DESIGN FOR SUPPLY CHAIN REQUIREMENTS
AN APPROACH TO DETECT THE CAPABILITIES TO POSTPONE

Max Brosch
Hamburg University of Technology
Hamburg, Germany

Dieter Krause
Hamburg University of Technology
Hamburg, Germany

ABSTRACT
Different development trends pose new challenges for companies. They often meet these challenges by developing new product variants. Internally, this leads to an increased complexity, both at the product and at the supply chain level, which are mutually connected.

The existing approaches and methods of complexity management only focus on one of the observed levels and do not consider the mutual connectivity.

Modularity and platform strategy are the most common approaches to reduce the complexity at the level of product design. At the level of supply chain processes, the most common strategies are postponement and process commonality.

These approaches do not support selecting the optimal complexity management strategy as for example the proper level of modularization or the optimal depth of added value (postponement).

Therefore, this paper presents an approach to detect the capabilities to postpone, which accomplishes more transparency about the supply chain processes and the opportunities and capabilities of the individual supply chain stations.

This transparency supports the supply chain management as well as the product development in the reduction of internal complexity.

INTRODUCTION
Developments such as the globalization of competition, dynamic requirements (regulatory, market specific, country specific, customer specific) as well as shorter product life cycles, provide companies with new and changing challenges.

Companies try to adapt to these trends by developing product variants [1], which consequently lead to an increased complexity, both internally at the product level and at the level of the supply chain (see Figure 1).

In order to fulfill the different and dynamic requirements of global markets, countries and customers, companies need to address the question of how to provide the necessary external variety with a low internal complexity.

Examples could be identified in the industrial practice, in which even small changes of the customer requirements have a great influence on different processes of the company. This was ascertained, for example, at a corona stations manufacturer. Corona stations prepare surfaces to optimize the adhesion of printing inks, adhesives, etc. These stations consist of a central system of electrodes as functional unit, the support roll, generators, side frames made of steel and spreader bars made of aluminum. The frames are not lacquered typically. If the customer wants these parts to be lacquered, it leads to an increase in complexity within different processes. At first, a new sub-process, the lacquering, has to be implemented, which is not part of the general process. In addition the customer's request induces the company to use other materials (the spreader bars have to be made of steel as well) because the impression of the color varies on different materials. This
The exchange of materials has further effects on the process of procurement, as new suppliers have to be found and new contracts have to be negotiated. Moreover, this leads to variations in the production process, if the new material requires different treatment.

In this example, the complexity is increased not only in the business process (new sub-process) but also in the supply chain (new suppliers, possibly outsourcing the lacquering) by providing another product variety. As this increase in complexity raises the indirect costs within the company, it is necessary to reduce the complexity.

There are different strategies to reduce the process and supply chain complexity like process commonality and postponement. To implement these strategies certain capabilities of the supply chain and a modular product structure are required.

An analysis of the different existing approaches and methods of complexity management has shown that the existing methods focus on either the level of the product design or the supply chain design. A holistic complexity management, considering both levels is not yet in focus. To handle these interacting types of complexity an adapted variety-management approach referring to the supply chain is being developed. This approach, the Design for Supply Chain Requirements (DFSCR) will extend the existing approach of the Institute of Product Development and Mechanical Engineering Design (PKT) to the level of the supply chain.

An important first step to handle the supply chain complexity is the identification of the optimal depth of added value to choose the right level of postponement.

Since this optimal level of postponement is company specific, DFSCR initially creates transparency about the capabilities and possibilities to postpone of the supply chain. Based on this transparency, the companies can then determine the optimal strategy of complexity management.

In this paper a guideline is presented, how to detect the capabilities to postpone within a supply chain and how to achieve transparency. Hereby the contribution focuses on the following questions:

- What is the actual situation of the product production along the supply chain?
- Where is supplemental value enhancement generated or removed along the supply chain?
- What are the capabilities, of the different supply chain stations, to postpone?

To describe the approach the state of the art is addressed first. The state of the art focuses mainly on complexity and the strategies to handle these. Further, the Integrated PKT Approach for Developing Modular Product Families (Integrated PKT Approach) is described in more detail, which will be expanded by DFSCR.

Following the approach of DFSCR is described. For this purpose, first a framework is demonstrated, which shows the connections between the level of product design and supply chain design and classifies the approach DFSCR. The approach is then illustrated by the examples of four scenarios. Finally, DFSCR is summarized in the conclusion, and its benefit is presented.

STATE OF THE ART

This chapter explains and defines conceptually the basic principles of design for supply chain. First complexity and variety-management are described; thereafter some approaches to design for supply chain are presented. Later the Integrated PKT Approach is presented. This will be extended by the DFSCR.

Complexity

There are many different definitions for the term complexity. For the required analysis it has become established in literature, that complexity depends on three variables, number and diversity as well as on variability over time. Number and diversity of a system mean the number of elements and their relationships. The variability over time further takes into account the dynamic changes [2].

Variety-Management

The better the variety-management, i.e. the ability to handle the variety, the greater the competitive advantage [3]. Therefore, successful companies are characterized by the holistic use of a variety-management, which plans, reduces and handles the diversity of products in all business departments and processes by using appropriate tools, principles and methods [4].

The terms of the variation and diversity are distinguished as follows. A variant is a product with a deviation from the standard product [5]. The term variety describes the number of the variants [6].

Usually different views exist on the need for a large number of variety within the companies. Thus, a high number of variety is preferred in the areas close to the customers, while an extensive standardization of products and thus a small number of variety is required in the areas close to the production [7].

Wildemann describes three strategies to deal with complexity [8]:

- to avoid variety
- to reduce variety
- to handle variety

A more detailed approach can be generated under consideration of the risk management systematization by Haller and Pfohl [9], [10] expanding Wildemann's three strategies with the strategies to transfer and to divide variety (see Figure 2) [11].
Transferring variety describes the outsourcing of complexity whereas dividing variety describes the partition of complexity to different supply chain stations.

Both, product-based strategies such as modularization and platform design as well as process-based strategies such as the postponement strategy and the concept of commonality exist within the variety-management. In this paper, the process-based strategies are particularly relevant.

The aim of the postponement strategy is to keep as many steps of the processes as possible independent of product variety. Postponement describes the shift of some activities within the value chain to take advantage of better information [12]. This postponement can occur on different levels. One step of the assembly process can be postponed further within the assembly process at the factory itself, but the step can also be postponed further to other supply chain stations such as different hubs or even customer [12].

Referring to variety-management, the concept of commonality describes a strategy that takes advantage of the equality of resources used across various end products within a product family, to reduce the internal complexity of production and therefore reduce the cost. The shared resources can be equipment, staff, knowledge, components and processes [13].

The described strategies to reduce and handle the process complexity are shown in Figure 3.

**Design for Supply Chain**

Within the supply chain, a distinction is made between the design of the supply chain and the design for supply chain. The goal of design of the supply chain is the optimal design of logistics networks and processes to reduce transportation costs, inventory and cycle times and increase security of supply or delivery capacity [abc]. The design for supply chain examines how products must be designed and manufactured to achieve an optimal supply chain design.

Currently, companies are trying to improve their supply chain performance through planning systems, operations management software and real time inventory management processes. However, the focus of these systems is operational and does not influence the design and supply chain decisions that set basic targets for supply chain performance of a product line [15].

Lee uses the term „Design for Supply Chain Management“ to describe such design concepts, which provide much greater efficiency and flexibility in the logistics and distribution aspects of the order fulfillment cycle by designing products which fit to the requirements of the order fulfillment process [16]. Design for Postponement and Design for Localization are two of these approaches.

**Design for Postponement**

In the manufacturing and the distribution of technology products, Lee and Billington differ five main steps [12]:

1. **Manufacturing** – The core product is produced, mostly this is a generic product, or only a small number of products (e.g. printer engine and body).
2. **Integration** – The core product is combined with the key sub-assemblies (e.g., printer circuit board)
3. **Customization** – The customer-requested customization of products are carried out (e.g. in case of computer products, different memories and software).
4. **Localization** – The products are configured for different markets (e.g. different power units).
5. **Packaging** – The product is packaged to customer specifications. Thus, the product is in a different number of items (e.g. a packet with one or more cartridges).

To simplify this complexity Lee and Billington suggest a design for postponement strategy. Hereby the point of product differentiation is postponed. Table 1 gives some examples of design for postponement principles for the different main steps [12].
After implementation of the design for localization only the generic printer without the power supply module and manual is produced in Singapore and shipped to the hubs in Europe and Far East. The power supply and manuals are added to the generic product in the hubs and sold to the customer.

To realize this postponement in the localization, HP had to change the product structure of the printer. It had to redesign the product so that the power supply module would be the last component added on and the hub could add it on easily. Moreover, the distribution center/hubs had to be converted to have the necessary capabilities to perform the kitting process.

**Design for Supply Chain Performance**

This approach determines the performance of the supply chain by the Supply Chain Operations Reference model (SCOR-model). According to Samsung, the key performance indicators are [15]:

- Availability – availability of products or components at that place and time where the customer or manufacturing process requires it
- Lead time – total lead time in the supply chain network
- Total cost – total cost of the supply chain and the product line

These key performance indicators are influenced by product configurability, production flexibility, postponement capability and robustness of the product to supply disruptions. The approach of design for supply chain performance is a cross-functional process and requires input from all organizational units and supply chain members. The approach is divided into 4 phases [15]:

<table>
<thead>
<tr>
<th>Postponement Stage</th>
<th>Examples of Principles</th>
</tr>
</thead>
<tbody>
<tr>
<td>Manufacturing</td>
<td>Standardization/ Commonality</td>
</tr>
<tr>
<td>Integration</td>
<td>Slide in integration/ Modularization</td>
</tr>
<tr>
<td>Customization</td>
<td>Modularization/ Design for Assembly</td>
</tr>
<tr>
<td>Localization</td>
<td>Universal/ External Power Supply</td>
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<tr>
<td>Packaging</td>
<td>Design for Bulk Packing</td>
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**Design for Localization**

Lee, Billington and Carter show based on Hewlett-Packard (HP) deskjet printers an example in which the localization steps were postponed from the factory to the distribution center/hubs. Before applying the design for localization as postponement strategy, the international variants of the HP deskjet printer were manufactured and packaged in Singapore, including the power supply. Afterwards these were shipped to distribution centers/hubs around the world [17].

After implementation of the design for localization only the generic printer without the power supply module and manual is produced in Singapore and shipped to the hubs in Europe and Far East. The power supply and manuals are added to the generic product in the hubs and sold to the customer.

**Phase 1 – Development and Deployment of Design for Supply Chain Model**

Development of the supply chain and of a financial model that can be used by cross-functional product teams. The input can be generated from spreadsheet templates and web-based systems.

**Phase 2 – Analysis and Simulation**

Development of procedures, which offer a continuous visibility into supply chain performance.

**Phase 3 – Continuous Improvement**

Optimization of the key performance indicators by a continuous improvement of the model created in Phase 1 considering the actual situation.

**Phase 4 – Connectivity**

Connection of the model and the system with the supply chain partners.

The SOCR-model only refers to the supply chain and its characteristics. To achieve an integrated variety-management approach product structure and product diversity have to be considered respectively.

**Integrated PKT Approach**

The aim of the variety-management is to produce variants with minimal costs. The Institute of Product Development and Mechanical Engineering Design (PKT) has developed the Integrated PKT Approach for developing modular product families, to reduce the internal variety with methods, which are aiming to handle, to reduce and to avoid complexity. For this purpose, the methods Product Program Planning [18], Design for Variety [19] and Life Phase Modularization [20] have been developed or are under development. These methods to handle the variety of products adapt the product architecture to offer a very high external variety on the market without increasing the internal diversity.

As a further step, the level of the supply chain complexity is now taken into account beyond the product-based methods and the Integrated PKT Approach is therefore substantially expanded [21].

![Figure 4](image-url)
Figure 4 shows the extension of the approach in which the internal variety is reduced by the described methods. At the new level, the supply chain complexity, which is induced by the product variety, is reduced.

In the development of modular product structures, the various requirements of the individual product life phases have to be taken into account. The method of Life Phase Modularization differentiated these requirements. For each product life phase as product development, purchase, production, sales, use and recycling various modularizations are developed and the generic phase-specific module drivers are used, which are summarized in Figure 5. These module drivers, developed by Erixon, were identified through case studies and are generally valid [22]. Bleses concretizes these module drivers through their specifications. The module driver “differentiator” is for example described in more detail through the various specifications of the product family [20].

These module drivers and their specifications are being assigned in the Life Phase Modularization to the generic phases and the company-specific characteristics are not considered. The approach described below examines these characteristics and the attribution to the individual phases.

All the described methods of complexity management focus only on one of the levels, the product design or the supply chain design. They try to design the product or the supply chain; they hereby do not support the decision making for the complexity management strategy or the optimal level of postponement. Since these decisions are very important to select the correct complexity management method, the DFSCR approach is described below.

**DESIGN FOR SUPPLY CHAIN REQUIREMENTS**

To handle the complexity holistically, a complexity management is needed, which considers the level of product design and of supply chain design. For this, the approach (Integrated PKT Approach) described above, is expanded by DFSCR to the level of the supply chain design. This approach will take into account the local order fulfillment and the global distribution within the product development. In future, this should create product structures that are optimized for the different supply chain strategies. Figure 6 shows the framework of this approach.

Considering the supply chain requirements in product development, the two levels product design and supply chain design can be distinguished. The product design, which creates the external and internal variety, is supported by a modular product structure. For the development of modular product structures, the module driver according to Erixon [22] and their specifications by Bleses [20] are used. The level of supply chain design deals with handling and reducing the complexity, which is induced by product variety. For this, postponement is a key driver.

![Figure 6 FRAMEWORK FOR DESIGN FOR SUPPLY CHAIN REQUIREMENTS](image)

In order to choose the strategic direction of the complexity management, the knowledge and the transparency of the capabilities of the existing supply chain is important. Therefore, an approach within the DFSCR was developed to detect the capabilities of postponing and to identify how the supply chain capabilities affect the module driver specifications.

**DETECTING THE CAPABILITIES TO POSTPONE**

The approach consists of four steps and lies within the described framework:

1. Detection and visualization of the supply chain processes
2. Identification of the points of product differentiation
3. Detection and visualization of the supply chain capabilities
4. Identification of the influence of the supply chain on module driver specifications

For better understanding, the steps are illustrated using an example. For confidential reasons the experiences with different companies are merged to a fictional example. This example is modified and contains fictional numbers. Company A is a manufacturer of electrical appliances. These consist of purchased electronic components and enclosure parts. The enclosure parts consist of two standardized side shields made of plastic and various aluminum sidebars to adjust the length,
because the electrical appliances exist in different size groups. The purchased parts are assembled in the factory. To distribute the appliances within Europe, the products are forwarded to two different hubs. Hub1 is in France and operates the Western European market and Hub2 operates the Eastern European market from Poland. The sale is carried out by different sales companies (SC) in different countries. Figure 7 shows the structural design of the Supply Chain.

Figure 7 STRUCTURAL DESIGN OF THE SUPPLY CHAIN OF COMPANY A

In this paper, four scenarios are examined which increase the supply chain complexity.

- Scenario 1 – The electrical equipment must be tested. In some countries law, however, requires a new testing every 12 months. Therefore, the testing should be carried out shortly before the sale.
- Scenario 2 – Some sales companies in Eastern Europe sell the electrical equipment with an electric valve instead of the standard pneumatic valve. Hub2 obtains the electric valves from another supplier, and assembles them in the electrical equipment.
- Scenario 3 – Similar to the mentioned corona example, some customers require a variant in which the side panels and the sidebars have the same color. For this, the side panels are also made of aluminum and lacquered together with the sidebars.
- Scenario 4 – An instruction manual in local language has to be sold with each product.

Detection and visualization of the supply chain processes

For the detection and visualization of the supply chain processes, DFSCR combines two different views. The first is the structural view of the supply chain, i.e. the structure and the arrangement of the supply chain stations, and the material flows between them. The structural view is shown in Figure 7. Secondly, the understanding of a supply chain as a process. In each supply chain station, different sub-processes are performed. Even identical sub-processes are carried out, maybe even different, in several stations along the supply chain, because of the increased complexity. To consider both views a swim lane diagram is used for detecting and visualizing the supply chain processes. The individual swim lanes represent the different supply chain stations. Figure 8 shows that representation. Top left shows the supply chain process for Company A.

Figure 8 PRESENTATION OF SUPPLY CHAIN PROCESSES USING SWIM LANES

Thereupon (not shown) for each increasing complexity scenario, a further representation is received, in which the additional sub-processes are marked in gray. In scenario 1, for example, the testing is postponed to the hubs. Therefore, a new sub-process “testing” is located and marked gray in the swim lanes of the hubs. Figure 8 shows at the right bottom the combination of the four scenarios. The increase in complexity by increasing the number of elements (sub-processes), their compounds and their time-variability can thus be represented.

Identification of the places of product differentiation

As part of the order fulfillment, the value enhancement does not only take place within the factory or the production unit, but also in the downstream stations of the supply chain such as distribution centers, hubs and sales companies. Therefore supplemental value enhancement is not only generated but also removed. Removed value enhancement means dismantling of already assembled parts, e.g. dismantling of a switching valve to install another valve. Those changes of value enhancement are the places of product differentiation within the supply chain.

DFSCR uses the following procedure to identify the supply chain stations where value enhancement is removed (marked with a red circle) and the stations where there is supplemental value enhancement generated (marked with a green quadrangle) (see Figure 9).

In Scenario 2, Hub2 dismantles the previously assembled pneumatic valve to assemble an electric valve. This change in the value enhancement is shown in Figure 9.

The supplemental value along the supply chain is not necessarily negative and unrequested. In course of a postponement strategy, it could be profitable to postpone the value enhancement within the supply chain. The added value however can only be analyzed by the described ascertaining and visualizing method.
Detection and visualization of the supply chain Capabilities

Besides the purely quantitative ascertainment of value changing, the technical and capacitive capabilities of each supply chain station are recorded within this step of the DFSCR approach. Especially within the product development, such information is highly relevant in deciding on the manufacturing strategy. If, for example, one hub is able to calibrate the electrical equipment or to conduct a separate testing on parts, but another hub is not able to do this, the product development needs this information to customize the product and its production structure. Even more when deciding on the modularization of a product, the knowledge of such capabilities is essential to identify module drivers or module restrictions and their specifications in the supply chain.

Scenario 1

As shown in Figure 10 the capability to be able to test is needed to postpone the testing process. The Factory and Hub1 have green light, which means that a postponement to Hub1 is possible. Hub2 has orange light, i.e. that minor changes have to be implemented before testing may be postponed to Hub2. It may be possible for example that a testing is technically feasible, but in order to do this, the packaging (which has already been added in the factory) has to be torn. This would lead to a removal of value enhancement, which is not wanted.

Scenario 3

To meet the customer's painting requirements the supply chain stations need the capability of lacquering. If this capability exists for example in the Factory and Hub2 but not in Hub1, the postponement strategy has to be adapted accordingly. In this regard, the following questions have to be answered:

- Does a postponement strategy make sense?
- Does it make sense to implement different postponement strategies in Eastern Europe and in Western Europe?
- Should Hub1 be converted to obtain the capability of lacquering?

Scenario 4

Adding the manual can be generally carried out in the factory, in the hub or in the sales company. Within the capabilities of the supply chain stations it could be found that, the manuals can be added in the factory and in Hub1 (green). Hub2 can add the manuals, but it has no access to them (orange) and the sales company cannot add the manuals.

Identification of the influence of the supply chain on module driver specifications

As discussed above, the module drivers according to Erixon are defined within the Life Phase Modularization and they are extended to their respective specifications. According to Blees, a three level view of the module drivers is used. For each of a product's life phase a set of module drivers is defined, which is made more concrete by using product specifications. Product life phases and module drivers are definitely defined, but the specifications are made by the user [20].

Regarding the internal process complexity, the fixed allocation of product life phases according to these approaches has to be relativized and extended by the supply chain. DFSCR accounts for this extension considering a supply chain-specific adaptation of the module drivers and their own specifications as follows.

Figure 9 Visualization of the change in value enhancement

Figure 10 Capabilities of the supply chain stations
A distinction is made between the different supply chain stations (Factory, Hub1, Hub2), within the product life phase of the production. Within the next step, the specifications of the module drivers for the supply chain stations, which are involved in the product life cycle, are defined (see Figure 11).

**Figure 11 SUPPLY CHAIN SPECIFIC ADAPTAION OF THE MODULE DRIVER SPECIFICATIONS**

DFSCR thus accomplishes on the one hand a more detailed view on the effect of the module driver specifications in the framework of modularization and on the other, there is a strong correlation between the capabilities of the individual supply chain stations and the module driver’s specifications.

**SUMMARY AND PROSPECT**

The approach of Design for Supply Chain Requirements and the guideline to detect the capabilities to postpone achieves within four steps an increase in transparency of the supply chain, a reduction of the complexity of the supply chain, an enhancement of value along the supply chain, a deep knowledge of the capabilities and skills of the supply chain stations and the influence of the supply chain on module driver specifications.

DFSCR is an approach to consider the difficulties of complexity holistically and to determine the levels of product design and supply chain design. Therefore, the benefits of the approach are on both levels as well.

At the level of supply chain design, this approach cannot answer to any of the four sample scenarios, but it gives the information needed to select the optimal complexity management strategy. Due to the resulting transparency, different solution scenarios can be conceived and their impact can be determined.

This transparency is helpful for the design for supply chain as well as for the design of the supply chain. The design of the supply chain needs the information about the capabilities to know which station has to be changed to reduce transportation costs, inventory and cycle times and increase security of supply or delivery capacity.

At the level of the product design DFSCR supports the product development to accomplish the strategic specifications and the optimal level of postponement. While designing for supply chain, the transparency can be used in different ways. Developing a new product, it helps to determine the variety-management strategies of the product and its variety, such as postponement. Furthermore, the level of postponement can be determined, knowing the capabilities of the supply chain stations. It is recognized that either the product design or the supply chain design has to be changed to achieve the desired level of postponement.

The resulting transparency is necessary to identify the requirements of the supply chain according to a high product variety. These requirements are used to define module driver specifications of a modular product structure.

The need to develop a method to design for supply chain requirements has been identified in various companies in practice. The approach to detect the capabilities to postpone is an important step within this method. The approach will be further detailed and its practicality verified in other companies.

**REFERENCES**


