** | .17** | .15* | .20** | .24** | .18** | .09 | .03 | .16** | .21** | .29** | .18** | .24** | .20** | .10 | .20** | .24** | .29** | .23** | .25** | .29** | .34** | .27** | .23** | .17** | .19** | .21** | .19** | .29** | .25** | .25** |
| Organization´s / Company´s size | 57 | .23** | .21** | .22** | .18** | .20** | .26** | .18** | .08 | .04 | .18** | .20** | .30** | .20** | .27** | .23** | .16** | .15** | .17** | .23** | .17** | .20** | .31** | .34** | .31** | .22** | .18** | .14* | .25** | .22** | .30** | .29** | .33** |
| Degree of centralization | 58 | .22** | .14* | .11 | .13* | .22** | .14* | .14* | .11 | .06 | .18** | .11 | .26** | .08 | .20** | .15* | .03 | .06 | .05 | .12* | .20** | .21** | .24** | .30** | .20** | .29** | .25** | .16** | .20** | .23** | .21** | .28** | .29** |
| Amount of simultaneous projects | 59 | .08 | .11 | .11 | .15* | .24** | .14* | .09 | .15** | .06 | .09 | .17** | .16** | .14* | .10 | .17** | .14* | .08 | .14* | .21** | .11 | .12* | .38** | .34** | .32** | .24** | .20** | .02 | .17** | .18** | .18** | .27** | .19** |
| Amount of simultaneous processes | 60 | .10 | .10 | .10 | .15** | .24** | .19** | .16** | .18** | .11 | .14* | .14* | .20** | .11 | .13* | .23** | .18** | .16** | .22** | .23** | .15* | .17** | .38** | .32** | .31** | .23** | .21** | .04 | .19** | .17** | .21** | .31** | .23** |
| Amount of employees | 61 | .05 | .083 | .10 | .06 | .13* | .20** | .18** | .13* | .12* | .10 | .19** | .15** | .16** | .17** | .21** | .15** | .12* | .18** | .27** | .15** | .15** | .24** | .24** | .29** | .25** | .18** | .15** | .16** | .13* | .23** | .26** | .21** |
| Requirements for company's control | 62 | .09 | .08 | .14* | .16** | .16** | .13* | .04 | .06 | .03 | .10 | .15* | .14* | .13* | .15** | .15** | .08 | .14* | .16** | .27** | .17** | .21** | .26** | .32** | .22** | .25** | .17** | .09 | .16** | .23** | .31** | .29** | .23** |
| Company's control level of detail | 63 | .12* | .12* | .15* | .18** | .12* | .14* | .07 | .11 | .10 | .13* | .14* | .14* | .10 | .16** | .13* | .08 | .13* | .15* | .25** | .13* | .17** | .25** | .32** | .20** | .24** | .13* | .09 | .16** | .22** | .31** | .32** | .22** |
| Company's communication system | 64 | .09 | .01 | .02 | .16** | .11 | .15** | .13* | .05 | .06 | .13* | .07 | .08 | .13* | .17** | .12* | .14* | .17** | .17** | .25** | .15** | .22** | .30** | .24** | .13* | .17** | .14* | .11 | .14* | .15* | .29** | .24** | .21** |

*Note:*

**= significant at the 0.01 level

* = significant at the 0.05 level

N = 295 companies

Explanation for intercorrelations:

- ■ Very strong correlations
- ■ Strong correlations
- ■ Medium correlations

*Table 9 – Part C: Intercorrelations between complexity drivers*

| Complexity drivers | ID | 33 | 34 | 35 | 36 | 37 | 38 | 39 | 40 | 41 | 42 | 43 | 44 | 45 | 46 | 47 | 48 | 49 | 50 | 51 | 52 | 53 | 54 | 55 | 56 | 57 | 58 | 59 | 60 | 61 | 62 | 63 | 64 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Product structure / design | 33 | 1 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Variety of parts and modules | 34 | .67** | 1 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Variety of the applied materials | 35 | .57** | .66** | 1 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Variance in product design | 36 | .38** | .35** | .33** | 1 | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Availability of materials or components | 37 | .38** | .34** | .47** | .34** | 1 | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Properties of modules and materials | 38 | .32** | .28** | .45** | .32** | .65** | 1 | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Product's degree of innovation | 39 | .37** | .36** | .41** | .34** | .33** | .34** | 1 | | | | | | | | | | | | | | | | | | | | | | | | | |
| Product life cycle length | 40 | .44** | .41** | .41** | .34** | .33** | .28** | .37** | 1 | | | | | | | | | | | | | | | | | | | | | | | | |
| Technology change / innovation | 41 | .35** | .25** | .31** | .23** | .31** | .27** | .43** | .45** | 1 | | | | | | | | | | | | | | | | | | | | | | | |
| Number of different applied technologies | 42 | .47** | .46** | .42** | .37** | .40** | .37** | .42** | .44** | .60** | 1 | | | | | | | | | | | | | | | | | | | | | | |
| Technology's complicacy | 43 | .42** | .44** | .38** | .39** | .33** | .31** | .42** | .39** | .52** | .77** | 1 | | | | | | | | | | | | | | | | | | | | | |
| Technology's combination | 44 | .40** | .40** | .36** | .33** | .34** | .30** | .38** | .35** | .40** | .61** | .62** | 1 | | | | | | | | | | | | | | | | | | | | |
| Technology life cycle length | 45 | .38** | .35** | .34** | .23** | .27** | .28** | .24** | .41** | .40** | .53** | .47** | .63** | 1 | | | | | | | | | | | | | | | | | | | |
| Product software | 46 | .32** | .38** | .19** | .24** | .22** | .15* | .22** | .34** | .29** | .38** | .39** | .41** | .49** | 1 | | | | | | | | | | | | | | | | | | |
| Data processing system | 47 | .28** | .26** | .22** | .18** | .28** | .23** | .15** | .33** | .31** | .38** | .35** | .33** | .38** | .66** | 1 | | | | | | | | | | | | | | | | | |
| Vertical range of manufacture | 48 | .27** | .26** | .30** | .24** | .33** | .30** | .25** | .28** | .32** | .35** | .33** | .37** | .27** | .07 | .12* | 1 | | | | | | | | | | | | | | | | |
| Production system | 49 | .36** | .32** | .34** | .24** | .27** | .32** | .24** | .27** | .37** | .45** | .43** | .37** | .29** | .16** | .20** | .78** | 1 | | | | | | | | | | | | | | | |
| Variety of processes | 50 | .32** | .38** | .39** | .24** | .31** | .31** | .30** | .32** | .30** | .37** | .35** | .37** | .36** | .18** | .25** | .57** | .58** | 1 | | | | | | | | | | | | | | |
| Amount of process interfaces | 51 | .38** | .39** | .35** | .25** | .27** | .27** | .31** | .30** | .30** | .42** | .44** | .47** | .43** | .29** | .34** | .45** | .50** | .78** | 1 | | | | | | | | | | | | | |
| Process degree of cross-linking | 52 | .33** | .34** | .32** | .24** | .24** | .26** | .32** | .30** | .32** | .41** | .41** | .46** | .39** | .30** | .36** | .38** | .43** | .68** | .82** | 1 | | | | | | | | | | | | |
| Process standardization | 53 | .28** | .31** | .25** | .14* | .24** | .27** | .20** | .21** | .24** | .37** | .33** | .42** | .34** | .26** | .26** | .31** | .35** | .52** | .58** | .67** | 1 | | | | | | | | | | | |
| Information flow's variety | 54 | .26** | .28** | .21** | .24** | .17** | .15* | .27** | .18** | .27** | .46** | .42** | .46** | .37** | .41** | .38** | .29** | .31** | .46** | .60** | .65** | .64** | 1 | | | | | | | | | | |
| Information flow's dynamics | 55 | .27** | .29** | .25** | .29** | .27** | .20** | .32** | .22** | .27** | .41** | .40** | .48** | .38** | .39** | .39** | .30** | .30** | .46** | .58** | .61** | .56** | .86** | 1 | | | | | | | | | |
| Amount of hierarchical levels | 56 | .35** | .31** | .35** | .27** | .30** | .26** | .23** | .32** | .29** | .36** | .33** | .35** | .31** | .28** | .35** | .29** | .32** | .40** | .47** | .41** | .34** | .45** | .45** | 1 | | | | | | | | |
| Organization´s / Company´s size | 57 | .32** | .30** | .34** | .30** | .27** | .22** | .31** | .30** | .31** | .37** | .36** | .35** | .31** | .27** | .33** | .27** | .32** | .41** | .51** | .49** | .35** | .47** | .48** | .80** | 1 | | | | | | | |
| Degree of centralization | 58 | .26** | .28** | .30** | .15** | .26** | .27** | .20** | .22** | .25** | .30** | .25** | .33** | .30** | .27** | .27** | .31** | .30** | .34** | .34** | .37** | .36** | .37** | .36** | .49** | .57** | 1 | | | | | | |
| Amount of simultaneous projects | 59 | .24** | .26** | .24** | .21** | .15** | .14* | .34** | .23** | .32** | .31** | .36** | .27** | .18** | .21** | .21** | .22** | .27** | .33** | .37** | .33** | .32** | .42** | .49** | .38** | .46** | .32** | 1 | | | | | |
| Amount of simultaneous processes | 60 | .25** | .30** | .26** | .25** | .28** | .26** | .33** | .29** | .36** | .45** | .42** | .33** | .24** | .22** | .25** | .25** | .30** | .48** | .49** | .46** | .39** | .47** | .52** | .42** | .48** | .37** | .76** | 1 | | | | |
| Amount of employees | 61 | .25** | .21** | .24** | .24** | .16** | .15* | .26** | .20** | .31** | .30** | .33** | .28** | .16** | .17** | .17** | .26** | .27** | .35** | .38** | .36** | .27** | .37** | .34** | .42** | .48** | .37** | .42** | .46** | 1 | | | |
| Requirements for company's control | 62 | .27** | .29** | .25** | .26** | .17** | .14* | .20** | .22** | .26** | .33** | .32** | .38** | .31** | .25** | .24** | .30** | .28** | .38** | .42** | .43** | .37** | .51** | .52** | .48** | .49** | .50** | .43** | .47** | .54** | 1 | | |
| Company's control level of detail | 63 | .27** | .29** | .27** | .30** | .17** | .13* | .24** | .23** | .25** | .31** | .30** | .39** | .27** | .21** | .21** | .29** | .27** | .35** | .44** | .44** | .38** | .52** | .56** | .50** | .51** | .50** | .42** | .40** | .46** | .87** | 1 | |
| Company's communication system | 64 | .29** | .31** | .28** | .29** | .20** | .16** | .28** | .26** | .30** | .35** | .32** | .35** | .35** | .28** | .31** | .36** | .33** | .41** | .43** | .43** | .30** | .43** | .48** | .41** | .39** | .45** | .37** | .41** | .42** | .59** | .60** | 1 |

*Note:*

**= significant at the 0.01 level

* = significant at the 0.05 level

N = 295 companies

Explanation for intercorrelations:

- ■ Very strong correlations
- ■ Strong correlations
- ■ Medium correlations

*Table 10: Total variance explained*

| Component | Initial Eigenvalues | | | Extraction Sums of Squared Loadings | | | Rotation Sums of Squared Loadings | | |
|---|---|---|---|---|---|---|---|---|---|
| | Total | % of Variance | Cumulative % | Total | % of Variance | Cumulative % | Total | % of Variance | Cumulative % |
| 1 | 16.177 | 25.276 | 25.276 | 16.177 | 25.276 | 25.276 | 8.154 | 12.741 | 12.741 |
| 2 | 3.853 | 6.021 | 31.297 | 3.853 | 6.021 | 31.297 | 6.600 | 10.312 | 23.053 |
| 3 | 3.078 | 4.809 | 36.106 | 3.078 | 4.809 | 36.106 | 4.034 | 6.303 | 29.356 |
| 4 | 2.800 | 4.375 | 40.481 | 2.800 | 4.375 | 40.481 | 3.947 | 6.168 | 35.524 |
| 5 | 2.379 | 3.718 | 44.199 | 2.379 | 3.718 | 44.199 | 3.692 | 5.769 | 41.293 |
| 6 | 2.200 | 3.438 | 47.637 | 2.200 | 3.438 | 47.637 | 3.314 | 5.178 | 46.471 |
| 7 | 2.174 | 3.397 | 51.034 | 2.174 | 3.397 | 51.034 | 2.920 | 4.563 | 51.034 |
| 8 | 1.912 | 2.988 | 54.021 | | | | | | |
| 9 | 1.513 | 2.364 | 56.386 | | | | | | |
| 10 | 1.439 | 2.248 | 58.633 | | | | | | |
| 11 | 1.421 | 2.220 | 60.854 | | | | | | |
| 12 | 1.295 | 2.023 | 62.877 | | | | | | |
| 13 | 1.196 | 1.869 | 64.746 | | | | | | |
| 14 | 1.071 | 1.674 | 66.419 | | | | | | |
| 15 | 1.025 | 1.602 | 68.021 | | | | | | |
| 16 | .980 | 1.532 | 69.553 | | | | | | |
| 17 | .970 | 1.516 | 71.069 | | | | | | |
| 18 | .937 | 1.464 | 72.533 | | | | | | |
| 19 | .877 | 1.371 | 73.904 | | | | | | |
| 20 | .831 | 1.299 | 75.203 | | | | | | |
| 21 | .809 | 1.264 | 76.467 | | | | | | |
| 22 | .765 | 1.196 | 77.662 | | | | | | |
| 23 | .732 | 1.143 | 78.806 | | | | | | |
| 24 | .728 | 1.137 | 79.943 | | | | | | |
| 25 | .660 | 1.032 | 80.975 | | | | | | |
| 26 | .638 | .997 | 81.972 | | | | | | |
| 27 | .611 | .955 | 82.927 | | | | | | |
| 28 | .588 | .919 | 83.846 | | | | | | |
| 29 | .568 | .888 | 84.734 | | | | | | |
| 30 | .546 | .852 | 85.586 | | | | | | |
| 31 | .527 | .824 | 86.410 | | | | | | |
| 32 | .504 | .787 | 87.197 | | | | | | |
| 33 | .455 | .712 | 87.909 | | | | | | |
| 34 | .452 | .706 | 88.615 | | | | | | |
| 35 | .428 | .669 | 89.284 | | | | | | |
| 36 | .412 | .644 | 89.927 | | | | | | |
| 37 | .407 | .636 | 90.563 | | | | | | |
| 38 | .386 | .602 | 91.166 | | | | | | |
| 39 | .371 | .579 | 91.745 | | | | | | |
| 40 | .357 | .557 | 92.302 | | | | | | |
| 41 | .349 | .546 | 92.848 | | | | | | |
| 42 | .340 | .532 | 93.380 | | | | | | |
| 43 | .316 | .494 | 93.874 | | | | | | |
| 44 | .299 | .467 | 94.341 | | | | | | |
| 45 | .294 | .460 | 94.801 | | | | | | |
| 46 | .274 | .427 | 95.229 | | | | | | |
| 47 | .267 | .417 | 95.646 | | | | | | |
| 48 | .255 | .398 | 96.044 | | | | | | |
| 49 | .251 | .392 | 96.437 | | | | | | |
| 50 | .231 | .361 | 96.797 | | | | | | |
| 51 | .211 | .330 | 97.127 | | | | | | |
| 52 | .204 | .319 | 97.446 | | | | | | |
| 53 | .193 | .302 | 97.748 | | | | | | |
| 54 | .186 | .291 | 98.039 | | | | | | |
| 55 | .169 | .264 | 98.303 | | | | | | |
| 56 | .162 | .254 | 98.556 | | | | | | |
| 57 | .156 | .244 | 98.801 | | | | | | |
| 58 | .144 | .225 | 99.025 | | | | | | |
| 59 | .130 | .203 | 99.228 | | | | | | |
| 60 | .116 | .182 | 99.410 | | | | | | |
| 61 | .106 | .166 | 99.576 | | | | | | |
| 62 | .098 | .153 | 99.730 | | | | | | |
| 63 | .093 | .146 | 99.876 | | | | | | |
| 64 | .080 | .124 | 100.000 | | | | | | |

**Extraction Method:** Principal Component Analysis

Table 11: Factor analysis on independent variables

| Complexity drivers | ID | First factor | Second factor | Third factor | Forth factor | Fifth factor | Sixth factor | Seventh factor |
|---|---|---|---|---|---|---|---|---|
| Information flow's variety | 54 | **0.76** | | | | | | |
| Information flow's dynamics | 55 | **0.73** | | | | | | |
| Requirements for company's control | 62 | **0.73** | | | | | | |
| Company's control level of detail | 63 | **0.72** | | | | | | |
| Process degree of cross-linking | 52 | **0.71** | | | | | | |
| Amount of process interfaces | 51 | **0.71** | 0.35 | | | | | |
| Company's communication system | 64 | **0.63** | | | | | | |
| Process standardization | 53 | **0.63** | | | | | | |
| Organization´s / Company´s size | 57 | **0.62** | | | | | | |
| Variety of processes | 50 | **0.62** | 0.38 | | | | | |
| Amount of simultaneous processes | 60 | **0.60** | | | | | | |
| Amount of hierarchical levels | 56 | **0.59** | | | | | | |
| Amount of simultaneous projects | 59 | **0.56** | | | | | | 0.39 |
| Degree of centralization | 58 | **0.56** | | | | | | |
| Amount of employees | 61 | **0.54** | | | | | | |
| Number of different applied technologies | 42 | | **0.67** | | | | | |
| Product structure / design | 33 | | **0.62** | | | | | |
| Product life cycle length | 40 | | **0.61** | | | | | |
| Technology's complicacy | 43 | | **0.61** | | | | | |
| Variety of parts and modules | 34 | | **0.59** | | | | | |
| Variety of the applied materials | 35 | | **0.58** | | | | | |
| Technology's combination | 44 | 0.40 | **0.56** | | | | | |
| Technology life cycle length | 45 | | **0.55** | | | | | |
| Product life cycle length | 32 | | **0.55** | | | | | |
| Availability of materials or components | 37 | | **0.55** | | | 0.37 | | |
| Technology change / innovation | 41 | | **0.53** | | 0.36 | | | |
| Properties of modules and materials | 38 | | **0.53** | | | 0.37 | | |
| Product's degree of innovation | 39 | | **0.51** | | | | | |
| Production system | 49 | 0.42 | **0.48** | | | | | |
| Vertical range of manufacture | 48 | 0.41 | **0.43** | | | | | |
| Variance in product design | 36 | | **0.42** | | | | | |
| Customer structure | 26 | | | **0.71** | | | | |
| Product variety | 28 | | | **0.68** | | | | |
| Customer's amount | 25 | | | **0.65** | | | | |
| Product range / Portfolio | 29 | | | **0.64** | | | | |
| Individuality of customer demands | 9 | | | **0.55** | | | | |
| Variety of customer requirements | 8 | | | **0.54** | | | | |
| Customer's participation | 27 | | | **0.54** | | | | |
| Demand's dynamics | 10 | | | **0.44** | | | | |
| Technological progress | 15 | | | | **0.69** | | | |
| Technological innovations & availability | 16 | | | | **0.65** | | | |
| Market's change | 12 | | | | **0.58** | | | |
| Market´s globalization | 14 | | | | **0.56** | | | |
| Competitor's dynamics | 13 | | | 0.36 | **0.53** | | | |
| Number & strength of competitors | 11 | | | | **0.47** | | | |
| Market's economic factors | 7 | | | | **0.45** | | | |
| Product software | 46 | | 0.34 | | **0.36** | | | |
| Data processing system | 47 | | | | **0.35** | | | |
| Amount of suppliers | 18 | | | | | **0.75** | | |
| Supply strategy or concept | 19 | | | | | **0.73** | | |
| Quality uncertainty of delivered goods | 20 | | | | | **0.71** | | |
| Uncertainty of delivery date | 21 | | | | | **0.67** | | |
| Variety of supplied goods | 17 | | | | | **0.66** | | |
| Environmental awareness in population | 2 | | | | | | **0.84** | |
| Ecological conditions / factors | 3 | | | | | | **0.80** | |
| Value change & value awareness | 1 | | | | | | **0.68** | |
| Political framework conditions | 4 | | | | | | **0.48** | |
| Legal factors | 5 | | | | | | **0.46** | |
| Market's infrastructure | 6 | | | | 0.36 | | **0.37** | |
| Business objective's change frequency | 23 | | | | | | | **0.69** |
| Business objective's time pattern | 24 | | | | | | | **0.51** |
| Amount of different targets | 22 | | | | | | | **0.50** |
| Product portfolio change frequency | 30 | | | | | | | **0.45** |
| New product launch´s frequency | 31 | | 0.40 | | | | | **0.45** |