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A NEW V-MODEL FOR INTERDISCIPLINARY PRODUCT ENGINEERING

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ABSTRACT

In this publication a new enhanced V-Model for interdisciplinary product engineering is presented. The new approach comprises continuous requirements elicitation and management, comprehensive modeling and analysis and emphasis on the entire product life cycle. The proposed V-Model unites the models of different development methodologies, e.g. VDI 2221 [3], Systems Engineering [4] and elements of the contemporary VDI 2206 [2]. This new approach is inspired by discussions led within the Technical Committee VDI GMA 4.10 "Interdisciplinary Product Creation" of the Association of German Engineers (VDI).

Index Terms **–** V-Model, mechatronic engineering process, Cyber Physical Systems, engineering methodology

1. INTRODUCTION

The original idea of a V-Model for engineering processes was created 1995 by BRÖHL and DRÖSCHEL in the application field of Software Development [5]. In the core, the symbol of the "V" represents decomposition of the system into its elements on the one thigh and gradual integration of elements and sub-systems into the entire technical system on the other thigh. Besides these two thighs of the "V", the properties of the product in development are continuously validated and verified. Thus, it is ensured that the "right" system (validation) is developed in the "right" manner (verification). This idea was successfully transferred to mechatronic engineering processes in the first edition of the guideline VDI 2206 "Development Methodology for Mechatronic Systems" published by the Association of German Engineers (VDI) in the year 2004.

Due to the obvious need for revision and extension of the initial V-Model for mechatronic engineering process, the Technical Committee VDI GMA 4.10 "Interdisciplinary Product Creation" of the Association of German Engineers (VDI) was founded in March 2016. In order to achieve excellent applicability in industrial practice, the core team was constituted by as many industrial as academic members. As the academic part was represented by scientific employees working on their phD thesis and their instructing professors, fast results were incorporated by deep discussions.

The core team collected impulses for rework and additions and discussed alternative approaches for a revision of the V-Model. The enhancement of the V-Model shall not be limited to the development of mechatronic systems, but extends to Cyber Physical Systems and all Interdisciplinary Technical Systems according to the Technical Committee's name "Interdisciplinary Product Creation". In this publication, a new enhanced V-Model for

Interdisciplinary Product Engineering is proposed and offered for further discussion. Starting from the revision requirements in chapter two, three main revision elements are introduced in the chapters three to five. In chapter six, the new enhanced V-Model is illustrated and an outlook on the further proceeding is presented.

2. IMPULSES FOR REVISION AND ADDITIONS

Today's engineering applications are characterized by high interdisciplinarity, networking, complexity and heterogeneity. Originally mechanically realized product functions extend over several interconnected specialized disciplines, such as mechanical engineering, electrical engineering and information technology as well as to different application domains. At the same time, a change in the control, regulation and operation of technical systems has taken place across the industry (figure 1). Thus, first technical products were mechanically controlled, e.g. by actuating cams, link plates, pushing rods or cable pulls (control level 1). This was followed by hydraulically and pneumatically controlled systems, such as servo steering or hydraulic control of aircraft flaps and rudders (control level 2). With today's electronically controlled technical systems, e.g. Fly-by-Wire, the system behavior has become more precise, more real-time and flexibly configurable (control level 3). The incorporation of a large number of embedded microprocessors and microcontrollers together with local and global networking leads to digitized and networked systems (control level 4). [6] The Internet of Everything (IoX) enables networking of things, people, animals and plants, among others. Such technical systems have properties such as robustness, adaptability, predictability and user-friendliness and are therefore also referred to as "smart" or "intelligent". With the provision and integration of services via the Internet, business processes change and new Digital Business Models emerge.

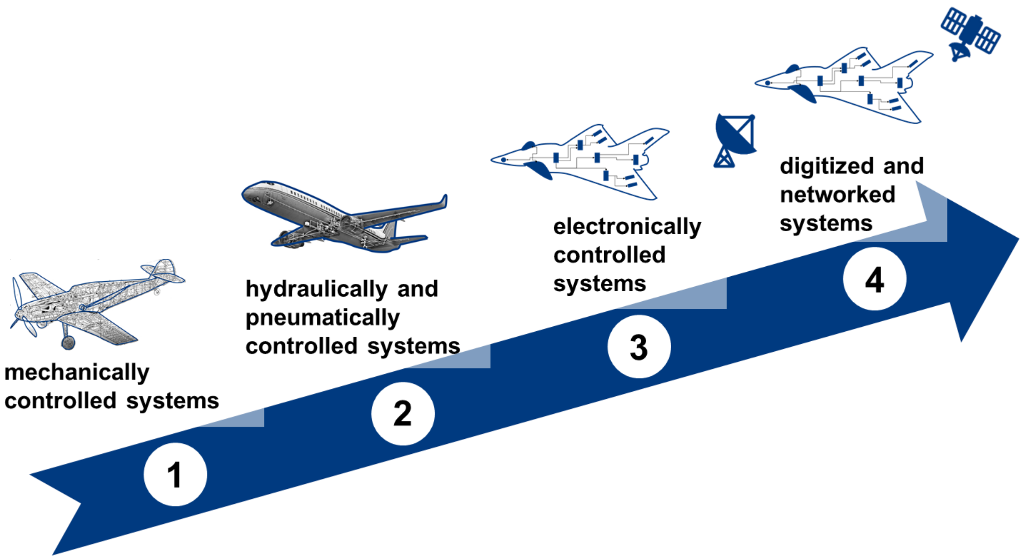

Figure 1: Change towards digitization and networking

The resulting transformation of classical mechanical engineering towards digitization and networking in connection with globalization and the growth of the service sector leads to the need to adapt planning and engineering activities as well as their underlying methodologies. Due to this need for an adaption, an immense growth of different interpretations of the V-Model has resulted. Some examples of variants of the classical V-Model can be found in [7, 8, 9, 10 and 11]. The range of contemporary international norming activities on the field of engineering methodologies for mechatronic and Cyber Physical Systems is illustrated in figure 2.

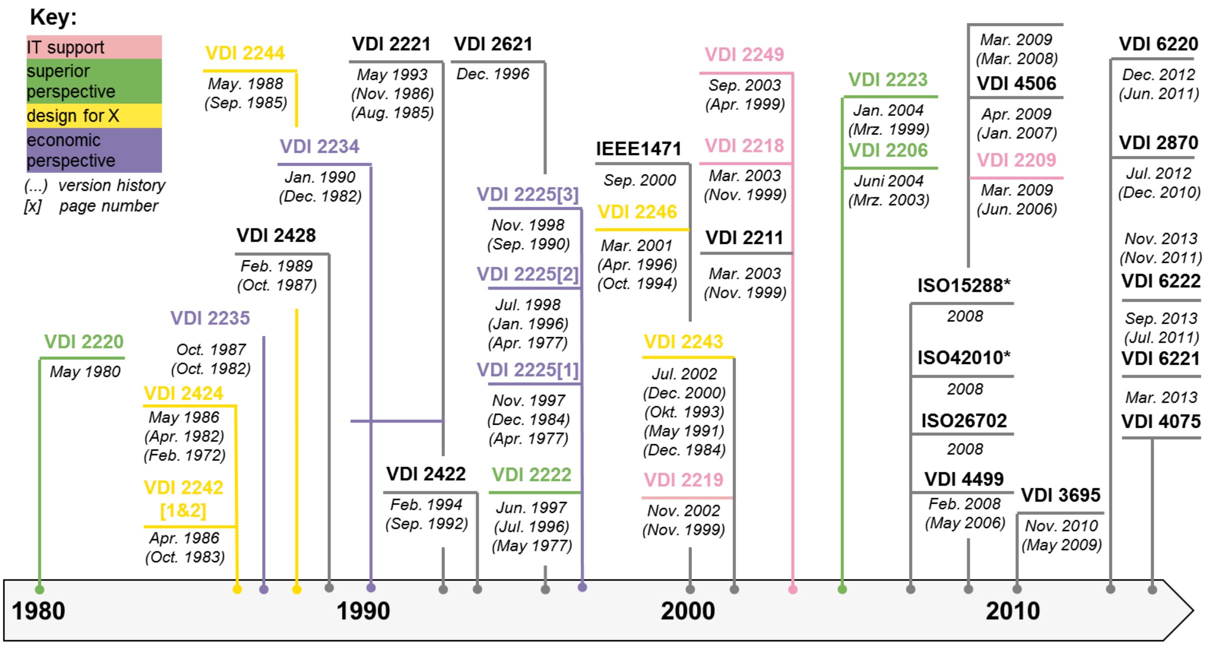

Figure 2: Overview on recent international norming activities

An overview of rework potentials was already published 2016 in [2]. In the publication at hand, an enhanced V-Model is proposed and concretized by three new Core Elements. The affiliated weak points are illustrated by means of contemporary version of the V-Model in figure 3.

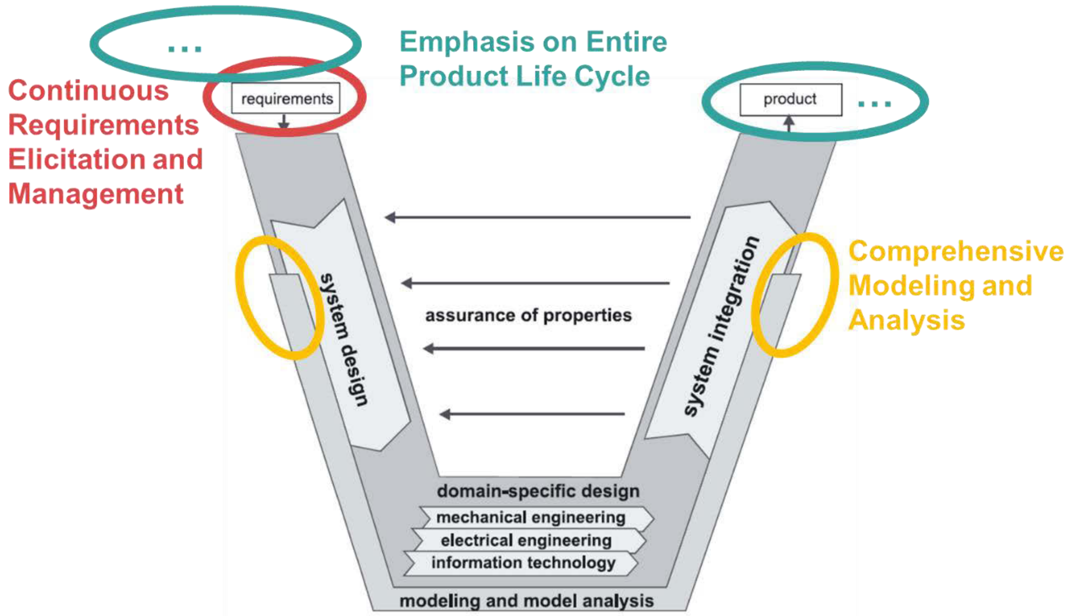

Figure 3: Three Weak Points of contemporary V-Model (illustrated by means of [1])

3. CONTINUOUS REQUIREMENTS ELICITATION AND MANAGEMENT

The first new Core Element consists in continuous requirements elicitation and management. A requirement is understood to be a clear, comprehensible, consistent and verifiable statement describing a function or property of a system, product or process. The acceptance of a product by stakeholders depends on the fulfillment of its requirements. In the V-Model version of 2004, requirements serve as well-defined input for actual engineering process, illustrated as input element to upper left thigh in the V-Model (figure 3). Neither the process of requirements collection and elicitation, nor requirements management, is represented in the contemporary V-Model. This kind of representation of requirements in the V-Model is based on the assumption that requirements could be collected once and completely. In engineering practice however, requirements and their values change along the product development process. This is due to external as well as internal reasons. Examples of external reasons are the change of customers' wishes or market demands. Internal reasons typically result from the deeper insight into the engineering problem and for example consist in changed feasibility limits. Continuous requirements elicitation and management therefore serves as key success factor of engineering projects. Requirements elicitation translates the customer's requirements into the technical specification of a product that has the required properties and performance [12]. Hence an internal survey of the Robert Bosch Company of the year 2004 for example has shown that inadequate requirements assessment and management represents up to 71% of the causes of field complaints in the automobile divisions.

Therefore, requirements elicitation and management is represented prominently and as continuous task in the enhanced V-Model (figure 4). Starting from the identification of stakeholders and target customers, current and future expected application scenarios, so-called "use cases" as well as customer requirements such as product load or reliability requirements are raised. Further, interfaces to the environment, to neighboring components, to the superordinate system, to the application, and to the user must be defined. Additional requirements result from the restrictions of downstream product lifecycle phases, e.g. production sites, production quantities, assembly conditions up to possibilities for an upgrade (compare chapter 5). For comparison, the data of competition products are included. In addition to the intended use, the common use which is still tolerated with regard to product liability must also be recorded and delimited from a misuse of the product. For example, the acceleration by means of a hammer beat counts as common use of a battery sensor which is attached directly to the battery. The reason for this is that batteries are usually disassembled by a hammer beat at a service station when the poles are stuck. Separating the battery by means of a welding torch however, would be a misuse of the battery sensor.

As the development progresses, the requirements list is successively supplemented by concretizing product properties. The objective is to quantitatively define all the essential requirements at the end of concept design and system architecture. In addition, requirements can change through feedback and iterations from downstream phases. Changes are therefore systematically pursued and evaluated. The result of the requirement specification is a product specification which describes the required system properties. Based on the requirements, the target parameters for verification are also derived.

4. COMPREHENSIVE MODELING AND ANALYSIS

The second new Core Element of the enhanced V-Model addresses comprehensive modeling and analysis. In the version of 2004, "modeling and model analysis" starts in the middle of system design. In the meantime though, model-based engineering approaches have become a standard in research and also in industrial practice. Modeling has not only been intensified in all engineering activities, but also upstream and downstream activities such as sketching Digital Business Models, analyzing stakeholders or drafting smart automation production facilities. The main advantage of model-based approaches lies in predicting system properties and behavior. Current work focuses on overcoming gaps and fractures between several discipline specific models. Gaps and fractures for example arise through different levels of detail, varying reaction times (e.g. real-time requirements), discrete versus distributed systems, partial versus ordinary differential equations and the specific boundaries of physics, chemistry or other disciplines.

5. EMPHASIS ON THE ENTIRE PRODUCT LIFE CYCLE

The third Core Element strikes enabling Digital Business Models. In order to invent new value propositions, engineers must closely work together with sales and marketing people, as they are the ones who keep the knowledge of emerging cross-cutting product and production technologies. In addition, engineers must understand the way the user applies the product in order to gain impulses for product innovations. For this reason, two wings are enclosed to the "V": one upstream wing referring to the product strategy and stakeholders and one downstream wing addressing production, application, maintenance and disposal. This idea is based on a V-Model approach proposed by the US Department of Transportation [14].

6. SUMMARY AND FURTHER PROCEEDING

The resulting enhanced V-Model is illustrated in figure 4. In order to enable emerging Digital Business Models, the V-Model is enhanced by wings and thus incorporates planning business and product strategy and analyzing stakeholders in the early tasks as well as the subsequent tasks producing, operating/ maintaining and disposing. The left thigh of the "V" embraces developing system architecture starting with eliciting requirements, deriving functional and principle structures. The decomposition of the system embraces breaking up the system into subsystems and system elements. In the center of the "V", the discipline specific elaborating and implementing is positioned. The right thigh covers validating and verifying properties. The three cords of the "V" represent engineering the considered System-Of-Interest, continuous eliciting and managing of requirements as well as comprehensive modeling and analysis. The presented enhanced V-Model is a generic model and thus is independent from different types of project management and organizational structures. It can be applied on different detail levels of the product and follows an iterative and incremental approach. Furthermore, the core idea of the "V" is kept up. The enhanced V-Model takes up the many derivatives of V-Models since the 2004 version and harmonizes them into one coherent approach.

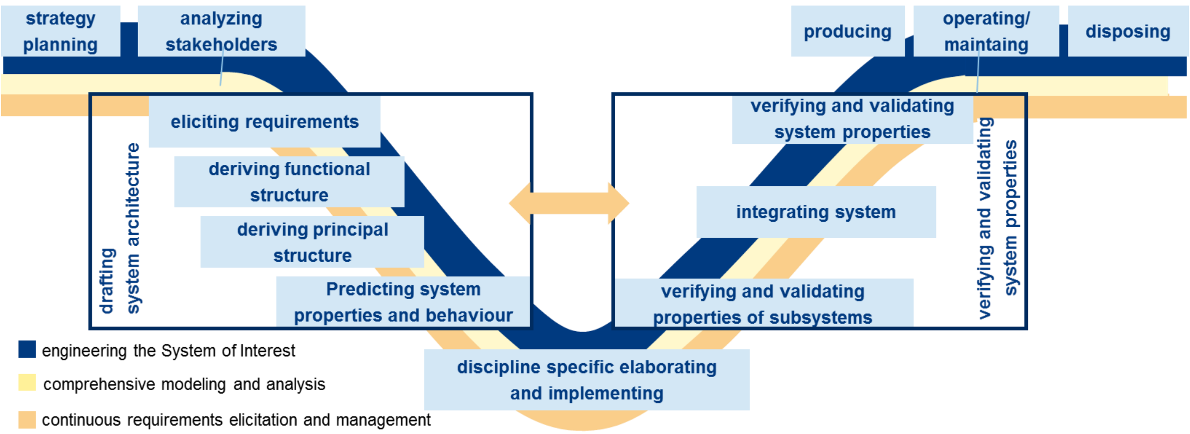

Figure 4: New Enhanced V-Model

The further proceeding consists in presenting and discussing this new approach to the Technical Committee VDI GMA 4.10 "Interdisciplinary Product Creation" of the Association of German Engineers (VDI) in the next meeting. In addition, the wings of the presented enhanced V-Model are to be embedded into a holistic product lifecycle model which is being worked out simultaneously in the Technical Committee VDI GMA GPP 07.02 "System House" of the Association of German Engineers (VDI). The next step within the Technical Committee VDI GMA 4.10 work will be a validation workshop with academic as well as industrial discussion partners on the actual revision status of the V-Model in order to receive coherent feedback in detail.

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