DEVELOPMENT OF PRODUCT WHILE CONSIDERING MATERIAL FLOW IN A PRODUCT'S LIFE

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The goal of this article is to demonstrate the dependencies between product development and material flow. The first part provides a compressed introduction to the topic. From the perspective of development, so called DfX (Design for X) approaches and methods are discussed as well as their possible influence on the business process, especially on the material flow. The purpose of this part is to provide a comprehensive overview of research notes in the given technical fields. The next part contains main steps of individual life cycle phases of a specific product – thee various methods of construction. It is figuratively explained how the selected type of final construction affects individual elements of material flow from the perspective of manufacturing, assembly, logistics, and sustainability. In the conclusion part, the research and the developed implementation is evaluated. The conclusion also contains an outline of possible future development.

KEYWORDS

Design for Manufacturing (DfM), Design for Assembly (DfA), Design for Logistic (DfL), Desing for Sustainability (DfS), Design for Ecology (DfE), Design for Supply Chain (DfSC), product development

1 "THE CUSTOMER IS ALWAYS RIGHT"

The current markets are described as markets with the manufacturing and transfer of products being performed in any manner and form, while taking the requirements of swift availability, low cost, high quality, and basically unlimited variability into account. In order to make this possible, using modern dynamic manufacturing processes and performing unceasing development of innovated or brand new products is a must.

Variety of products is given by the variety of consumers' requirements. That often leads to partial solutions resulting in increased effort of any type and form. Last, but not least, are special solutions leading to changes of internal and external business processes and material flows. From the perspective of manufacturing, the consequences of the situation are that it is necessary to partially change flows, implement additional flows, or, in extreme cases, develop entirely new material flows.

In order to reduce the effort, sources, and costs while meeting the customer's requirements for design, quality, and price, various methods and approaches became established in practice. These are generally focused on optimization of processes in terms of manufacturing, specifically during manufacturing operations or logistics. It is often emphasized that ultimately, the success on a market, where the competition, which is now strong enough, continuously increases as well as the offered variety, can be achieved only by optimizing the processes, including material flow, on all levels of the business.

2 CHARACTERISTICS OF SELECTED DFX APPROACHES AND METHODS

Following the term "material" is to be perceived as a superior term, which can mean raw material, auxiliary and business resources (information or energetic), unfinished parts, complete products, or assembly systems. (Comparison in [Arnold 2007]). Material flow is perceived as continuous, interconnected chain of processes, where motion, amounts, and transformation of material in time are related.

Without a doubt, construction of a given product, its design, has the primary influence on the material flows in product's life, this is reflected in the creation and behavior of internal and external material flows within business processes. Given methods, also called techniques, aim to affect the development phase (level, in which the directions of future material flows are pre-set) and the following optimization of product's construction, focusing on given parts of a product's life cycle, are covered by term Design for X. According to [Arnette 2014], the X are specific activities, goals, or properties that need to be focused on during the development. Additionally, all current construction optimization, all DfX, can be taxonomically separated to three categories – economic, environmental, and social. The aforesaid categorization aims to unite the regarded DfX under a Design for Sustainability. Additionally, according to [Arnette 2014], another possible categorization method of the current DfX assigning methods to phases of product's life cycles. This method is extended by development phase, since it contains a cornerstone for determining fundamental processes and determines steps of the following phases, i.e. sourcing, production, distribution, usage, and, finally, the final stage of the product's life – reversion (in terms of disposal or recycling).

As said before, implementation of DfX aims to influence the product's design and achieve certain improvement that is in direct relation to the given product. If the goal is to positively affect the product's life cycle, there is an option to optimize the design in terms of supply chain (SC) (Wertschöpfungskette in German, Supply Chain is about increasing material value during the material flow within the chain, starting at the supplier of raw material and ending at the consumer. Supply chain includes planning and implementing processes, therefore all processes of development, localization, production, and distribution. Comparison in [Becker 2008]. Supply Chain must be extended by processes of user phase and reversion.), which according to Design for Supply Chain (DfSC), methodology based on Supply Chain Operation Reference Model (SCOR Model) according to Supply Chain Council, means to strategically focus on optimization of material flows. When regarding all DfX approaches, the SCOR model must be extended by the user phase.

The supply chain is formed by manufacturing, logistic, and management processes. First part of the following research focuses on the first two parts. However, manufacturing and logistics do not include user phase, and the disposal phase is included only partially. The disposal/back-flow is tightly connected with ecology. Ecology plays an important role in development of new generation of products, therefore, it contributes on increasing the value of material. From the perspective of product attractiveness and company's competitiveness, taking the period of use into account as well as the customer's point-of-view is imperative. Wide range of the same product offered by various manufacturers provides a wide selection to the customers, who is then selecting the product based on own economic, social, and environmental requirements. The said criteria are characteristic for a sustainable development. For that reason, the research discusses this area, which is DfS (Design for Sustainability), as well. The research of methodology and approaches to optimization of construction is briefly chronologically described in the next part of the paper. Table 1 provides a sufficient overview of product's life cycle phases influenced by individual methodologies.

2.1 Design for Manufacturing and Assembly (DfMA)

According to [Boothrroyd 1987], DfA has a key role in achieving successful DfM. Its implementation includes two main steps – minimizing the amount of parts and improvement of the possibility to assemble the assembly system, leading to positively affecting material flows throughout the whole manufacturing process and ultimately to decreasing manufacturing costs.

In [Gerhart 1991], DfMA is implemented with the aim to use simultaneous engineering to decrease time required to develop new products, resulting in increased productivity. Factors that are a premise for successful optimization of product development are: detailed specifications, integration of suppliers, creating a team consisting of members of various departments, training, access to up-to-date information for all team members, implementing review processes, and rapid prototyping. In the specific example, the result was reached by reducing the amount of parts within an assembly group, thus reducing the amount of assembly operations and ultimately decreasing the total assembly time to a third of the original time period. It shall be said on the subject of the given example that it is a serial-line product consisting of a large amount of items. External experts were involved in the process, and a total of 34 members of various departments were involved. [Fabricius 1994] perceives the term DfM as a way of transfer from the original design to a new one, while the aim is to prevent occurrence of well-known problems related to the original design. The 7 steps below are designed for reaching the said goal:

1. Product assessment, comparison with adequate products on the market.
2. Determination of the intention for the purpose of manufacturability.
3. Definition of primary features.
4. Evaluation of parameters and ideas.
5. Concepts of new designs.
6. Evaluation and selection.
7. New and detailed design.

The main thought of design development optimization is based on a finding that it is not good to start with the design of the current product. The main criterion for creating a new design is its function shared by both generations of products. Management processes are not integrated and the time necessary to develop new product is not considered. The primary intention is to reduce material flows of material, parts, and components.

[Petzelt 2009] orients on implementing findings from production planning for development and starts to use technical participation on construction that must be standardized, meaning it is necessary to for the production planning department to provide structured requirements for constructions and properties.

Development of methodology for implementation of DfM to the context of engineering with focus on manufacturability is addressed in [Vallhagen 2013]: *„There is a need to make efficient use of domain tools in combination with experiences and continuous improvement"*. In this regard, the paper defines the framework of robust development with key components: using platforms (platforms for manufacturing, product, technology, and information), using virtual methods (modelling and simulation), consideration of life cycle, consideration of sets and systems.

2.2 Design for Logistic (DfL)

Consideration of logistic requirements of material flows to product's development can be performed on the levels of logistics subsystems, therefore procurement, production, distribution, and reverse logistics. This distribution shows direct affinity to phases of product's life cycle.

According to [Rosemann 1998], implementation of logistic influence on construction depends on complexity of the products. Simplification of construction of limitation of product's variants leads to decrease of costs on transportation, storage, transshipment and the commission (unloading of material according to defined criteria). Direct relationship between DfMA and DfL are also clear from [Pawellek 2002], whose aim is to positively influence the material flow by the content of the product. That can be achieved by ensuring controlled, effective, and continuous communication. So called integrated model of product and process is described as an implementation methodology as well. Also, the term disconnection point is also used (point between the customer-defined manufacturing and anonymous /standard/ manufacturing) must be placed as close to the end of manufacturing process as possible. The positive outcome of this is the decrease of manufacturing sensitivity to variable solutions of the product.

Influence of logistics costs when using DfL with key components of economic packaging and transport, parallelism of manufacturing processes and standardization is regarded in [Dombrowski 2006]. Using design optimization of an existing product while considering the requirements of logistics is discussed in [Pawellek 2007]. The goal is to create a system that meets the inspection function (i.e. shows the influence of product construction on logistic characteristics) and optimization function (decrease of lead time). The said system consists of two main tools, namely:

- Inspection list for review of the current design,
- List of methods for optimization of the current design.

Methodology for evaluation of product proposals from the perspective of logistics is drafted in [Dombrowski 2008]. The result is a degree of logistic readiness that considers the company and other criteria of a product. The following steps must be made to reach it:

- Evaluation of the product drafts pursuant to logistic requirements of procurement, production, distribution and disposal logistics,
- Evaluation of the considered logistic requirements from the company's perspective and specific perspective of the product,
- Determination of logistic criteria consideration level and followed classification of design drafts, selection of the best design,
- Optimization of the selected design's drawbacks.

The disadvantage of this methodology is the necessity to have at least to designs drafts of the product. That is linked to an increased investment of resources into the design development.

<table>
<tr><th colspan="6">Product's life cycle in terms of SCM</th></tr>
<tr><th>Development</th><th>Sourcing</th><th>Production</th><th>Distribution</th><th>Usage</th><th>Disposal</th></tr>
<tr><td colspan="3">[Boothrroyd 1987] DfA</td><td></td><td></td><td></td></tr>
<tr><td colspan="3">[Gerhart 1991] DfMA</td><td></td><td></td><td></td></tr>
<tr><td colspan="3">[Fabricius 1994] DfM</td><td></td><td></td><td></td></tr>
<tr><td colspan="6">[Rosemann 1998] DfMA, DfL</td></tr>
<tr><td colspan="3">[Hoffmann 2000] DfS</td><td></td><td></td><td></td></tr>
<tr><td></td><td></td><td></td><td></td><td>[Wiese 2001] DfS</td><td></td></tr>
<tr><td colspan="4">[Pawellek 2002] DfMA, DfL</td><td></td><td></td></tr>
<tr><td colspan="4">[Pawellek 2007] DfL</td><td></td><td></td></tr>
<tr><td></td><td></td><td colspan="2">[Dombrowski 2006] DfL</td><td></td><td></td></tr>
<tr><td colspan="4">[Dombrowski 2008] DfL</td><td></td><td>[Dombrowski 2008] DfL</td></tr>
<tr><td></td><td></td><td>[Petzelt 2009] DfM</td><td>[Pawellek 2009] DfL, DfS</td><td></td><td></td></tr>
<tr><td></td><td></td><td>[Woll 2011] DfS</td><td></td><td></td><td>[Woll 2011] DfS</td></tr>
<tr><td></td><td></td><td colspan="4">[Vallhagen 2013] DfM</td></tr>
<tr><td></td><td></td><td></td><td></td><td>[Eigner 2014] DfS</td><td></td></tr>
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Table 1. Classification of methods based on product's life cycle

Combination of implementation of DfL and ecology is clear in [Pawellek 2009]. The goal is the optimization of product's design for the purpose of limiting the amount of Carbon dioxide ejection into the atmosphere during transport. The amount of ejected CO_2 can be measured and used as characteristics for evaluating the success of the product's design optimization process. The means for CO_2 reduction is to set lower, but achievable product weight.

2.3 Design for Sustainability (DfS)

Expert literature often works with the term sustainability (Nachhaltigkeit in German) in relation to ecology. This is also confirmed by the focus of optimization in the researched sources. Environmentally focused implementations of product design are summarized under the term Design for Ecology (DfE). When comparing with DfL and DfMA, the environmental focus of the development must consider the behavior of the product during the whole life cycle. From the perspective of DfS, it is also necessary to consider economic and social aspects. The possibility of regarding economic aspects lies in integration of findings and methodology arising from DfMA and DfL focus. Generally speaking: reduction of material flow, which is the main idea of the said optimization methods, leads to smarter usage of resources and lower costs. Additionally, it is necessary to carry out extension with social goals in individual product life cycles.

In [Hoffmann 2000], an economic development of a product is discussed, if the environmental aspects are considered in all phases. The goal is to achieve environmental optimization in all manufactured products (whole manufacturing spectrum). When performing technical designing of the product as well as strategic planning, environmental thinking is required to reach this goal. Furthermore, the optimization must be performed step-by-step and in presence of the management with environmental agenda.

The concentration of DfS methodology must be sufficiently focused on the usage and disposal phase. An interdisciplinary cooperation of engineer and social science is required to consider user phases of the product's life cycle, see [Wiese 2001]. Here, the technical part of the team develops environmentally oriented product, while social sciences aim to motivate the consumers to an environmental usage of the product. Electric appliances may give a good example – they consume a significant amount of electric energy during their active phase of life cycle. During implementation, it is possible to reduce the product's power or define an energy consumption index, making the consumer able to know about the product's energy consumption.

[Woll 2011] points out the necessity to consider all criteria of sustainable development, as well as economical, environmental, and social criteria, while the last criterion is difficult to specify. It implements the "House of Sustainability" methodology that shows dependencies between product's parameters and properties of the process, specifically assembly and disassembly. The next step is three developed variants of a product that are evaluated by a traffic-light principle from the economic, environmental, and social perspective. The said procedure is to be applied to all processes working with balance between the effort made and utility.

According to [Eigner 2014], a feed-back of findings from all parts of the life cycles must be projected to the product's development phase. It primarily focuses on the environmental perspective in the consumer phase, which is the phase that affects the environment the most. In order to develop an environmentally sustainable construction process, it is necessary:

- Interdisciplinary view on complex manufacturing systems, and
- Orientation to life cycle in terms of manufacturing systems.

From the perspective of DfS, further steps may lead towards development of methodology that limits material flows from global to local, stimulates consumers during their selection of product according to a given criterion and, above all, defines social aspects that can be influenced during the product development phase.

3 EXAMPLE

The following part shows various construction designs of a single product (Tab. 2). The aim is to show how these variants affect the supply chain processes within the product's life cycle.

It should be noted that no internal sources of any company were used. The base for creating the shown DfSC-focused construction variants is description of the product's functions and features. There are three possible construction variants able to function as required. The product is considered in all life cycle phases, the main steps for increase of material value in the flow are shown. In this case, the definitive product is a small square-shaped side table with limited load capacity. Its purpose is to be a decorative piece of furniture serving as a stand.

As the example clearly shows, the development phase

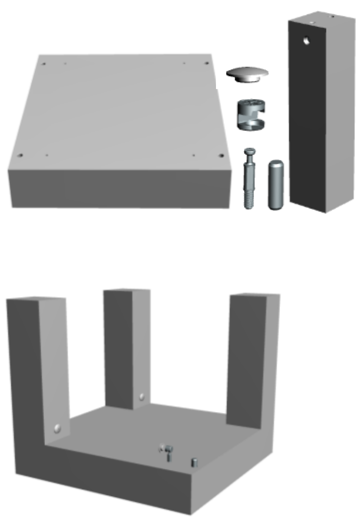
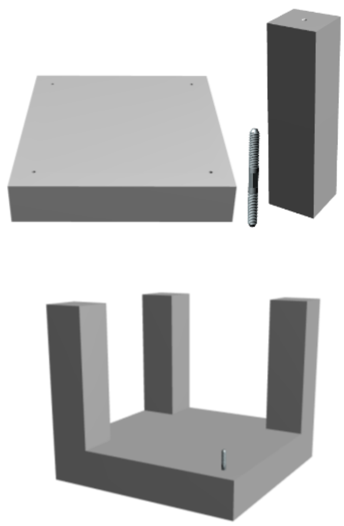
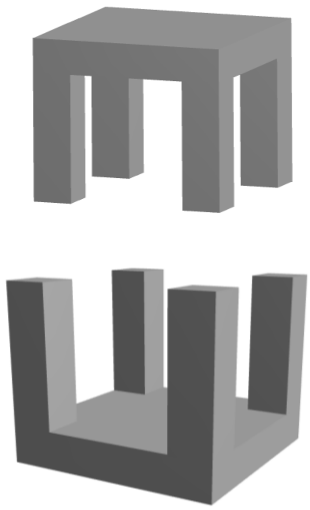
Variant 1	Variant 2	Variant 3
Development		
Material		
Particleboard, foil, fiberboard, plastic		Plastic
Conventional manufacturing		Additive manufacturing
		
21 parts	9 parts	1 part
Construction/development		
Construction of 6 types of parts and product	Construction of 3 types of parts and product	Construction of product
Sourcing		
Procuration of max. 6 types of parts	Procuration of max. 3 types of parts	Procuration of material
Production		
Manufacturing of max. 21 parts	Manufacturing of max. 9 parts	3D printing of the product
Hole drilling: - 4 x Ø D1; 4 x Ø D2; 4 x Ø D3, 4 x Ø D4	Hole drilling: - 8 x Ø D1	
Distribution		
- 5 operations during commission - standard quadratic packaging	- 3 operations during commission - standard quadratic packaging	- non standard packaging
Consumption/use		
- insert pins to a tabletop, put screws in the tabletop, fit table legs to pins and screws, insert eccentric links to holes in table legs, tighten the eccentric links, insert cover of the eccentric link.	- put screws in the tabletop, fit table legs to pins and screws, tighten the screws	
- evaluate the ability to meet the required function from the customer's perspective, evaluate quality, design, surface, target time of use		
Reversion/disposal		
- Disassembly of the total of 21 parts, component sorting, recycling	- Disassembly of the total of 9 parts, component sorting, recycling	Recycling

Table 2. Example of influence of design to supply chain

influences the whole life cycle of the product. With increasing amount of parts, the complexity of operations during individual phases increases as well. Also, selection of manufacturing technology and material has a significant role when forming material flows. The aforesaid product variants are then briefly discussed in terms of value increase within the material flow chain and sustainability, using three mentioned perspectives.
When reviewing the amount of parts and material, the highest amount of planning and completion processes during the production, logistics, and management is clearly in the first variant. When considering manufacturing technology, variant 2 seems to be optimal. Also, the value of product in the chain must be observed as well when watching the supply chain. The value must be in direct relation with the value from the customer's perspective, and is formed by economic, social, and environmental requirements of the consumer. However, a balance of these requirements is important on both sides, the customer's and manufacturer's. Otherwise, the sustainability is not guaranteed. Example of customer's and supplier's categorization requirements on the said product is shown in Table 3.

	Consumer	Manufacturer
Economic	product price	costs
Environmental	duration and manner of use	selection of material and material flows
Social	competency of the consumer during assembly, satisfaction with design (quality, colour, surface)	working conditions

Table 3. Example of value categorization

4 SUMMARY

Research of the considered DfX methodologies confirms the complexity of product development optimization. Almost every approach has transitions between product's life cycle phases and methodologies themselves. In general, the aim is to reduce material flow from the perspective of the given focus. In terms of information flows, there are ways to perform them, but not to reduce them. Process reductions are not considered, they are often exactly opposite – further processes are generated. Moving operations from one life cycle phase to the other is not considered in any of the approaches. The benefits of implementing a methodology and the ratio of utility and effort made are not always clear, the amount of necessary changes in the material flow chain is confusing. There is not quantitative evaluation of benefits during optimization. Character and type of the product is not considered. (Example: electric appliances have the highest influence on environment during the user phase. Other products such as furniture have this influence in localization, manufacturing, distribution, and reversion phase.)
The target of the said methodologies is large-scale production. Processes in DfX methodologies are inapplicable to small-scale production and custom production.
The question is: Is it possible to develop a methodology that would consider the main effects when increasing value in the material flow chain that would be generally applicable?
In this regard, it is important to maintain systematic procedure and quantitative expression of benefits of individual optimization steps.
As mentioned above, the considered optimization of product development can be linked with individual life cycles of the product in direct relation to supply chain. Additionally, the whole life cycle of a product is clearly formed by economic, environmental, and social aspects. These aspects are reflected to the value of product from the perspective of manufacturer and consumer, while the type of product and organization define the material flows. The said elements and their combination must be regarded. Using correlation disc may of help (Fig. 1). The disk consists of five levels:

1. **Value** – the central and base point of optimization is to understand value from the customer's or supplier's perspective.

2. **Sustainability** – definition of value in terms of economy, ecology, and sociology.

3. **Product** – character of a product

4. **Organization** of material flows

5. **Product's life cycle** – behavior of elements during individual stages.

When considering all combination, the result is 162 combination for consumer's value and 162 combinations for manufacturer's value. Therefore, it is necessary to start defining specific targets of value optimization in terms of economy, ecology, and sociology.
These are the base for determining the required combination in the correlation disc that is used to perform the optimization of product's construction. A scatter of the set value can be used to quantitatively express the benefits of optimization for individual combinations.

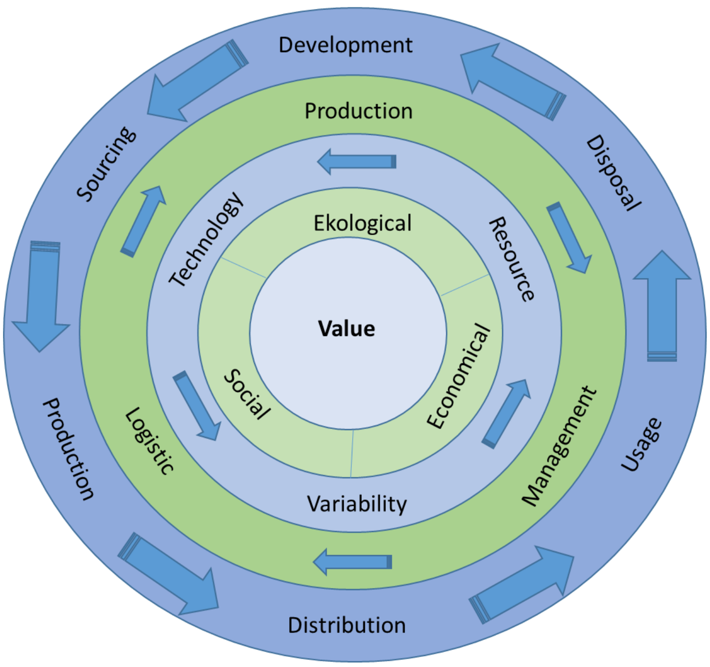


Figure 1. Correlation disc for Design for supply Chain

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