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DESIGN FOR X-GUIDELINES AND LIFECYCLE PHASES WITH RELEVANCE FOR PRODUCT PLANNING – AN MDM-BASED APPROACH

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ABSTRACT
Frontloading an integrated systems understanding to the early stages within the innovation process prevents from unnecessary changes in the later phases of the product lifecycle. In this context, approaches to increase transparency among product goals and potentials – arising from different lifecycle phases (product development until recycling) – are needed. One approach consists in analyzing generic design guidelines (i.e. applicable to different industries) and their interrelations. Also increased transparency concerning interrelations among lifecycle phases is pursued to enhance the task of product planning. This paper therefore sheds light on the interrelation of Design-for-X guidelines based on the respective addressed product characteristics. Furthermore, the interrelation of lifecycle phases based on their association with DFX-guidelines is researched. The analyses are carried out using a MDM-based approach; this includes deriving respective Design Structure Matrices to allow the detection of central lifecycle phases and DFX-guidelines based on structural metrics addressing the centrality of elements.

Keywords: Design for X, DFX, lifecycle, product planning, MDM

1 INTRODUCTION – LIFECYCLE-ORIENTED PRODUCT PLANNING

1.1 Motivation

Producing companies face the challenge to enhance their effectiveness and productivity in innovating products due to an increasingly competitive environment characterized by rapidly changing technologies and dynamic market needs (Cooper and Edgett 2005). A promising approach in this context consists in frontloading an integrated systems understanding to the early stages of planning future products. This systems understanding is supported by taking in a lifecycle-oriented perspective – considering potentials and demands of future products throughout the stages of developing, producing, transporting, utilizing and disposing/recycling. In consequence, the increased transparency allows anticipating possible conflicts of interest early in the innovation process and thus prevents unnecessary changes along the future lifecycle. Thus, companies avoid accordingly provoked lifecycle costs, which grow exponentially the later unintended changes are made within the lifecycle (Ehrlenspiel et al. 2007).

In order to involve the lifecycle information within the planning process, different procedures – depending on the goal of including the information – are possible. One possible approach – which intends to include context-specific demands and potentials due to a certain situation of a company within the planning phase – consists in analyzing interrelations among product goals and possible solutions. Therefore, methods such as Quality Function Deployment (Akao 2004) to analyze interrelations among customer needs and technical characteristics as well as an lifecycle- and system-oriented approach (Hepperle et al. 2011) to identify and analyze context-specific interrelations among product goals and potentials in the early planning stages have been developed.

In contrast, another approach consists in considering and analyzing more generic information – i.e. applicable to manifold industries. This information may not directly address company-specific requirements and solution ideas; nevertheless, it allows transparency in understanding superordinate mechanisms concerning the lifecycle of future products already in the early stages of product planning and development. One promising way to include this more generic, lifecycle-oriented information within the early stages of the innovation process is the consideration of 'Design for X' (DFX) guidelines (Meerkamm 1994).

In the past decades, multiple DFX-guidelines (Lindemann 2007) have been addressed in order to allow the design of products suitable for the different phases of the product lifecycle. DFX-guidelines provide generic design propositions for developing and planning products. The 'X' articulates in respect to which specific issue along the product life design propositions are stressed. Often, DFX-guidelines directly address the design for certain lifecycles phases (e.g. Design for Manufacturability, Design for Recycling, etc.). However, different authors (e.g. (Bramklev and Hansen 2007); (Otto and Wood 2001)) state that DFX-guidelines are supposed to address interrelations within and in-between the different areas of the lifecycle. Besides the lifecycle-phase-specific DFX-guidelines, also DFX-guidelines addressing issues relevant to different lifecycle phases (e.g. Design for cost) exist. Thus, the DFX-guidelines provide a proper basis for considering generic, non-company-specific, lifecycle-oriented information in the early stage of the innovation process. Still, in order to increase transparency for planning products, a deeper look into how the different DFX-guidelines and lifecycle phases are interlinked is necessary. Therefore, the following section 1.2 stresses different challenges in dealing with this topic.

1.2 Focus of research

One challenge to handle in the context of dealing with manifold DFX-guidelines is that the DFX-guidelines are not independent from each other, as the design propositions within the different DFX guidelines partially address the same product characteristics. E.g. the 'Design for assembly' guideline as well as the 'Design for ergonomics' guideline both address design propositions concerning the product material. Thus, there may be a conflict in pursuing both mentioned guidelines. Looking at a network of different DFX-guidelines, some of the DFX-guidelines show many linkages to other DFX-guidelines, whereas other DFX-guidelines are only poorly interconnected. Therefore, one goal of this paper is to shed light on how this network of DFX-guidelines can be characterized. Providing a more detailed view on this network helps to identify the central DFX-guidelines which show interaction to many other guidelines. In consequence, a more systematic approach to identify possible conflicts of interests can be established and accordingly provoked changes along the subsequent phases of the product lifecycle can be avoided.

Another challenge for lifecycle-oriented product planning consists in increasing the transparency concerning interrelations among the lifecycle phases. Thereby, interrelations among the lifecycle phases can be shown based on their association with different DFX-guidelines. Conclusions about which phases play an important role in pursuing and meeting certain lifecycle-oriented goals and how these phases are interlinked are of interest. In consequence, this may allow identifying the relevant stakeholders along the lifecycle to be included in the product planning process. Thus, this second focus is also addressed in this paper.

The two presented, interrelated topics especially focus – as mentioned in section 1.1 – on generic (i.e. applicable to manifold industries) information (DFX-guidelines, lifecycle phases) and according mechanisms. Still, an important note for this paper is that the procedure of shedding light on the interrelations among lifecycle-phases and DFX-guidelines may also be applied to more company-specific scenarios; e.g. taking certain internal design guidelines, specific demands and potentials in the respective company, market and environmental context into account.

In the next section, the setting for the analysis of interrelations among DFX-guidelines is shown. Then, in section 3 the research procedure is presented in detail and corresponding findings are explained and interpreted. Finally, conclusions regarding the consideration of the approach within the product planning phase are drawn in section 4 and an outlook on further work is given.

2 SETTING FOR ANALYZING LIFECYCLE AND DFX INTERRELATIONS

2.1 Approach of analyzing interrelations

Based on the setting of research questions, a Multiple-Domain-Matrix (MDM) based approach (Lindemann et al. 2009), using different Domain Mapping Matrices (DMM) and Design Structure Matrices (DSM) (Browning 2001) distinguishes itself to be promising in order to shed more light on the interrelation of DFX-guidelines and lifecycle phases. Before providing more insights how the

MDM-based approach is applied, the above described research challenges are split down. Thereby, two major challenges can be articulated:

Challenge 1: Focus is on the identification of central *DFX-guidelines* on the basis of *product characteristics* the respective DFX-guidelines address. Background is that different DFX-guidelines can address the same product characteristics and thus interrelations among DFX-guidelines exist.

Challenge 2: Focus is on identification of central *lifecycle phases* on the basis of *DFX-guidelines*, by which the lifecycle phases are addressed. Background is that one DFX guideline can be associated to different lifecycle phases and accordingly interrelations between different lifecycle phases exist.

Both challenges have in common, that DFX-guidelines are involved in the analysis setting. As there are uncountable DFX-guidelines, in this work a representative set of DFX-guidelines addressing issues along the whole lifecycle has exemplarily been selected. The guidelines cover different amounts of recommendations and also the levels of concretization of the recommendations are varying. Nonetheless, the DFX-guidelines can be compared mutually as all of them address certain, partially overlapping product characteristics. In Table 1, the respective DFX-guidelines are presented. How the DFX-guidelines and lifecycle phases are further analyzed is shown in Section 3.

Table 1: 27 analyzed DFX-guidelines and respective references

Design for **assembly** (Koller 1994), (Pahl et al. 2007), (Otto and Wood 2001), (Roth 2000)	Design for **manufacturing** (Koller 1994), (Roth 2000), (Otto and Wood 2001)	Design for **recyclability** (Koller 1994), (Roth 2000), (Otto and Wood 2001)
Design for **cost** (Ehrlenspiel et al. 2007), (Koller 1994)	Design for **ergonomics** (Pahl et al. 2007), (Roth 2000)	Design for **high impact material reduction** (Otto and Wood 2001)
Design for **individualized products** (Lindemann and Maurer 2006)	Design for **piece part production** (Otto and Wood 2001)	Design for **reliability and safety** (Koller 1994)
Design for **chipping** (Roth 2000)	Design for **interface constraints** (Koller 1994)	Design for **functional construction** (Roth 2000)
Design for **disassembly** (Otto and Wood 2001)	Design for **maintenance** (Pahl et al. 2007)	Design for **stress** (Koller 1994)
Design for **energy efficiency** (Otto and Wood 2001)	Design for **casting** (Roth 2000)	Design for the **environment** (Otto and Wood 2001)
Design for **remanufacturing** (Otto and Wood 2001)	Design for **material** (Koller 1994)	Design for **tolerance** (Koller 1994)
Design for **forming** (Roth 2000)	Design for **minimum risk** (Pahl et al. 2007)	Design for **variance** (Kipp and Krause 2007)
Design for **industrial design** (Pahl et al. 2007)	Design for **production** (Pahl et al. 2007)	Design for **welding** (Koller 1994)

3 DETAILED RESEARCH PROCEDURE AND FINDINGS

2.1 Research procedure for challenge 1: Identification of central DFX-guidelines

As mentioned above, the interrelations among DFX-guidelines exist as the different DFX guidelines partially address the same product characteristics. Looking at the DFX guidelines, in particular the following categories of product characteristics can be identified: Geometry, Volume, Surface, Color, Position, Energy, Material, Signal, Symmetry, Number of singular components. In order to determine the interrelations among DFX-guidelines based on their addressed product characteristics, the DSM of DFX-guidelines (*DSM_dfx1*) is calculated using matrix multiplication algorithms within MDM-context. Therefore, first the DMM linking DFX-guidelines to Product Characteristics (*DMM_dfx_char*) is needed. This DMM was filled in based on the text analysis of the DFX-guidelines. E.g. the 'Design for the environment' guideline says, that the material selection influences strongly the environment: '*Different functionally equivalent materials can have drastically different impact on the environment*' (Otto and Wood 2001). In the next step, a first calculation case was performed for the *DSM_dfx1*. For the calculation, the *DMM_dfx_char* is multiplied with the respective transpose DMM. The according equation to determine the *DSM_dfx1* can be described as follows:

Case 1: $DSM\_dfx1 = DMM\_dfx\_char \ * \ DMM\_dfx\_char^{Transpose}$

In this paper, another calculation case for determining the DSM of DFX-guidelines (*DSM_dfx2*) was performed. As the selected categories of the product characteristics are not independent from each other, also the DSM of Product Characteristics (*DSM_char*) was included in the second calculation case. The *DSM_char* was deduced based on physical interdependencies (e.g. Volume is associated to

Geometry). Again, the *DSM_dfx2* was calculated based on matrix multiplication and the respective equation can be described as follows:

Case 2: $DSM\_dfx2 = DMM\_dfx\_char \ * \ DSM\_char \ * \ DMM\_dfx\_char^{Transpose}$

2.2 Research procedure for challenge 2: Identification of central lifecycle phases

The interrelation between lifecycle phases can be determined, as the different DFX-guidelines can partly be associated to different lifecycle phases. To be able to analyze which of the respective lifecycle phases is highly interlinked with other lifecycle phases based on their associated DFX-guidelines, the DSM for lifecycle phases (*DSM_life*) is calculated – again based on matrix multiplication within an MDM-context. For this calculation, the DMM which explains the linkage between the lifecycle phases and the DFX-guidelines (*DMM_life_dfx*) is needed. This was again deduced based on a text analysis of the DFX-guidelines. E.g. the ‘Design for cost’ guideline has impact on different specific lifecycle phases. In the following the equation for identifying the *DSM_life* is shown:

Case 3: $DSM\_life = DMM\_life\_dfx \ * \ DMM\_life\_dfx^{Transpose}$

2.3 Summary of analysis procedure and applied structural metrics

As a summary of presenting the research procedure, the relevant domains and corresponding DMM and DSM for analyzing the interrelations among lifecycle phases and among DFX-guidelines are shown in the MDM of Figure 1.

	DFX-Guidelines	Product Characteristics	Lifecycle Phases
DFX-Guidelines	**DSM for DFX-Guidelines** ***DSM_dfx1* for case 1** ***DSM_dfx2* for case 2** calculated for case 1 and case 2	**DMM for linking DFX to Product Characteristics** ***DMM_dfx_char*** filled in based on text analysis of DFX guidelines	
Product Characteristics		**DSM for Product Characteristics** ***DSM_char*** filled in based on physical dependencies	
Lifecycle Phases	**DMM for linking Lifecycle Phases to DFX-gudielines** ***DMM_life_dfx*** filled in based on text analysis of DFX guidelines		**DSM for Lifecycle Phases** ***DSM_life*** calculated for case 3

Figure 1. Analyzed MDM of DFX-guidelines, product characteristics and lifecycle phases

In order to be able to apply further metrics to analyze the interrelations, the ‘Distance Matrices’ (Lindemann et al. 2009) were calculated both for the DFX-guidelines (based on the *DSM_dfx1 and DSM_dfx2*) and the lifecycle phases (based on the *DSM_life*). Finally, to assess the importance of a certain guideline respectively a certain lifecycle phase the following structural metrics have been applied: Degree Centrality, Distance Centrality and Betweenness Centrality. Freeman (Freeman 1979) defined them for social networks to identify central actors. Braha and Bar-Yam applied these metrics in the context of complex system development processes (Braha and Bar-Yam 2004). Further, Sosa et al. (Sosa et al. 2005) applied them to product structures to measure the modularity of components.

- **Degree Centrality:** This is the number of relations a node is incident to. The node is more central if it is connected to many other nodes. Degree Centrality measures the direct influence of a DFX-guideline / lifecycle-phase on others.
- **Distance Centrality:** This is the sum of the distances from a node to all other nodes in the networks. The node is more central if it is closer connected to the other nodes. Distance Centrality measures the immediacy of influence of a DFX-guideline / lifecycle-phase on others.

- **Betweenness Centrality:** This is the number of shortest paths which run across a node. The node is more central if many paths run across it. Betweenness Centrality measures the control about influence chains of a DFX-guideline / lifecycle-phase.

Based on applying the presented methodology and respective metrics, section 3.4 presents the calculated results of the three cases.

2.4 Findings

Case 1: In the first case, among the 27 analyzed DFX-guidelines in particular three DFX-guidelines were identified having both an above-average value for Degree, Distance and Betweenness Centrality: A) 'Design for stress', B) 'Design for disassembly' and C) 'Design for assembly'. While many other DFX-guidelines show also high values for Degree and Distance Centrality, the Betweenness Centrality of these three guidelines is a lot higher compared to others. As an interpretation for product planning this means, that by controlling the interrelations between the three guidelines and their directly linked nodes (DFX-guidelines), many closely indirectly linked nodes can also be handled.

Case 2: Also considering the DSM of product characteristics within the calculation, different DFX-guidelines in comparison to case 1 showed significant values. In case 2, the guidelines a) 'Design for ergonomics', b) 'Design for cost' and c) 'Design for reliability and safety' can be emphasized – all having above-average values for the three kinds of centrality. Still, also the three guidelines d) 'Design for assembly', e) 'Design for stress' and f) 'Design for production' show relatively high values in particular for the Degree and Distance Centrality. For a), b) and c) a similar interpretation for product planning can be made as for the guidelines A), B) and C) in case 1. For all guidelines a) to f) the interpretation that they show a high interconnectivity and immediacy to many other guidelines due to their high distance centrality can be deduced. In addition, the conclusion that the guidelines a) to f) play an important role for product planning is drawn as each of these guidelines shows direct linkages to at least 19 other guidelines ('Design for cost' even 24 direct linkages).

Case 3: Looking at the interrelations among lifecycle phases, overall 16 different lifecycle phases from the production planning and production until the phases of disassembly and recycling were taken into consideration. Among these 16 lifecycle phases, in particular the phases I) 'Manufacturing' and II) 'Assembly' show relevance due their high values for Degree, Distance and Betweenness Centrality. In addition, the phases III) 'Packaging and Warehousing', IV) 'Transportation' and V) 'Maintenance' show high values for the Degree and Distance Centrality. An interpretation for the stage of product planning is that the stakeholders of these lifecycle phases should be involved in the planning process, when trying to apply the 27 considered DFX-guidelines. The lifecycle phases – the stakeholders are responsible for – show a high interconnectivity and thus, they should be involved when prioritizing certain DFX-guidelines due to conflicts in trying to apply all 27 guidelines. In addition, due to the high Betweenness Centrality, the stakeholders of phases I) to III) are central players for coordinating the information flow between linked stakeholders on short paths.

4 CONCLUSIONS AND FURTHER WORK

The chosen procedure to process generic information by using non-company-specific design guidelines and a set of lifecycle phases, which can be recognized in many products, helped to understand, which lifecycle phases and which DFX-guidelines play a more central role in their respective network than others. This information can be valuable for a product planner; it may help to involve respective stakeholders along the lifecycle and it may support to consider and prioritize certain DFX-guidelines already in the planning phase. Nevertheless, the explanatory power is limited due to several reasons: firstly the calculated values are figures leaving a lot of space for interpretation; secondly the interconnectivity was calculated based on certain relations, but a product planner has to take various further dimensions – in particular company-specific goals and potentials – into account; thirdly the aspect that certain DFX guidelines show different – eventually conflicting – recommendations is not considered so far, but has to be handled to get even more precise.

In further work, it has to be tested how robust the results are in respect to adding further DFX-guidelines to the analyses. Moreover, further approaches to allow a more specific interpretation of gathered results are necessary. In addition, the approach should be tested using company-specific examples. This also leads to the point of validation, in which both the approach as well as the gathered findings should be considered.

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Design for X-Guidelines and Lifecycle Phases with Relevance for Product Planning – An MDM-Based Approach

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INVEST ON VISUALIZATION

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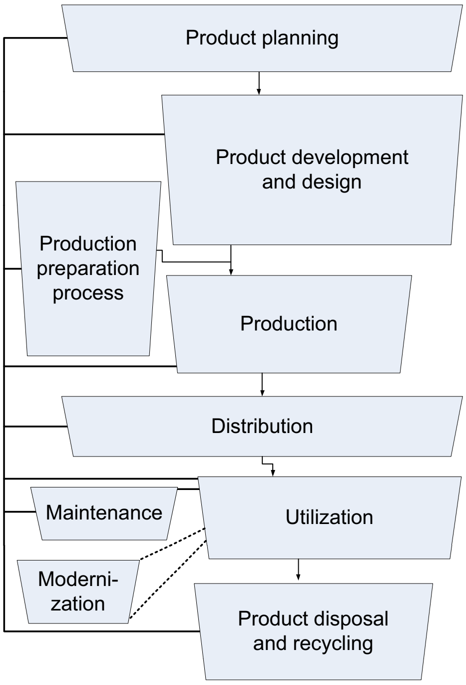
Background of research

Motivation

- Frontloading an integrated systems understanding within the innovation process prevents unnecessary changes in later phases of the product lifecycle

Goals

- Increasing transparency among product goals and potentials arising from different lifecycle phases
- Enabling anticipation and handling of superordinate interrelations throughout the lifecycle



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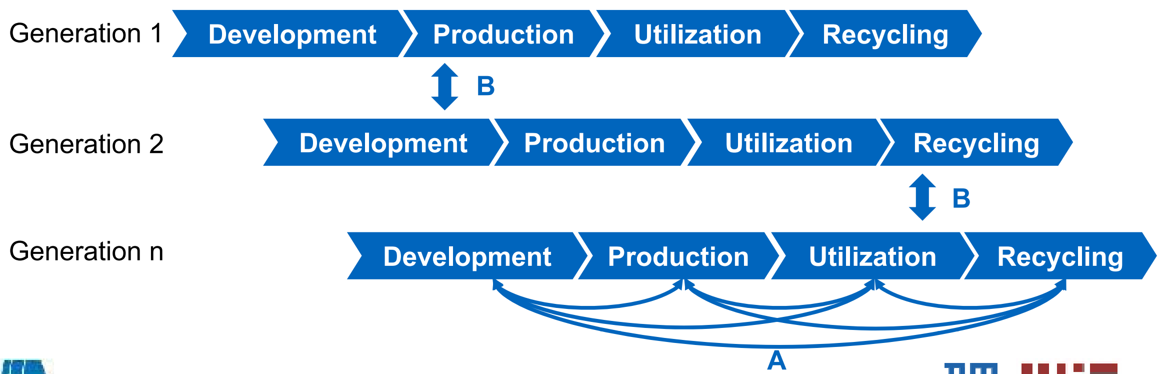
Focus of research

- Lifecycle-oriented product planning includes consideration of interrelations
  - between lifecycle phases (see **A** in Figure)
  - between lifecycle generations (see **B** in Figure)
- Research questions:
  - How can these interrelations be identified on a generic level?
  - How can the identified interrelations being managed?



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Focus of research

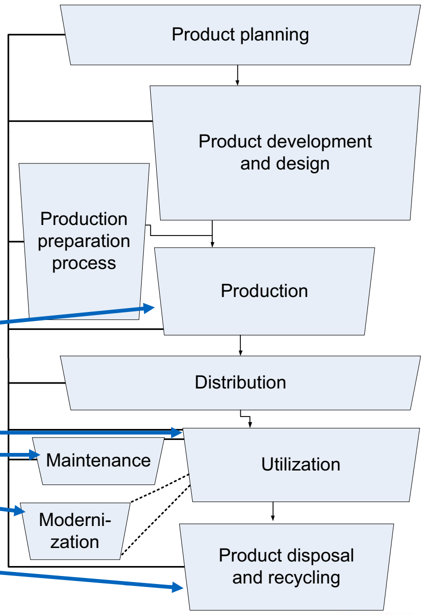
Analysis of Design for X (DFX) guidelines and lifecycle phases

- Design for X (DFX) guidelines often directly address the design for certain lifecycles phases
- Identification of generic interrelations based on DFX-guidelines (focus of paper)
- Approach should also be transferable to company specific planning contexts

Design for production
Design for assembly

Design for ergonomics
Design for ease of maintenance
Design for upgradeability

Design for recyclability



Focus of research

Characterization of analyzed DFX-guidelines

- Representative set of 27 different DFX-guidelines has been included
- The guidelines cover
  - different amounts of recommendations
  - several levels of concretization
- Nevertheless the DFX-guidelines can be compared mutually as all of them address certain, partially overlapping product characteristics
- Exemplary addressed aspects of DFX-guidelines:
  - Design for production [Pahl et al. 2007]:
    - Design of interfaces which are easy reachable in production
  - Design for ergonomics [Roth 2000]
    - Design of rounded edges of components for injury prevention
  - Design for cost [Ehrlenspiel et al. 2007]
    - Reduction of size of components (if possible) to reduce material costs

MDM-based approach for analyzing lifecycle and DFX interrelations

Challenges

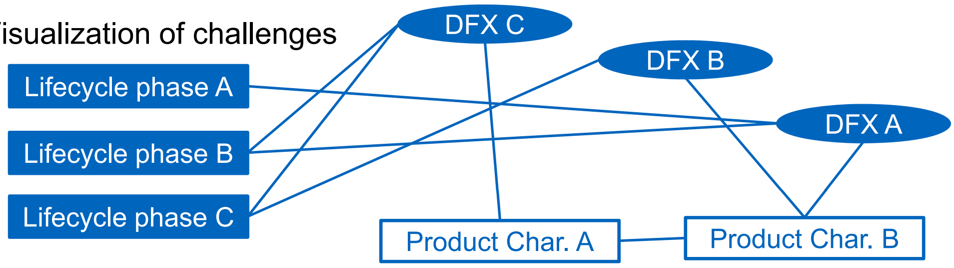
- **Challenge 1:** Identification of central **DFX-guidelines** on the basis of the addressed **product characteristics**. Several DFX-guidelines can address the same product characteristics. Thus, interconnections among the guidelines exist.
- **Challenge 2:** Identification of central **lifecycle phases** on the basis of **DFX-guidelines**, by which the lifecycle phases are addressed. One DFX guideline can be associated to several lifecycle phases. Accordingly, interconnections between lifecycle phases exist.

Procedure

- MDM-based identification of **central, planning relevant interrelations**
  - among lifecycle phases
  - among DFX-guidelines

MDM-based approach for analyzing lifecycle and DFX interrelations

- Visualization of challenges



- Identification and analysis of interrelations under consideration of
  - 27 DFX-guidelines addressing the various lifecycle phases
  - 16 lifecycle phases
  - 10 categories of product characteristics
- Steps of MDM-based approach

Definition of goals: identification of central, planning relevant DFX-guidelines and lifecycle phases → **Information acquisition:** Literature analysis of DFX-guidelines based on the defined MDM (see paper Figure 1) → **Calculation and analysis of relevant DSMs:** → DSM of lifecycle phases → DSM of DFX-guidelines

Equations for calculating relevant DSMs

Challenge 1:
Identification of interrelations among DFX-guidelines –
Calculation of relevant DFX-DSM

Case 1 *(based on interrelations between DFX-guidelines and assigned product characteristics):*

$$DSM\_dfx1 = DMM\_dfx\_char \; * \; DMM\_dfx\_char^{Transpose}$$

Case 2: *(based on interrelations among Product Characteristics and interrelations between DFX-guidelines and assigned product characteristics):*

$$DSM\_dfx2 = DMM\_dfx\_char \; * \; DSM\_char \; * \; DMM\_dfx\_char^{Transpose}$$

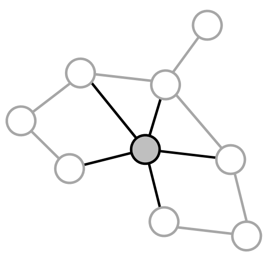
Challenge 2: Identification of interdependencies among lifecycle phases –
Calculation of relevant Lifecycle-DSM

Case 3 *(based on interrelations between DFX-guidelines and assigned lifecycle phases):*

$$DSM\_life = DMM\_life\_dfx \; * \; DMM\_life\_dfx^{Transpose}$$

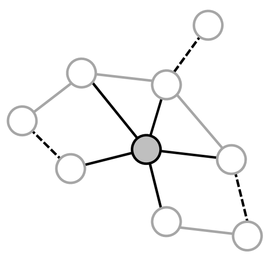
Analyses of calculated DSMs: applied structural metrics

Degree Centrality



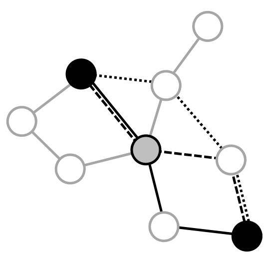
This is the number of relations a node is incident to. The node is more central if it is connected to many other nodes. **Degree Centrality** measures the direct influence of a DFX-guideline / lifecycle-phase on others.

Distance Centrality



This is the sum of the distances from a node to all other nodes in the networks. The node is more central if it is closer connected to the other nodes. **Distance Centrality** measures the immediacy of influence of a DFX-guideline / lifecycle-phase on others.

Betweenness Centrality



This is the number of shortest paths which run across a node. The node is more central if many paths run across it. **Betweenness Centrality** measures the control about influence chains of a DFX-guideline / lifecycle-phase.

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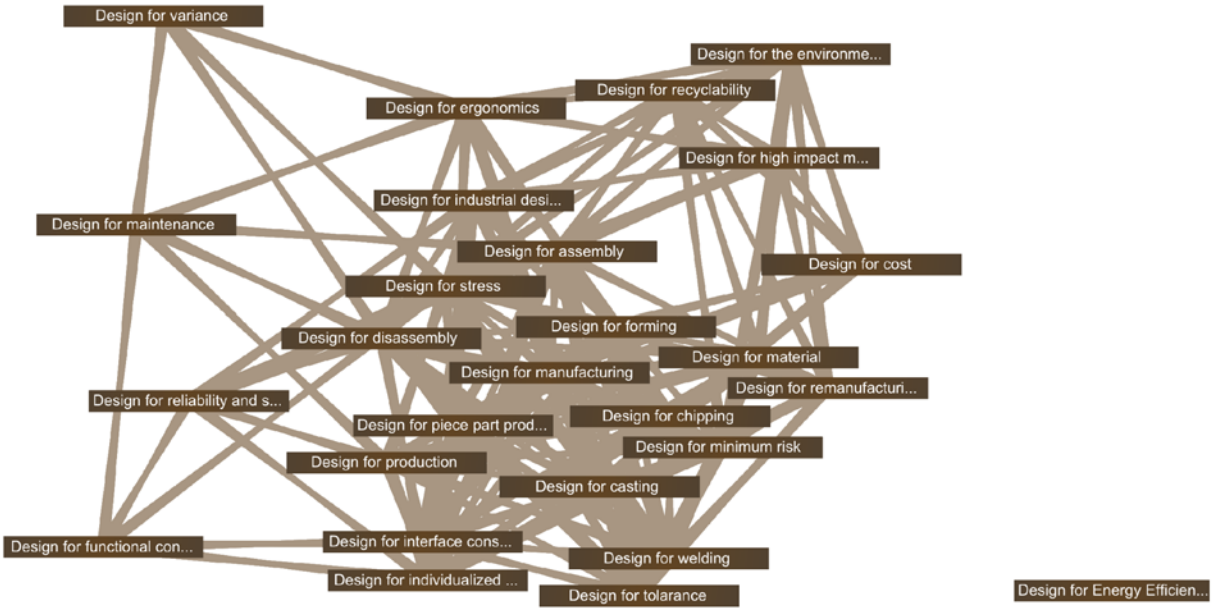
Case 1: Analyzed graph of DFX-guidelines based on calculated DSM_dfx1



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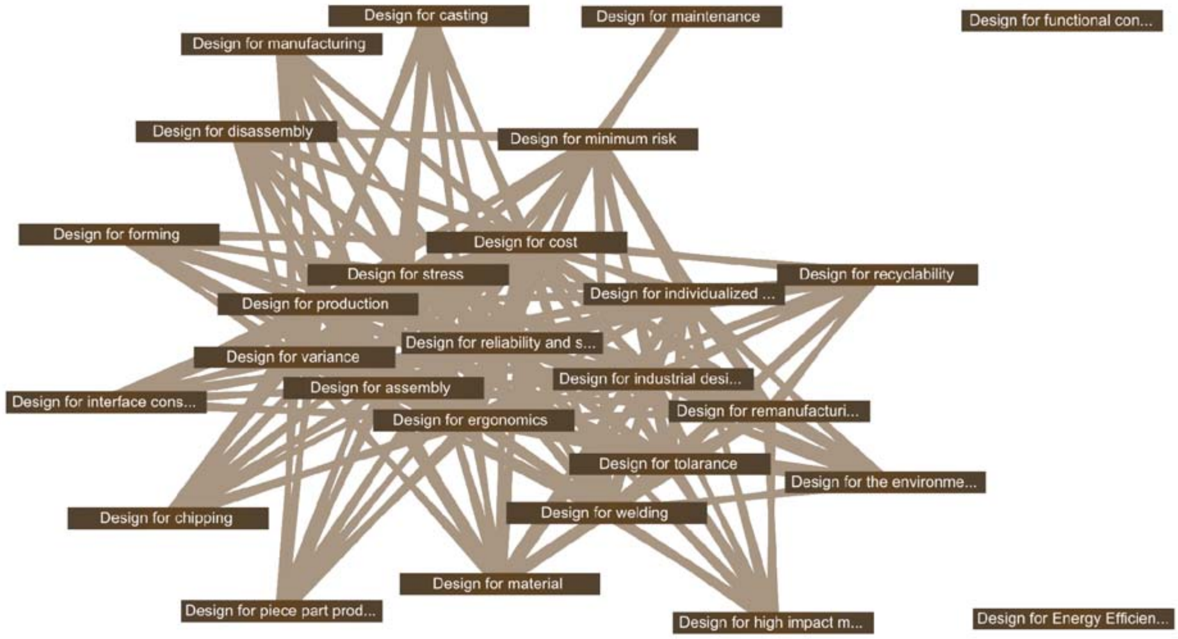
Case 2: Analyzed graph of DFX-guidelines based on calculated DSM_dfx2



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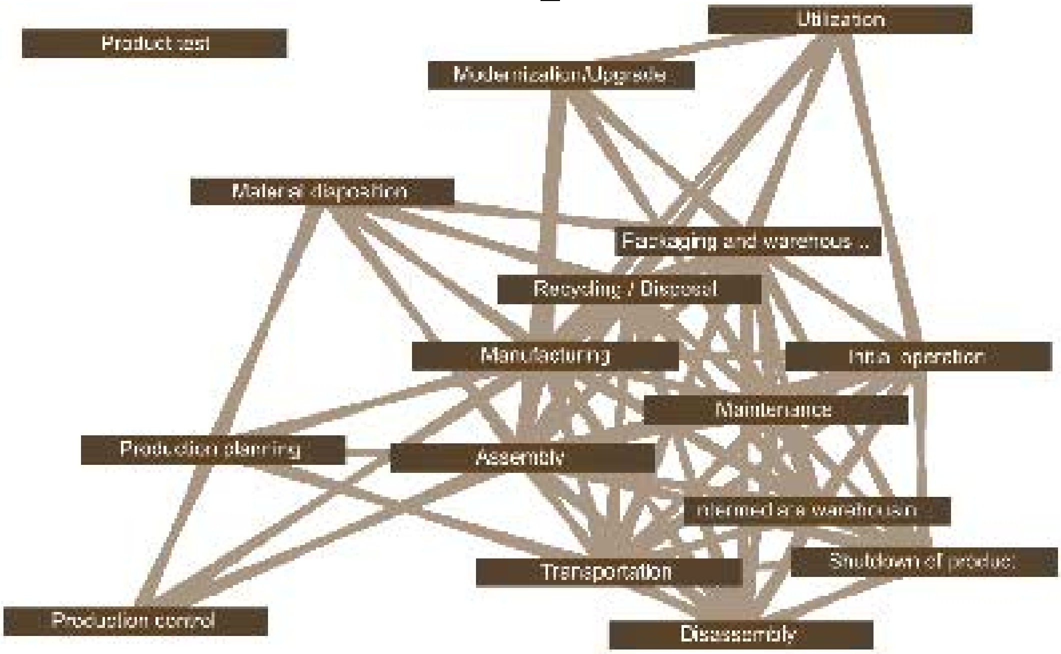
Case 3: Analyzed graph of lifecycle phases based on calculated DSM_life



Interpretation of findings based on applying structural metrics

Case 1 – Findings

- Three DFX-guidelines were identified having an above-average value for the Betweenness Centrality compared to other guidelines: A) ‘Design for stress’, B) ‘Design for disassembly’ and C) ‘Design for assembly’.

Case 1 – Interpretation

- Controlling the interrelations between the above mentioned guidelines and their directly linked nodes (DFX-guidelines), many closely indirectly linked nodes can also be handled.

Case 2 – Findings

- a) ‘Design for ergonomics’, b) ‘Design for cost’ and c) ‘Design for reliability and safety’ and d) ‘Design for assembly’, e) ‘Design for stress’ and f) ‘Design for production’ show all relatively high values for the Degree and Distance Centrality.

Case 2 – Interpretation

- The guidelines a) to f) are relevant for product planning as each of these guidelines shows direct linkages to at least 19 other guidelines (‘Design for cost’ even 24 direct linkages).

Interpretation of findings based on applying structural metrics

Case 3 – Findings

- I) 'Manufacturing' and II) 'Assembly' show relevance due their high values for Degree, Distance and Betweenness Centrality.
- In addition, the phases III) 'Packaging and Warehousing', IV) 'Transportation' and V) 'Maintenance' show high values for the Degree and Distance Centrality.

Case 3 – Interpretation

- The stakeholders of the mentioned lifecycle phases should be involved in the planning process, when trying to apply the 27 considered DFX-guidelines.
- The respective lifecycle phases – the stakeholders are responsible for – show a high interconnectivity.
- Thus, they should be involved when prioritizing certain DFX-guidelines due to conflicts in trying to apply all 27 guidelines.
- In addition, due to the high Betweenness Centrality, the stakeholders of phases I) to III) are central players for coordinating the information flow between linked stakeholders on short paths.

Conclusions, limitations and further work

Conclusions

- Increased systems understanding in early planning phases by shedding light on central, planning relevant DFX-guidelines and lifecycle phases

Limitations

- Interpretation from presented approach using generic DFX-guidelines shows limits in applicability for company specific planning issues
- Results highly dependent on acquired information concerning the considered lifecycle phases, product characteristics and DFX-guidelines
- Interpretations are not evaluated – thus these can rather being seen as a basis for hypotheses for further research
- The aspect that DFX-guidelines show different – eventually conflicting – recommendations is not considered yet

Further work

- Evaluating robustness of generic approach by considering further DFX-guidelines
- Applying approach to company specific design rules and lifecycle phases