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AN APPROACH FOR CYCLE-ROBUST PLATFORM DESIGN

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ABSTRACT
Product platforms are frequently applied in industry for designing product families. The product platform builds the basis for the derivation of the offered variants. As the platforms are characterized by a long life cycle, changes induced by internal and external influences will occur to the product family during the utilization phase. This results in new variants which often cause a lot of effort for implementation. To avoid these time-consuming and costly efforts, the dynamic changes and variations during the life cycle of the platform must be anticipated and considered in the planning of the platform. The platform structure can be planned and designed according to the expected changes and decrease their later change impact. The revisions of the platform can be scheduled in accordance to the changing context. This paper presents an approach to anticipate the influences which cause changes to the platform structure and consider them in the design of the platform and module structure. Thereby, occurring changes during the life cycle of the platform have lower impact and can be implemented in fast and cost-efficient way.

Keywords: platform strategies, product families, product lifecycle management, complexity

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1 INTRODUCTION

Due to globalization and competitive advantages, companies are forced to offer their products in many different markets. In these global markets, various local legislation, standards, and approvals, as well as the diverse customer needs have to be satisfied by the products. The requested high external variety results in multifaceted product families.

This entails various challenges for companies. More and different functionalities must be provided, the units produced decrease and the internal complexity increases. Accordingly, the development and manufacturing costs rise. To offer external variety resulting from product differentiation while reducing the internal complexity and costs the application of product platforms are proposed (Baldwin and Clark, 2000; Sanchez, 2004).

Product platforms realize economies of scale (Meyer and Utterback, 1993) by using synergies like commonalties of product elements. The platform builds a constant core which should be stable and unchanged during the product life cycle. The product differentiation is achieved by flexible modules attached to the platform. They can differ in functionality or other characteristics, so as to the derivative products meet the different requirements.

During the planning and definition of a platform, diverse requirements for the different markets and customers have to be considered. Moreover, the constant part of the platform has to be defined in order to use the commonality synergies within the product family. The flexible, differentiating elements must be identified, resulting in the initial variant structure. The planning takes into account current requirements and boundary conditions for a long lasting future portfolio. Some changes are considered in advance. Unplanned changes to the platform affect all derivative products and risk the economic success of the platform. The planning quality of a platform is a critical issue because of the long planning horizons and life cycle (Schenkl et al., 2011).

2 MOTIVATION

In the course of the life cycle of the product platform, the initial requirements and boundary conditions for the platform planning can change, caused by various dynamic influences. These can be triggered through dynamics initiated e.g. by competitors, markets, customers, legislation, or new technologies. As the product platform is mostly planned in a static way, the dynamics of influencing factors cause a lot of effort to implement the technical changes to the platform (Schuh and Lenders 2009) - even if revisions or a certain kind of flexibility are already defined in the platform planning. Another challenge is that the relevant influences to the platform portfolio occur in different temporal periods. For example, communication technologies change in very fast cycles whereas other technologies such as combustion engines last for decades. Besides technological cycles, the source of the influences to the product platform again can arise from markets, politics, legislation or competitors. In addition to these external driven influences, internal influences impact the planning and development, and later in the life cycle, the revision and the release management of new variants. Internal influences on the platform can be for example cycles in the innovation process or changes of the own organization. The described situation because of the external and internal influences on the planning and utilization phase of the initial platform is shown in Figure 1.

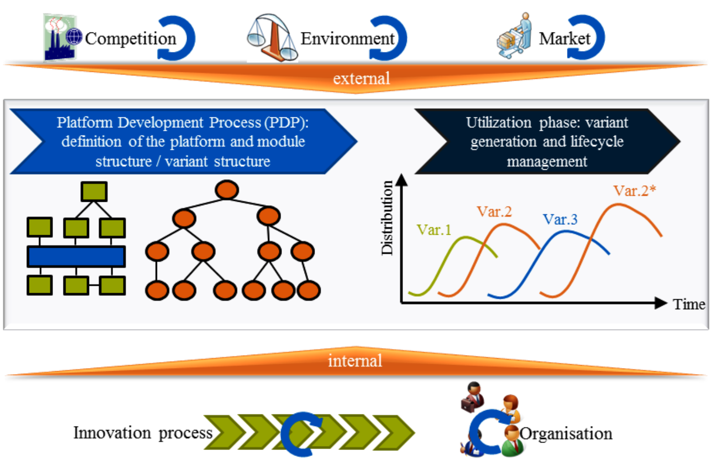

Figure 1. Influences on the life cycle of the product platform

To overcome these challenges and avoid costly and time-consuming changes during the life cycle, a platform structure which can manage the above managed influences must be designed during the planning phase. The design of the architecture is a meaningful lever. In the stage of architecture design, the elements (functions or components) of the platform are known and their interactions are defined in the means of interfaces. Having this information at hand, the common set of assemblies or parts (Meyer and Lehnerd, 1997) is defined as the platform for the product family. To meet the different requirements by derivative products, the other elements are designed in a flexible way. For the decision, if an assembly or part is implemented in the platform or the flexible part, the knowledge about the cyclicality and the development of the above mentioned influences to the platform must be known. Only with this information, robust platform architectures can already be defined in the planning phase. The cycle-robust platform should be constant during the whole life cycle to avoid extensive changes. The flexible modules and their interfaces to the platform must be defined in a way so as to the changes in the utilization phase can be managed and the changing requirements during the life cycle of the platform family are met. Therefore, the dynamic changes and variations of external and internal influences must be anticipated and be considered for the decision which elements will be incorporated in the platform and which not.
This paper provides an approach to anticipate and characterize the relevant influencing factors and combine this knowledge with product family architecture. Based on this, a support for the decision-making for the constant platform architecture and the flexible module design is presented. Before pointing out this approach, an overview about both, existing platform design approaches and the identification and anticipation of internal and external influencing factors is given.

2 BACKGROUND

2.1 Product platform design approaches

According to Meyer and Lehnerd (1997) a platform is defined as a set of common assemblies, modules and parts, which form a mutual basis. Robertson and Ulrich (1998) expand the component view by three further categories: processes, knowledge, people and relationship. The objective of incorporating a platform is to achieve synergies by using same elements (e.g. components, functions, technologies) in several products. According to the aspired commonalties and required product differentiation the product structure is divided into platform and non-platform elements (Blees, 2011).
In the context of this paper, a platform is defined as a technical system composed of components which are common for all product family variants and along the product life cycle. The product variants themself are composed of different modules to meet the differentiation requested in the planning phase as well as during the life cycle due to required changes driven by the influences mentioned above. A module is specified as a set of components with a high internal and a low external communication such as geometric, flow or informational interfaces (Ulrich 1995). The overall concept of platform and module architecture, composed of the platform and the various modules to build the single variants, is illustrated in Figure 2.

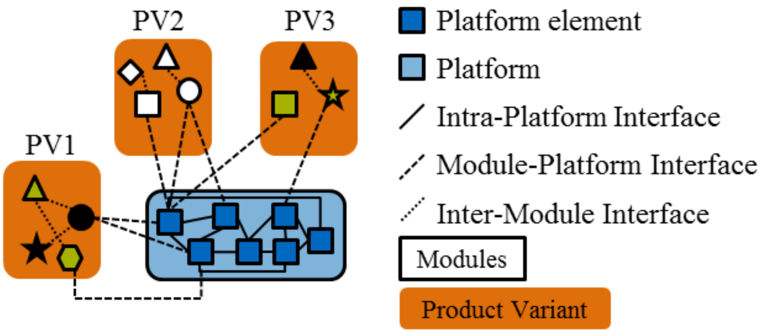

Figure 2. Platform and Module Architecture

Various approaches to structure the platform architecture into platform and non-platform elements exist in literature. Stone et al. (2000) define modules using functional models. They apply heuristics to identify modules based on material and signal flows in the functional model. Ericsson and Erixon (1999) base their method Modular Function Deployment (MDF) on Quality Function Deployment (QFD). In several matrices they map customer requirements to functions and functions to technical solutions respectively assemblies. The technical solutions are assigned to module drivers. Independent modules are identified based on the number and strength of relations and assessed using rules and metrics. Design for Variety (DfV), developed by Martin and Ishii (2002), consider the dependencies between components as well as the effort for development of modules due to changing requirements and the integration of modules in several product generations. Therefore, key figures are applied. It is shown how to optimize these figures and taking into account changing requirements.

Another type of methods for identifying modules within products uses Design Structure Matrices (DSM). Pimmler and Eppinger (1994) analyze the product architecture with DSM by depicting the dependencies between components or functions. In order to identify optimized and reintegrated modules clustering algorithms are used. Kalligeros et al. (2006) also use the DSM in order to identify product platform elements on a physical level. Schuh et al. (2007) apply a matrix-based approach to map customer requirements, functions and components to design a product portfolio. They expanded this method by the development of future scenarios (according to Gausemeier et al., 2009) to design several portfolio alternatives (Schuh and Lenders, 2009) which meet possible future trends.

All these approaches incorporate strategies to identify robust elements for the platform and flexible units for the modules. Besides the approaches of Martin and Ishii (2002) and Schuh and Lenders (2009), all of them consider a platform as static. The two works take into account changes of both customer requirements, and different possible future scenarios to a certain point of time. Changes of the platform during the life cycle, caused by the dynamics of internal or external influencing factors, are neglected. They show neither which elements should be implemented in the platform in a robust way that it is not affected by these changes or in flexible modules which handle these changes. The aspect of tackling this issue in order to avoid unplanned and costly changes of the platform during the life cycle to provide new required variants was often mentioned in interviews with experts from industry.

2.2 Dynamic influencing factors

In the context of this paper, influencing factors are defined as factors within and outside the company which have an effect to the contemplated object, here the platform and module structure, in an indirect or direct way. Influencing factors to be considered during the platform planning must be identified in order to avoid or actively manage changes during the life cycle. The knowledge about such trends and their dynamics are crucial for economic and technical success of the platform strategy. According to Keijzer (2008) changes are caused by dynamics in legal, sociocultural, technical and competitive environment.

In order to identify the relevant influencing factors, Gausemeier et al. (2009) propose different creativity methods and short description of each factor. The relevant key factors are identified by assessing their relevance and activity. Langer and Lindemann (2009) developed a model in order to identify and classify mainly external influences on the product development process. They recommend both, a context classification (e.g. environment, market, and company interfaces) and classes of influences (e.g. technology/knowledge, socio-economics, and politics/legislation).

To gain knowledge about the influencing factors, they have to be characterized concerning different categories. Fricke (1998) recommends two characteristics: the likelihood of change to the object in question and the impact of a change to the object. By multiplying these two figures the risk of change is calculated and the influencing factors are transferred in a risk of change-portfolio. The relevance of influences is described by Gomeringer (2007) as the degree of influence and the degree of uncertainty. On the one hand, the impact to the object in question must be extensive. On the other hand, the influencing factors should feature a certain degree of uncertainty. Based on this, Gomeringer (2007) develops a matrix for the identification of key factors.

For this research, the characterization of influencing factors in terms of their dynamic is essential. The dynamic can be described as the temporal change of elements and relations of a system. It is differed between the system induced dynamic and heteronomous dynamic of the environment. Besides the definition of the relevance of influencing factors by degree and relevance of the induced change, Langer and Lindemann (2009) also present temporal aspects of influencing factors. They describe the re-occurrence and cyclicality of influences by the aspects time of occurrence, frequency of change, rate of change and probability of change.

Having the key factors and their characterization at hand, the anticipation of the key factors plays an important role. Anticipation is seen as the ability to act in presentiment of future occasion or state of the environment (Zamenopoulos and Alexiou, 2007). Anticipation also includes circularity. Rhodes and Ross (2009) postulate that the ability of anticipating future developments is closely connected to a model of the environment or the own system. This enables the proactive acting consistent with the future and environmental developments, not only using experience. Verganti (1999) identified three mechanisms of anticipation: systematical learning, teamwork and communication, and proactive thinking. Methods for anticipation of cyclic influencing factors, dependent from their characteristics, are for instance expert interviews, lead user integration, scenario techniques, roadmaps, technology s-curves, environmental forecasting, time series analysis, historical analogies, or trend impact analysis.

3 APPROACH FOR CYCLE-ROBUST PLATFORM DESIGN

The proposed approach for a cycle-robust platform design is built up of four main phases. The approach is shown in Figure 3.

Phase 1 treats of the impact of changes to the underlying platform and module structure. In the second phase, the need of changes caused by the cyclic influencing factors is identified. As phase one and two are independent from each other, they can be run through in parallel. The knowledge from the first two phases are combined in phase 3: the platform and module structure is connected to the influencing factors in order to identify which platform characteristic or product component is affected by which influence. In phase 4, the current module and platform structure is designed in a life cycle robust way based on the cyclical influencing factors. The platform and modules are cut in a way that planned changes can be executed in a flexible way whereas the platform will not be affected by changes during the product family's life cycle. An iteration to step 1 may be necessary to analyze the received concept again.

In the following sub-sections each step is explained in detail.

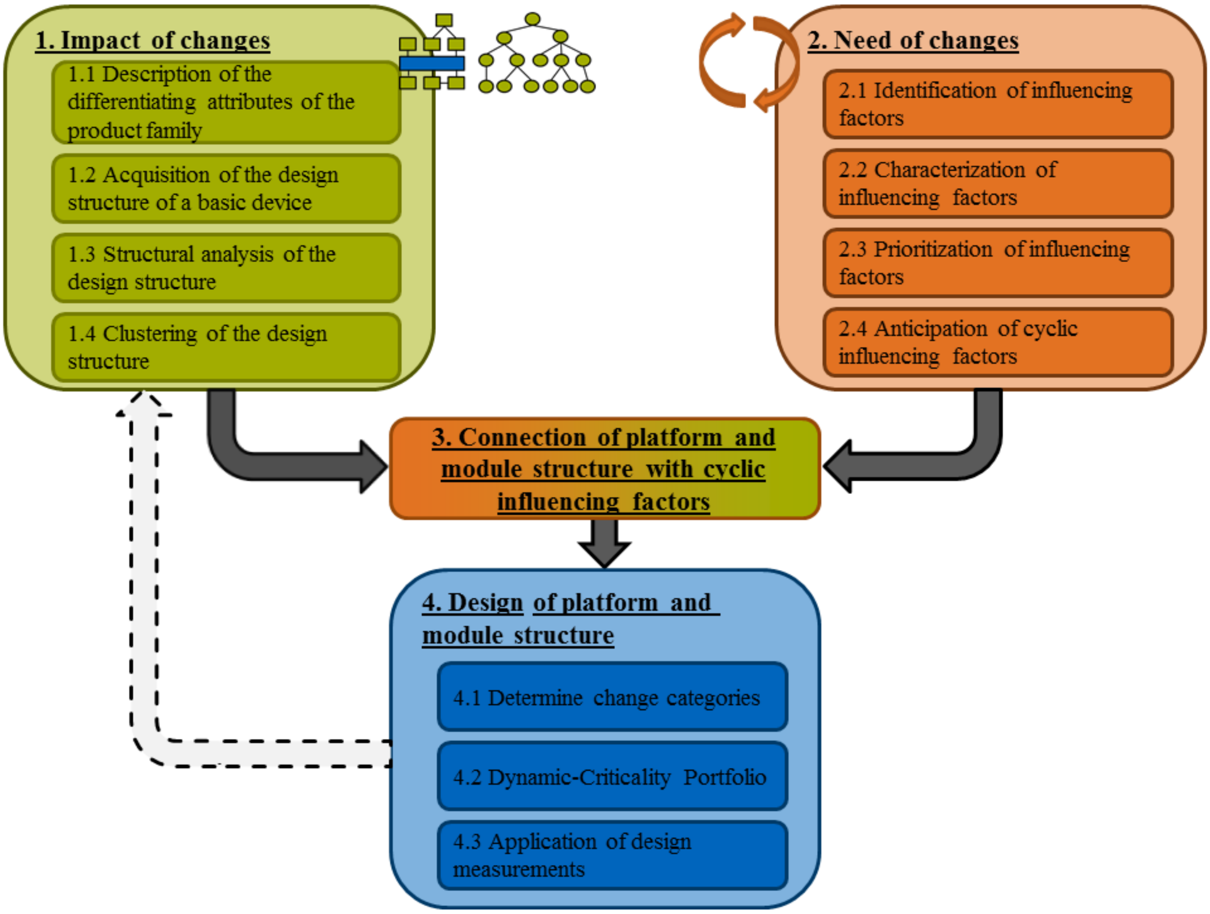

Figure 3. Approach for cycle-robust platform and module design

3.1 Phase 1: Impact of changes

The first phase contains the description of the platform and module structure of the current portfolio and the assessment of the product structure towards changes. First of all, the characteristics and properties of each product of the product family are identified and listed. Depending on the amount of differences of their attributes, the characteristics are structured in a feature tree showing the configuration of each product. A first structuring and overview of the product family is at hand.

Next, the interface structure of a basic unit is acquired within a Design Structure Matrix (DSM) according to Lindemann et al. (2008). The elements of the DSM represent the physical components of the basic unit. The type of relations between the physical components delineates geometric contact, signal flow, material flow or energy flow. These relations stand for the different types of interfaces between the components. In combination with the knowledge of the product family's feature tree, the structure of other variants can be deduced from the structure of the basic unit. Differences and communalities between the structures of each variant can be analyzed by summing up all DSMs (see Daniilidis et al., 2010).

In the next step, the structure of the basic unit is analyzed by calculating structural characteristics (see Lindemann et al., 2008). As the impact within the product structure caused by a change of an element is of importance, the active and passive sum of each element are calculated. The active sum of an element indicates how many other elements are influenced by this element. The higher this figure the more active the element is and can induce changes. As the actives sum gives notice of the change effect of an element, high active elements should be embodied in the platform of a product to avoid changes to a high number of other elements in the whole structure. In contrary, the passive sum of an element describes how many other elements influence this element. The higher the passive sum, the more elements can change this element. Passive elements should be incorporated into modules because they are sensitive to changes. In this way, changes do not spread into the platform structure but only propagate within modules.

The criticality of an element is calculated by the multiplication of the active and passive sum. The criticality represents the role of an element within the structure based on the in- and outgoing dependencies. The higher the criticality, the more sensitive this element is against changes and can cause numerous changes to other elements, too. Hence, the criticality is used as a change index in this context. Elements with a high criticality (a lot of in- and outgoing dependencies) should be implemented in the platform structure and kept constant because of their sensitivity towards changes.

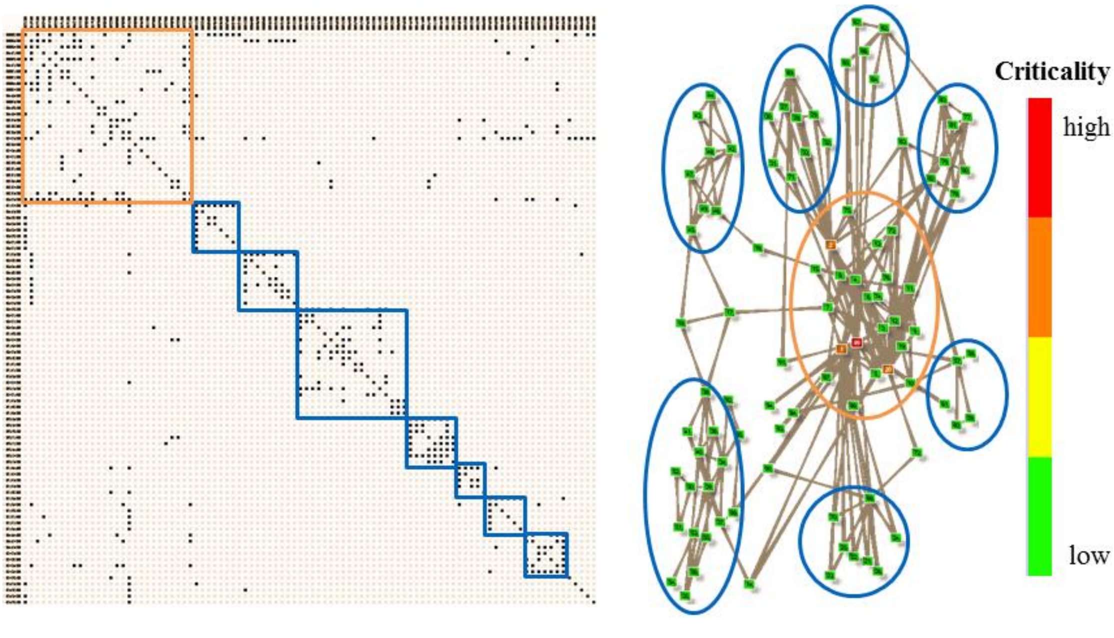

Figure 4. Clustered platform and module structure of a refrigerator - matrix (left), force-directed graph (right)

As a last step of phase 1, the DSM of the basic unit is clustered applying a cluster algorithm. Closely connected elements are grouped into clusters which can be interpreted as modules (see 2.1). By transforming the DSM into a force-directed graph, the clusters can be visualized in an appropriate way. If there is a central cluster which connects a lot of other cluster this cluster is a structural platform. To verify the resulting platform and module structure, a plausibility check is performed by comparing the criticality of the elements and the position in the clustered structure. Critical elements must be located in the platform structure whereas less critical elements tend to be within modules.

Figure 4 shows the clustered matrix on the left, the according force-directed graph on the right side. The structure represents a basic unit of refrigerator product family. The platform elements are framed in orange, the modules in blue. In the force-directed graph, the elements are colored according their criticality. All critical elements are located in the platform structure.

3.2 Phase 2: Need of changes

The second phase of the approach describes the determination of the need of changes caused by the cyclic influencing factors. The occurring influencing factors to be considered in the platform planning are identified first by applying the context model of Langer and Lindemann (2009). This model serves the systematic search and documentation of influencing factors. By going through the different search fields of the model, as many influencing factors as possible are gathered. It is best practice to involve experts from different fields of the company, e.g. production, planning, development, marketing, procurement, to achieve a wide range of perspectives and consequently a high number of influencing factors.
After the identification of the influencing factors, they are characterized according their degree of influence and the degree of uncertainty according to Gomeringer (2007). These characteristics are similar to the characterization proposed by Fricke (1998). According to Gomeringer (2007), both characteristics of the influencing factors are rated by a four-point-scale. The uncertainty is rated from 1st order (low uncertainty) to 4th order (high uncertainty). The results are transferred into the anticipation portfolio (see Figure 5, including exemplary extracts).

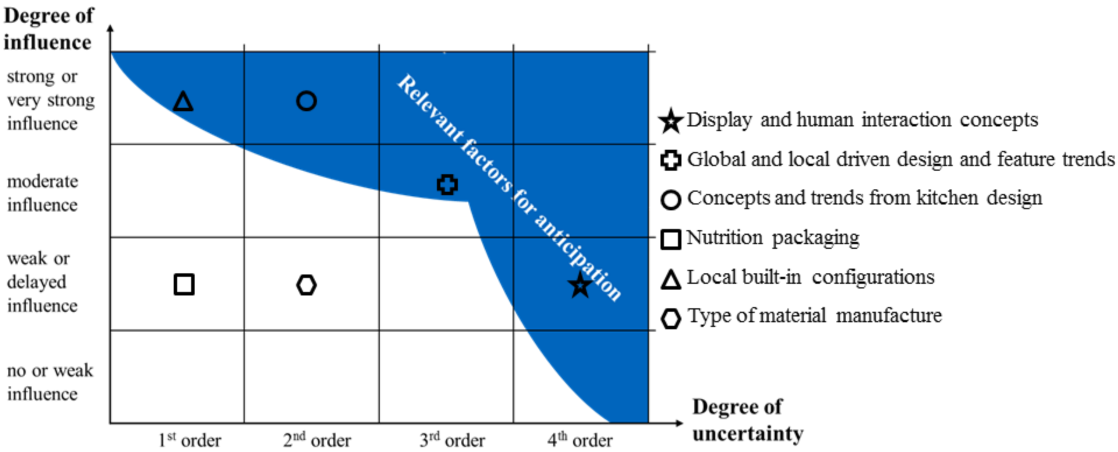

Figure 5. Anticipation portfolio

Based on the portfolio, the relevant influencing factors are filtered for a closer consideration. The prioritized factors are located in the color-coded area. Only those have to be anticipated concerning their temporal development and dynamics. These involve not only the influencing factors at the top right corner but also the ones with either a high uncertainty or a high degree of influence.
The most relevant influencing factors are anticipated concerning the time of occurrence, dynamic behavior and frequency of change over the planned platform life cycle. The cyclicality of the influencing factors is determined by applying methods described in section 2.2, depending on available data and experts.

3.3 Phase 3: Connection of platform and module structure with cyclic influencing factors

Phase three connects the domain of cyclic influencing factors to the domain of the current platform and module structure of the product family. For this step, two Domain-Mapping Matrices (DMM) are generated. In the first DMM, one axis represents the cyclic influencing factors, while the other axis shows the differentiation attributes of the product family. The elements of the two domains are connected if a differentiation attribute of the product is affected in the means of a change by a certain influencing factor. The same procedure is run through on a more detailed level for the second DMM: a component is connected to an influencing factor if the occurrence of this factor changes the component in question. These two DMMs contain the information about the dependency of the cyclic influencing factors and their object of change, the platform and module structure. They build the basis for the step of designing the module and platform structure in a cycle-robust way.

3.4 Phase 4: Design of platform and module structure

The fourth phase is about the design of the cycle-robust platform and module structure. In this phase, different change categories are determined in order to structure the components according to the influencing factors which change the components. The change categories are derived from the dynamic and cyclic behavior of the relevant influencing factors. According to the underlying cyclicality, the differentiating attributes and depending components are grouped into these categories. With this categorization at hand, conflicts of objectives can be identified. These conflicts of objectives result from changes to a differentiating attribute or a component which are caused by cyclic influencing factors characterized by different cyclical re-occurrence. For example, a certain component can be changed by an influencing factor occurring very frequent, and at the same time from two other influencing factors appearing only once in the product life cycle. To visualize those conflicts of objectives between the components, a portfolio consisting of two axis, dynamics and criticality, is spanned. On the one hand, the dynamic of the change of a component is shown; on the other hand, the criticality presents the role of the component within the product structure concerning the structural impact of a change. The portfolio is divided into six fields. For each fields, measurements for the design of the component respectively its interfaces are given in order to design different platform and module structures. The portfolio is shown in Figure 6.

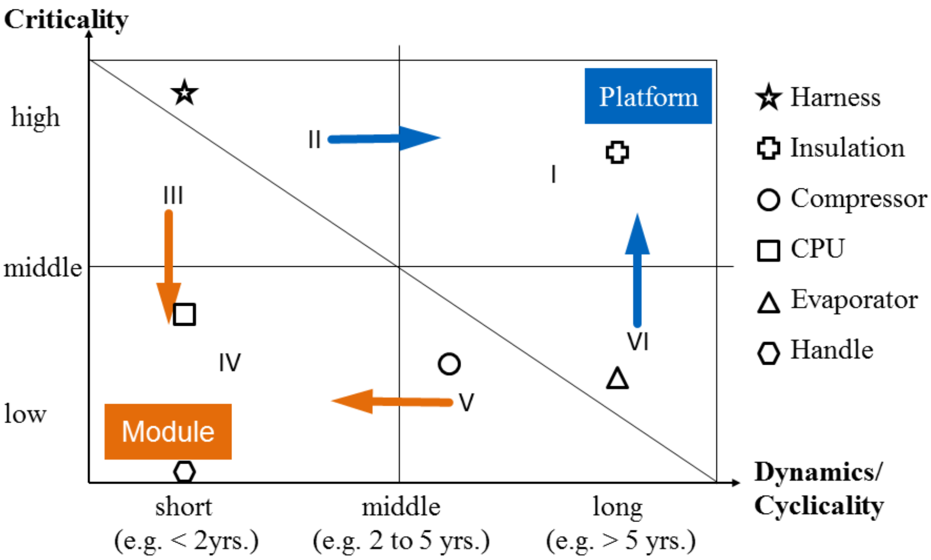

Figure 6. Dynamics-Criticality Portfolio

All differentiating attributes respectively the physical components are transferred into the portfolio. Depending on the position of the elements within the six fields, different measurements for structural design can be applied:

- Field I: Elements in this field do hardly change during the product life cycle and possess a high criticality. These elements are assigned to the platform.
- Field II: These elements tend to change often during the product life cycle but possess a high criticality. Because of the high criticality, they should also be incorporated into the platform. To overcome the frequent changes, they can be designed for instance in an oversized way.
- Field III: Elements in field III change very often but are characterized by a high criticality. These elements should be encapsulated into modules. Their criticality has to be lowered, for example by providing flexibility and interchangeability by specific interface design or standardization.
- Field IV: Elements of this field should be integrated in modules as they change quite often and possess a low criticality.
- Field V: Elements in field V should also be assigned to modules. They have a low criticality but change rather seldom during the life cycle. These elements can be designed in a way that they represent a new differentiating attribute if reasonable
- Field VI: These elements do not change during the product life cycle. To implement them in the platform structure, their criticality can be increased, for example by standardization and application within all products of the product family.

The implementation of the design measurements based on the dynamics and the criticality of the elements (Bauer and Maurer, 2011) lead to a re-design of the current platform and module structure. Applying these measurements will result in different platform and module structures which can deal with the occurring influencing factors. The main reasons for splitting elements into modules or to incorporate them into the platform is their frequency of change induced by cyclic influencing factors as well as their criticality in the current platform and module structure. The resulting structural concepts can be assessed according to further objectives besides the robustness against cyclical influencing factors, e.g. production or assembly issues. With the knowledge about the behavior and occurrence of the influences, the releases of the product variants generated during the product life cycle can be planned in a better way. The implementation can be run through faster and cheaper because the platform and module structure is designed according to these changes.

4 DISCUSSION

By applying the presented approach for a re-design of a product family, the influences which re-occur during the planned product life cycle can be anticipated and integrated into platform design. The platform and modules are designed to meet the foreseen changes and implement them in a fast way.
The approach is currently deployed in an industrial case study dealing with a product family of refrigerators. As a pilot study, only a few influencing factors were considered to prove the validity of the approach. The considered factors change both, differentiating attributes and components. The results show that the approach is working in order to re-design the current platform and module structure according to the identified influencing factors.

5 OUTLOOK

Further research will be done in the field of the characterization and anticipation of the cyclic influencing factors. As they serve as the basis for the platform and modular design, the significance of the characterization and anticipation must be lowered as far as possible. Further ways of characterization of the cyclic influencing factors is done currently, always in accordance with the available data and its reliability as well as the needed information for designing the platform and module structure.
Moreover, the scope will be widened from one to multiple product families. On the one hand, many cyclic influencing factors act on all offered product families, e.g. fairs, upcoming laws, innovation process cycles, or organizational issues. On the other hand, the synergy effects in terms of economies of scale are increased by considering multiple product families across the company. The component view will also be enlarged by functional aspects. Emphasis will also be put in the elaboration on multi-dimensional clustering as the consideration of numerous influencing factors can lead to many various platform concepts.

6 CONCLUSION

The paper presented an approach for a cycle-robust design of platforms and modules for a product family. It points out the need of appropriate structural design to deal with influencing factors which re-occur during the product life cycle and cause changes to the platform and module structure. It is shown how to identify, characterize and anticipate the relevant influencing factors and combine them with information about the current platform structure, such as a feature tree or structural models of single products. Finally, it is shown how to design the platform and the modules for a product family in accordance with the occurring influencing factors and the underlying product family structure.

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