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Design for Changeability: Incorporating Change Propagation Analysis in Modular Product Platform Design

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Abstract

Modular product platforms (MPP) enable the derivation of multiple product variants while realizing beneficial effects like economies of scale. In order to preserve the benefits throughout the platform's lifecycle it is necessary to design a changeable system. This can be achieved by defining degrees of freedom (DoF) within the platform design that are suitable for the realization of future product variants and changes. In this paper an approach will be presented that supports the design of a MPP achieving an increased changeability by incorporating a change propagation analysis in an early stage. The approach enables the systematic identification and evaluation of DoFs in a system. Using a matrix-based change propagation analysis the effects on the system caused by a variation of a DoF will be calculated and used for the definition of a changeable system design.

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1. Introduction

Companies often try to satisfy increasingly individual customer requirements in saturated markets through an increasing number of product variants [1]. This high variety leads to an increased complexity of products and organisations. To manage this complexity modular product platforms (MPP) have proven to be an useful approach [2]. A MPP enables the derivation of single product variants while realising economies of scale. When designing a MPP the entire lifecycle of a platform has to be taken into consideration. During the utilisation phase of a platform product variants will be created by changing certain design parameters of the product. Typically, these changes enable an increase in performance or an adaption to market-specific requirements [3]. In the design phase of a MPP it is essential to define degrees of freedom (DoF) within the platform design that enable a variation of design parameters achieving the required outcome. In order to preserve the desired economies of scale throughout the lifecycle it is necessary to select DoFs that have a low impact on product commonality and product costs.

For the purpose of selecting favourable DoFs this paper presents a model that incorporates change propagation analysis in the design of modular product platforms. The model consists of an explanatory model quantifying the effects of a DoF variation and a decision model enabling the selection of favourable DoFs using a change propagation analysis.

2. Current state of research

In the following the current state of research regarding the design of modular product platforms and design for changeability will be presented. Furthermore, the basics and recent advances in the field of change propagation are described.

2.1. Modular product platforms

A product platform can be defined as the collection of assets which are shared by products, including component designs [4]. This definition can be extended according to Feldhusen et al. who define a modular product platform as machines, subassemblies and components that can be combined as modules to fulfil different overall functions [5]. A module is further

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characterized by a low physical and functional dependency to other system elements and standardized interfaces that enable a reconfiguration [6]. The crucial step in platform design is the modularisation. Hölttä-Otto et al. provide an extensive overview of modularisation methods [7]. Product platform design can be separated from the initial phase of platform planning and the subsequent phase of platform implementation. Simpson et al. collected a broad overview of different approaches in these phases [8]. Schuh provides a holistic approach for the creation of modular product platforms integrating the planning, design and implementation in one process model [9]. In the reviewed approaches only Schuh focuses on the determination of degrees of freedom in the design of a product platform. The aspect of changeability in the lifecycle perspective of a product platform is still a deficiency in current approaches. Suh addresses this issue with his work on flexible product platforms [10]. His approach however lacks the focus on functions and ranges of function requirements that usually have to be fulfilled by a modular product platform. This needs to be regarded especially when designing MPP for mechatronic or cyber-physical systems [11].

2.2. Design for Changeability

Changeability can be described as the ability of a system to easily undergo various changes [12]. Aspects like dynamic marketplaces or the technical evolution are reasons why a system needs to be changeable [13]. While Ross et al. use three categories to describe changeability, namely robustness, scalability and modifiability, Fricke et al. propose four aspects in order to define the Design for Changeability (DfC) [14]:

- *Robustness:* insensitiveness towards changes,
- *Flexibility:* ability to change easily,
- *Agility:* ability to change rapidly, and
- *Adaptability:* ability to adapt itself

To support the implementation of DfC a system or an architecture can be divided into basic and extending principles, which on the one hand influence the just named aspects of DfC and on the other hand interrelate with each other [14]. The usage of DfC can be considered, if the architecture contains products having the same basic function, and only varying in secondary functions [13]. In order to minimize both costs and time consumption during the DfC it is essential to only change components of the architecture with secondary functions, while the ones with basic functions should be insensitive towards changes [15]. If changes are made in the basic functions, one has to keep in mind that the first modification could lead to numerous modifications in other components of the architect-ture. The planned upgrading of products and product platforms is addressed by Umeda et al. [16]. Using function-behaviour-state modelling they are able to minimize unwanted changes due to function and design parameter couplings.

2.3. Change propagation

The phenomenon of multiple changes occurring in a system as a result of a change of a single component is commonly referred to as change propagation [17]. In practice, a change is often followed by up to four additional changes in the existing system [18]. The initial change can either be externally caused, e.g. by changed customer requirements or changes in demands, or internally, e.g. due to errors in the technical functions of a product [19]. Nevertheless which kind of change arises the changing process is less complex, when existing interfaces between the single parts of the architecture can remain the same, rather than having to change all parts completely. The components in the architecture, which might be changed, can be categorised into four different types: constants, absorbers, carriers and multipliers [19].

To gain an overview of the dependencies between single components, it is crucial to not only reveal the directly visible connections between them, but also the indirect ones, where their linkage is achieved by the interplay of one or several other components [20]. Several methods for this visualisation are available, e.g. the Design Structure Matrix (DSM), Propagation Networks or the Multilayer Network Models. For a quantitative analysis the Change Propagation Index can be used [20], [21]. Conducting an analysis of change propagation in the early phase of the design process of a system helps to minimise the arising costs for the implementation of all following changes [22]. It is helpful to combine different methods of analysis, as this will enable a comprehensive understanding of change propagation, including all interdependencies of components within the architecture, their likeliness to arise and the costs they will cause.

3. Challenges regarding the design of a changeable modular product platform

The starting point of any platform design tasks are the functional requirements (FR) of the product platform and the mapping of suitable design parameters (DP). A functional decomposition and a systematic mapping process can be achieved by applying the principles of Axiomatic Design which are formulated by Suh [23]. For each DP different degrees of freedom (DoF) can be identified. **A DoF is defined as the range of a possible variation of a DP**. Multiple DoFs can be assigned to one DP. This relationship is depicted in figure 1.

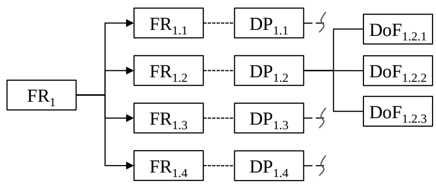

Fig. 1. Mapping process and assignment of degrees of freedom (DoF)

The main challenge regarding the design of a modular product platform is that ranges of FRs need to be satisfied by the use of specific DoFs [11]. The required FR ranges result from different product variants that will be derived from the platform during its lifecycle. The design of a product platform for machine tools for instance could require the realization of maximum spindle speeds ranging from 16.000 to 40.000 rpm. Analysing the corresponding design parameter, in this case the spindle, different degrees of freedom for a possible variation can be identified. The key challenge for the design of a changeable product platform is now to identify suitable degrees

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