Design for Value Chain – Towards an Evaluation of Global Value Chain Complexity

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Abstract
An increasing number of customized product variants produces complexity at the product level and at the level of value and supply chain. To avoid a corresponding increase of cost, the complexity in the company’s global supply and product distribution has to be reduced by controlling and avoiding complexity in the early stages of the product development process.

The Institute PKT developed the Integrated PKT-Approach for Developing Modular Product Families (PKT-Approach), which adapts the product architecture to offer a high external variety without increasing the internal diversity likewise (Krause and Eilmus, 2011). As product variety also induces complexity at the level of the supply chain, the PKT-approach was to be expanded by the method Design for Value Chain (DfVC), which focuses on the simultaneous management of complexity at the value and supply chain as well as at the product level. DfVC will create product structures optimized to the supply chain strategy, learning from the experiences of existing product families and their product variety induced complexity. To judge the potential improvement on the product and value chain level by DfVC, an evaluation of different product and value chain concepts is of high relevance to complexity management methods.

This paper will therefore focus on
- the analysis of the value chain,
- identifying the complexity within the value chain,
- identifying the complexity drivers and
- evaluating the value chain complexity.

DfVC has been developed in cooperation with Dräger and is explained using this case study.

The result is a radar chart, which uses various company specific complexity factors to evaluate different product and value chain concepts according to their complexity.

Keywords: Design for Value Chain, Product Development, Complexity, Evaluation
1. **Motivation and Introduction**

In times of globalization and shorter product life cycles, companies offer their customers an increasing external product variety. In addition, companies operate globally and therefore new requirements within the order fulfillment process have to be considered. These requirements have a major influence on both the product and the value chain and have to be considered during the product development process. During the development of new products, the value chain can change likewise. Therefore a value chain concept has to be developed, which fits to the new product concept. Experience in industry has shown that the product and the value chain concepts are usually developed separately from each other and the communication between the various developers needs to be improved.

Not perfectly matched concepts lead to a high and unnecessary complexity in the value chain. An increased effort due to the increased number of variants can be detected for all stations of the supply chain (Wildemann, 2000). To handle this complexity, the methodical approach DfVC was developed in cooperation with Dräger. It extends the PKT-Approach, which was developed by the Institute PKT. This approach has the goal to reduce the internal complexity by using different methods, without changing the offered external product variety (see Fig. 1). Both the level of products and the level of processes are considered in the PKT-approach.

![Fig. 1 Integrated PKT-Approach for Developing Modular Product Families](image-url)
Within the development of products and value chain processes, different concepts are elaborated. These concepts, especially the value chain concepts have to be evaluated to be able to choose the best product and value chain concept to fulfill the customer needs efficiently and effectively. In order to evaluate different product and value chain concepts, an assessment of the value chain complexity is urgently needed, within the DfVC.

Since complexity is not a unified measure, such as the force or velocity that can be measured or calculated, the next section explains the general concept of complexity and describes the understanding of complexity within DfVC. Based on this, various methods for evaluating the complexity are analyzed.

The third section introduces a methodical approach to evaluate the value chain complexity, which was developed within DfVC. The aim is to evaluate what the company understands by complexity. The approach is a systematic proceeding to analyze the company specific complexity and to evaluate different value chain concepts. The method focuses mainly on

- the analysis of the value chain,
- identifying the complexity within the value chain,
- identifying the complexity drivers and
- evaluating the value chain complexity.

Subsequently the application of the approach at Dräger will be presented, a reflection of the method is carried out and is completed with a conclusion in section six.

2. State of the art

Complexity is currently a commonly used buzzword (Andreasen, 2009). The concept of complexity has to be explained as a gradual property for the consideration of complexity management. This buzzword is often used in everyday life and in literature, without defining and reflecting its meaning (Grochla, 1980). Therefore, the following subsections describe the concept of complexity as well as methods in literature to evaluate complexity.

2.1 Complexity

Dealing with complexity varies from scientific fields such as biology or physics, to engineering and theoretical computer science, to scientific fields like sociology. Not
only one, but many definitions of complexity exist (Abdelkafi, 2008). Each of these disciplines has different goals and defines complexity quite different (Blecker et al., 2004; Scherf, 2003; Stacey, 1997; Kirchhof, 2003). Therefore, it is not possible to find a single definition, but different definitions and perspectives are required (Gell-Mann, 1994). Based on these definitions of complexity in the various scientific fields, the following six different interpretations can be differentiated and are explained in more detail in (Brosch and Krause, 2011) (Fig. 2).

**Fig. 2 Six Different Interpretations of Complexity**

- **Complexity as the size of a system**: The number of elements of a system determine the complexity (Kersten et al., 2006) (Fig. 2. top left).
- **Complexity as the diversity and variability of a system**: The interaction between the elements, the different types of elements, their linkage and the
dynamic changes within the system configuration are considered (Ashby, 1985; Kuhn and Hellingrath, 2002) (Fig. 2 middle left).

- **Complexity as the entropy of a system**: Entropy is a criteria of the average information content or information density of a system. The more characters are received from a source, the more information will be sent and the uncertainty about what could have been sent, decreases (Shannon, 2001) (Fig. 2 bottom left).

- **Complexity as the combinatorial variety of a system**: Complexity of a system is described by the plurality of different system states (Malik, 1996; Bliss, 1998) (Fig. 2 top right).

- **Complexity as the length of the description of a system**: Complexity is determined by the amount of words, which are needed to describe a system (Gell-Mann, 1994) (Fig. 2 middle right).

- **Complexity as the subjective perception**: Experience and knowledge of the individual actors determines Complexity (von Foerster, 1977) (Fig. 2 bottom right).

These six interpretations are not valid alone but interact with each other. The following four different perspectives are distinguished for a general and holistic understanding of the complexity within the DfVC (Brosch and Krause, 2011). The six described interpretations are not extended, but further complemented and specified.

- Design property of complexity
- Appearance of complexity
- Reference of complexity
- Impact of complexity

The **design property** describes complexity as the number and variety of system elements and their relationships. It combines the interpretation of complexity as the size, variability and combinatorial diversity.

In addition, the **appearance of complexity** is differentiated between objective and subjective complexity. This perspective adapts the interpretation of complexity as a perception. The objective appearance reflects the perspective of the design property. The subjective appearance describes complexity perceived by the observer. The same idea of objective and subjective complexity is also described in literature by
other terms. **Wildemann** distinguishes for example between individual and structural complexity (Wildemann, 2009) and **Kirchhof** uses the concepts of structural and functional complexity (Kirchhof, 2003). The third perspective identifies complexity on the perspective of the reference objects, which means the level of detail (Gell-Mann, 1994). The fourth perspective is the **impact of complexity**. Here, the business relevance of complexity is taken into account (Wildemann, 2009). Complexity is generally associated with negative attributes, but has a positive side however, if for example unique features and selling points can be generated (Dalhöfer, 2009). In the context of this paper, complexity can be summarized as a reason for additional efforts, the use of additional resources and an increased need for information to global companies.

### 2.2 Evaluation of Complexity

For the derivation of complexity factors, a workshop was conducted at Dräger to analyze existing Key Performance Indicator (KPI). Two different concepts were analyzed using the different KPIs. After a group work session the small groups presented their results. The application of the selected methods to given process concepts has shown that all methods can be used to evaluate complexity, but each one will assess only a certain aspect of value chain complexity.

An approach to evaluate complexity, applied mainly in industry, is the evaluation by cost. In this case, three main factors have to be considered. On the one hand the shift from cost shares to the overhead costs needs to be considered. With additional versions of indirect activities the overhead costs increase and the ascertainment and allocation of complexity cost through cost accounting systems becomes more difficult. Furthermore, an increased complexity leads to step costs, because some resources can often only be expanded or reduced in discrete steps. The final effect is the cost resistance. With decreasing capacity, utilization cost does not decrease proportionally. This means that the loss of the company is even greater than the loss due to the lack of orders (Meyer, 2006).

Aspects of controlling and cost accounting have to be considered in more detail in order to investigate the complexity costs. The aim is to make the additional effort and benefit measurable, which is caused by complexity. Traditional cost accounting
systems have significant deficits (Jania, 2005; Schuh, 2005). Therefore, the assessment of complexity based on cost is not conclusive enough. Since there are different interpretations of cost determination, the result will never be beyond doubt. Furthermore, a balance between cost and benefit is very important. It should not arise more costs to determine the complexity than can be saved by the transparency of complexity.

Apart from the cost analysis, several other approaches to measure the complexity within the value chain are mentioned in the literature. The information from literature can be divided into two categories. On the one hand, the evaluation of the supply chain, which deals with the performance of the supply chain (Beamon, 1999), (Lambert and Pohlen, 2001), (Kaluza et al., 2006), (Bhagwat and Sharma, 2007). On the other hand, there is the assessment of the complexity (Raufeisen, 1998), (Gell-Mann, 1994), (Crippa et al., 2006), (He et al., 2008). Only very few sources combine the two elements and introduce a concrete measurement of complexity within the supply chain (Modrak and Pavol, 2011), (Kaluza et al., 2006), (Frizelle, 2004).

None of these methods allows any statement whether key processes are well handled and whether customer requirements are ideally fulfilled. The problem of distributed production sites is also not addressed. The origin of this problem often lies in the fact that supply chain management is considered merely as an advanced logistics outside the company. Actually, logistics is a part of global supply chain management. Logistics cover the planning, implementation and control of an efficient and effective flow and storage of goods, services and related information from the point of origin to the point of consumption to meet customer requirements. Supply chain management includes the entire consideration of the key processes through the entire supply and value chain in relation to goods, services and information (Lambert and Pohlen, 2001).

The large deficit of today’s supply chain metrics is a focused and detailed examination of individual aspects of the supply chain, without the consideration of the whole supply chain. In the following, an approach is presented which supports the holistic evaluation of value chain complexity in the early stages of product and value chain development.
3. **Approach to Evaluate Value Chain Complexity**

Important aspects in the evaluation of performance of a value chain are the parameters of quality, time, flexibility and cost. When introducing an evaluation system basic questions appear:

- What should be measured at all?
- How to determine the necessary data?
- How to put together the evaluation aspects into a unified assessment system?

A problem is that no system is similar to the other. Consequently, the evaluating system needs to be adapted on the individual case, in order to meet the needs of the individual requirements. The aim is to develop an approach that evaluates the company-specific complexity and makes it comparable.

The approach outlined below is divided into four distinct steps, which answer the questions above (see **Fig. 3**).

**Fig. 3 Approach to Evaluate Value Chain Complexity**

### 3.1 Identification of Complexity and its Drivers

In the first step, a recording and analysis of the order fulfillment processes take place to identify complexity within the value chain processes. In the second step the reasons of complexity, described by complexity drivers are identified and visualized.

The aim of these first two steps is to answer the questions “What should be measured at all?” and “How to determine the necessary data?”. Since complexity and its drivers are company-specific, it has to be ensured that any evaluation of value chain complexity is not carried out only based on generic complexity drivers. **Fig. 4** shows the systematic approach to identify complexity drivers that are necessary to evaluate the complexity.

The recording and analysis of the processes can be performed either by the inspection of existing documents, interviews with experts and by the observation of
processes. To illustrate the global distribution of goods through a global company, a structural supply chain representation is used. This allows a quick overview of the existing stations, the number and geographical location of the value chain and the existing flow of goods (Beckmann, 2004).

**Fig. 4 Approach to Identify Complexity Drivers**

The complexity of processes within the value chain cannot be identified at this level of detail. For this reason, the local processes of the value and supply chain stations are identified and visualized in detail with the help of a swim-lane representation. Thereby the Actual-Plan-Process, meaning the order fulfillment process how it should run is determined. This way the detail-complexity is identified. For each increasing complexity scenario, a further representation is received, in which the additional sub-processes, meaning the extra effort of the company are marked in grey. All these complexity scenarios merged together add up to the complexity in the order fulfillment process. Examples of these complexity drivers are limited capabilities of computer systems or dynamically changing customer requirements, which increase the complexity of the order fulfillment process (Brosch et al., 2011a).

### 3.2 Derivation of Complexity Factors

Since there is no uniform definition of complexity and complexity thus cannot be detected with a single KPI, a performance measurement system must be developed. After the identification and definition of company specific complexity and its drivers,
company specific complexity factors can be derivate. Every aspect of the different interpretations of complexity (see subsection 2.1) like number of elements, number of different relations or uncertainty are examples of complexity factors. These are then visualized using a radar chart. The efforts to collect the metrics and the benefits to be drawn from them have to be in a reasonable proportion to each other. Sometimes data is required for the calculation of KPIs, which is not available in the early stages of product and value chain development. A collection of such data would involve a significant effort. Thus, the availability of data determines the effort to determine KPIs. To use the metrics collected for communication purposes, they must be comprehensible and understandable. Therefore the complexity factors do not equal the complexity drivers, but are a subset of them.

3.3 Evaluation of Value Chain Complexity

After the preparation of the radar chart with the identified complexity factors, different concepts can be compared and evaluated. To determine the evaluation and the range, i.e. the minimum value and maximum value, an interdisciplinary workshop is performed. All stakeholders, which take part in the product and value chain development, participate in this workshop. This way, all existing opinions are equally respected and there is another important exchange of the different disciplines. For this evaluation, the value of each individual complexity factor is determined. In determining the complexity the uncertainties of the data have to be taken into account, since not all data is available in the early stages of product and value chain development. The degree of uncertainty is indicated by smiles. When the data is obtained by test results and specific findings, this is indicated with a happy smiley. An expert assessment based on a numerical scale or a calculated measure in which many assumptions were made in the calculation is marked with a neutral smiley. A sad smiley visualizes a simple estimation based on intuition.

Within a workshop, not everybody will evaluate a concept equally. A normal distribution is expected. Therefore, the range of the assessment is taken into account and is marked in the radar chart (see Fig. 5). This consideration is intended to promote the transparency in the early stages of product and value chain development. To ensure the comparability of the evaluation of the individual complexity factors, the various factors are normalized to a uniform scale of 1-10. By
this, a complexity factor like number of elements (e.g. 130 elements) and a factor like number of cycles (e.g. 2 cycles) can be compared. To normalize the factors a reference value chain process (an existing value chain process) is used as mean value (scale of 5). Afterwards the different value chain concepts that can be fulfilled by different product concepts can be evaluated. The result is not one number, meaning concept one is more complex than concept two, but is a visualization of the complexity of different complexity factors which has to be interpreted.

Fig. 5 Evaluation of Different Concepts

4. Implementation at Dräger

Dräger offers innovative products in the world of medical and safety technology and is already successful in meeting the country-specific market and customer requirements. To be even more effective and efficient in the future, the methodology outlined above was applied to the product of a portable multi-gas monitor system. The findings are described below. For reasons of confidentiality, no internal company knowledge is used.
4.1 Ascertainment and Analysis of the Value Chain

In the first step, the international distribution channels of the company were recorded. Dräger is currently distributing products through a worldwide distribution network. The production takes place mainly in globally distributed self-controlled factories. To identify complexity drivers within the second step of the approach, the processes were analyzed in more detail using a swimlane diagram.

The task of providing a variety of countries and markets with products poses a particular challenge, because all possible customer needs should be met. Challenges for Dräger are particularly high and variant safety regulations that have to be considered within the product and process development (Brosch et al., 2011b).

The identification of complexity resulted in complexity drivers in different areas such as marketing, sales, design, product planning and introduction of products on the market (Brosch et al., 2011c).

The result of these two steps is the recording of two different value chain processes for implementing a special customer request. First, the proposed process flow (actual-plan-process) and secondly the actual-complexity-process. A process is called actual-complexity-process (Fig. 4), if complexity driver create additional and unplanned processes.

4.2 Derivation of Complexity Factors at Dräger

Due to the implementation of the approach at Dräger, different complexity factors were identified, e.g.

- Opacity
- Number of elements
- Complexity costs

The aim of the opacity factor is to illustrate how well the company processes are known and illustrated. The processes of operations and the hubs are very well known and ascertained at Dräger. The processes that are occurring within the Sales Companies, however, are only known to a certain extent. A lower transparency means a higher uncertainty in the process and thus represents a higher complexity compared to a more familiar process. A possible indicator of the transparency factor is the ratio of well-known and visualized processes to the total number of processes in the network.
An important factor to evaluate the complexity of value chains is the **number of occurring elements**. For the number of elements in the value chain, different aspects have to be considered. At Dräger, it is interesting how many business units and supply chain stations are involved in the whole process. If Dräger is shipping directly from the distribution center to the Customer, the additional path via the Sales Companies is saved and thus the complexity is reduced.

As described above, an assessment using only the **cost of complexity** is not sufficient to capture the overall complexity of a supply and value chain. But as a factor in the evaluation scheme, the cost is not negligible. Complexity costs are to be considered as additional costs incurred, if an alternate value chain is compared to a target value chain. These include the additional efforts when a further business unit is integrated into the network. However, it should be no detailed cost allocation, but existing data should be used. At Dräger the costs of various production sites and transport routes are known. These are sufficient to obtain an overview of the situation from the perspective of the complexity costs.

5. **Reflection of the Approach**

The presented assessment method provides transparency regarding the complexity of the company specific value chain and thereby reduces the subjective complexity. The objective complexity is visualized and can support the developers in the early stages of the product and value chain development. The goal and the result is not an automated decision finding, but to support the experienced developers. The result of the measure is not one single KPI, but the visualization and the comparability of different complexity factors, which are weighted and prioritized differently from case to case. In the literature there are different approaches to reduce the result shown to one single number. **Elstner and Krause** propose a calculation using fuzzy logic and the center of gravity (Elstner and Krause, 2012). As part of DfVC this is not recommended, because the strength of the approach is the analysis of company-specific complexity and its transparency. A reduction to a single KPI poses the risk that it will not be accepted and will not support the communication between product and value chain developers.
6. Conclusion

The approach presented describes a methodology for evaluating the company's specific value chain complexity in the early stages of product and value chain development. The approach was developed in cooperation with Dräger and extends the PKT-approach to the level of value chain processes. So far, the methodological approach was developed, the value chain complexity was determined at Dräger, complexity drivers were identified and complexity factors were derived. Both the integration of the assessment method in the product development process at Dräger and the validation and verification of the method at Dräger and other companies are subject of future research.

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