INTERNATIONAL DESIGN CONFERENCE - DESIGN 2006
Dubrovnik - Croatia, May 15 - 18, 2006.

DESIGN 2006

THE DIGITAL MATURITY MAP – MOTIVATION FOR AN EDM-BASED DIGITAL VALIDATION METHOD

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Keywords: maturity, digital validation methods, cross-domain EDM

1. Introduction

The degree of maturity is a popular and widespread instrument for controlling and coordinating distributed product development processes in the automotive industry. Besides Computer aided design and validation applications (CAx-applications), the management of engineering data (EDM) plays a key role. This contribution will introduce new aspects for the specification of CAx methods and EDM concepts based on a maturity map.
In order to control the results of certain stages of the product development process in the automotive industry, a variety of different methods are applied to create information that delivers the foundation for decision-making processes. Throughout the assembly process chain, for example, digital methods such as DMU or tools of the digital factory are used. These applications have become increasingly powerful in recent years. Despite these improvements, it remains challenging to define a balanced validation process: How to cope with different requirements in a cross-domain scenario? How to allow the stakeholders their own, appropriate view of data and information?
As [Mueller 2005] illustrates, a holistic view of maturity and coverage is essential. The consideration of different facets of maturity and their interrelations can avoid wrong decisions. Based on some fundamental definitions, this contribution introduces a maturity map as a new approach to specify requirements for a CAx/EDM concept. These new aspects lead to an enhanced CAx/EDM concept, which will be introduced in section 4 as well as the results of a first prototypical implementation. The discussions of these results conclude this contribution and open questions for further research (section 5).

2. Definitions and the Maturity Map

This section introduces basic definitions and the coherence between maturity and the different methods of coverage. These reflections lead to a maturity map, which summarizes classes of maturity and their interrelations.

2.1 Basic Definitions

While there are several definitions for the terms “degree of maturity” or “maturity levels”, no common understanding has thus far been established. A recent approach comes from VDA [VDA 2005], (VDA – association of German car manufacturers). In general, maturity levels are part of project controlling and development process tracking models and are used to quantify the development status of a product. Ehrlenspiel [Ehrlenspiel 2003] defines the process of judging the development status of a product as the interaction of analysis and quantification. Because of this relation between maturity levels and product analysis methods, these methods are used in a first step to subdivide maturity levels into different classes.

2.2 Methods of Validation

In the automotive industry, many product analysis methods are established and used in daily business. These validation methods include both digital (“virtual”, “software”) and physical (“hardware”) methods. This contribution focuses mainly on digital product analysis methods, as they are more important in early product development stages than hardware methods. Table 1 lists frequently used issues of digital product validation and also citing examples of tools used while applying the method. This selection of methods represents some of the main activities in the final assembly process chain in the automotive industry.

Table 1. Validation issues and Applied Tools in the Final Assembly Process Chain

No.	Validation issue	Tools
1	Validation of strength, stiffness, harshness, etc.	FEM simulation
2	Tolerance analysis	Tolerance simulation
3	Packaging analysis	DMU and virtual reality applications
4	Assembly validation	DMU applications
5	Digital production planning	CAP applications
6	Digital planning validation	CAP applications

In recent years, due to approaches such as the digital factory, it was possible to increase the focus of validation methods from chiefly product-centered methods to more production-oriented investigations. New methods broaden the view of the product, thereby distinguishing more facets of the product's behavior. This provides in this contribution a basis for subdividing the degree of maturity into different classes.

2.3 Maturity Level Classes and Maturity Map

As mentioned, it is important to consider both digital and hardware validation methods from a project controlling perspective. The maturity map in [Mueller 2005] thus differentiates a digital and a hardware degree of maturity. This contribution centers on upstream product development stages, where hardware methods play a less important role. Thus, in figure 1, only the digital section of the maturity map is introduced in detail. The digital maturity of a product development project consists of three different contributors, called maturity classes. These three maturity classes are described in the following.

2.3.1 Digital Product Maturity

Digital product maturity compares the analyzed behavior of the digital model with the required properties of the product. The behavior of a product can be judged within different views. The functional view addresses properties in the sense of “functional properties “[Suh 1990] or “Soll-properties” [Weber 2001]. The production-oriented view is an example for a number of possible and, from case to case differing, “x-oriented views” in the sense of design-for-X approaches.

2.3.2 Data Maturity

As all digital methods use data, it is necessary to control the syntactic correctness of the data. Yet it is not just this syntactic view that is relevant. Digital validation methods employ data to define models. A model is defined as the abstraction of reality [Baer 1998]. A “semantic” view is therefore necessary. Thus, it is possible to judge and observe the correct level of abstraction of a model regarding the validation method in which the model is to be used.

2.3.3 Engineering Process Maturity

Engineering process maturity describes the quality of the development process. The integration of different stakeholders in the various engineering domains is not directly related to the maturity of the

product, but it is a prerequisite for a successful product development project. To give an example, consider results of validation methods that are based on outdated product data.
The description of the state of the art in the assembly process chain in chapter 3 illustrates manifold activities to ensure the maturity of a development project. Chapter 4 then details how a new CAx/EDM concept can deliver an even more seamless validation process in early stages.

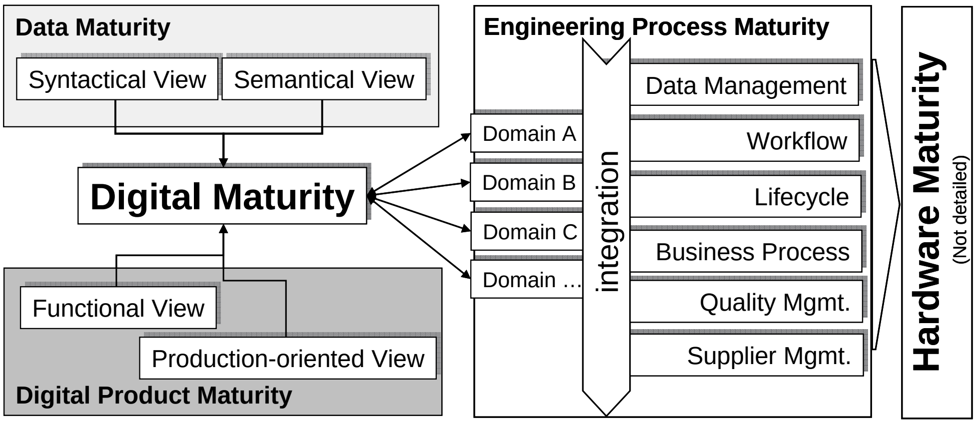

Figure 1. Digital Maturity Map

3. The State of the Art in the Assembly Process Chain

This section is divided into two sections. First, a brief description of the product development process concentrates on the assembly process chain. Digital validation methods and cross-domain interaction are then used to fit the current process into the maturity map introduced in section 2. This allows the specification of requirements for a new CAx/EDM concept in section 3.2.

3.1 The Assembly Process Chain Between Product Development and Production Planning

After completing early design stages and the digital validation of functional properties, e.g., packaging validation using DMU, the first hardware validation activities begin. The prototype assembly process is guided by digital assembly validation methods. The focus here is to judge the assemblability of a car under volume-production conditions, insofar as information of the upcoming serial process is available or defined at this very early stage, making any kind of viable assessment possible. In a concurrent process, production planning domains employ digital factory applications to define and optimize the serial assembly process.
Then, digital planning validation methods used to detect assembly or ergonomic problems. At this stage, the production-oriented properties of the product are investigated. Figure 2 portrays the activities along the assembly process chain as integrated into the digital maturity map.

3.2 Requirements for the Assembly Process chain

In order to specify requirements for the assembly process chain, a closer look is taken at the three maturity classes of the digital maturity map as drivers, in figure 2.

3.2.1 Requirements Driven by the Digital Product Maturity Class

As indicated in figure 2, mainly function-oriented engineering domains are involved in early stages of the product development process. Thus, digital maturity represents a more or less functional view during these stages. The production-oriented view of the digital maturity of a product is developed in later stages of the product development process, e.g. in the assembly process chain using digital planning validation. In order to proffer a more production-oriented view of digital maturity in upstream stages, both enhanced or new validation methods and new validation tools are required.

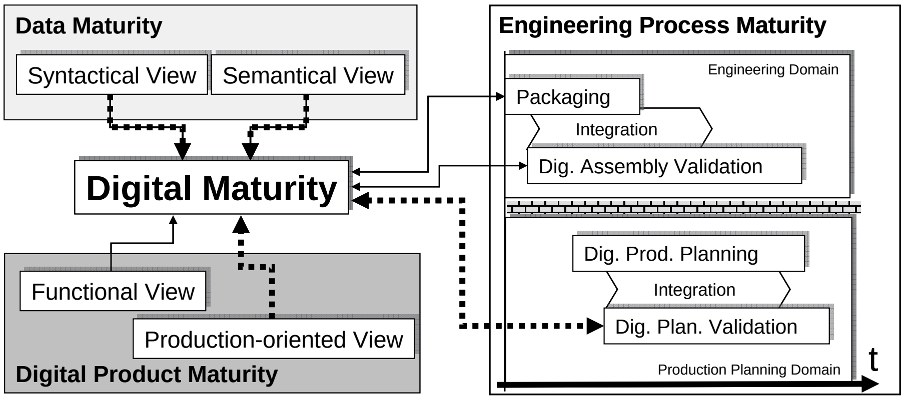

Figure 2. The Assembly Process Chain in the Digital Maturity Map

3.2.2 Requirements Driven by the Data Maturity Class

In order to deliver sustainable results of validation examinations, it is essential to use up-to-date and correct input data for every validation method. This syntactic view is a general requirement that is universally valid and not specific for the assembly process chain. As different validation methods apply different tools, it is necessary to deliver data that fulfill the requirements of these tools. Hence, all relevant information has to be represented in the data. This semantic view may differ from one organizational domain to another or, quite often, from information-generating tool to information-analyzing tool. A quite popular example is the difference between a regular CAD model and a meshed model of the same product that is to be used in FEM analysis.

3.2.3 Requirements driven by the Engineering Process Maturity Class

As it is desirable to detect and solve problems as early as possible in the product development process, the interaction of the product development and production planning domains and their contribution to digital maturity are the focus of figure 2. The gap between these two domains might be caused by many factors: different organizations that bear the responsibility, lack of uniform infrastructure, varying views of the product, and use of different methods and tools, to name a few. New concepts are called for to fit in the early engineering infrastructure and to cope with the prevailing requirements of these engineering stages, e.g., seamless change management and version and variant management.

4. CAx/EDM Concept for Early Assembly Validation

Section 4 presents a new CAx/EDM concept geared for fulfilling (at least some of) the requirements formulated in section 3. This application-oriented concept targets geometry-oriented assembly validation in upstream product development stages. Therefore, standard CAx and EDM technologies will be used to validate the concept by means of prototype implementation. This prototype includes both the adaptation of a digital planning validation tool and the definition and establishment of an enhanced data management concept. The impact of this concept on the digital maturity map is set out in figure 3.

4.1 Introduction of the concept

This concept consists of three main parts. The adaptation of a digital planning validation tool is introduced in 4.1.1. In order to supply this application with valid input data, section 4.1.2. looks at the specification of an EDM structure that merges the necessary data from the engineering and production planning domains. The third part (section 4.1.3), the reorganization of legacy operational sequences at the interface between product development and production planning, is very important and a prerequisite for a successful realization of this concept. Nevertheless, it is not elaborated in this contribution as it goes beyond the scope of the topic at hand.

4.1.1 Method for Automatic Accessibility Validation

In order to allow a more production-oriented view in early product development stages, it is necessary to investigate the interaction of the product and the resource as early as possible. Practical experiences show that, apart from quality problems, many product changes after ramp-up are caused by a product design that is not in line with the requirements of production. A typical example for lacking design for manufacturing is poor accessibility of assembly components, for example, standard parts such as screws and clips. And it is this concept that is able to tackle this problem.

Hence, a method for the automatic accessibility validation was developed. This method is an adaptation of a digital planning validation method and inserts a pre-validation stage into the engineering domain. Figure 3 shows how this contribution of this new method fits into the framework of the digital maturity map. Please consider the additional pre-validation stage named Digital Planning Validation I. The former Digital Planning Validation stage is now called Digital Planning Validation II.

The scope of this method is not to investigate whether parts are assemblable or not. This is a packaging problem and thus investigated in earlier sessions using DMU applications. Instead, this method enables a validation whether the required interaction of resources such as drivers or devices and the product works without interference. With regarding to the interaction of the domains involved – in this example product engineering and production planning – it is also possible to validate a first assembly sequence, which also increases digital product maturity.

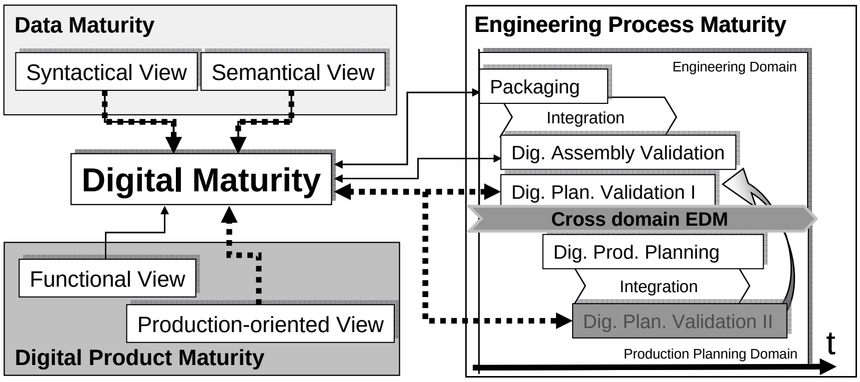

Figure 3. Consequences of the Concept in the Digital Maturity Map

When desiring to execute an automatic validation process, it is, of course, necessary to prepare the data. Section 4.1.2 illustrates how the necessary information is merged in a cross-domain EDM structure. This validation structure supplies the input data for the investigation and meets other requirements such as seamless version and variant management, non-redundant data, and change management.

4.1.2 Cross-Domain Validation Structure in EDM

To provide the relevant data for the validation process, this concept uses an EDM system to merge data from different domains, namely product, resource, and assembly process data (see figure 4). Thus this is quite similar to a concept proposed by Burr et. al. [Burr 2004]. Both product and resource data are usually available as product and resource structures, respectively, and include the structural and the geometric definition of the products and resources. The associative integration of product and resource data is indicated by the dotted lines in figure 4. Assembly process data such as factory and assembly station layout and assembly sequence information are not available in common EDM environments. They have to be established once, either through import from production planning databases, or, aiming at even earlier stages, concurrent to the prototype (“hardware”) assembly process.

As this assembly validation concept adapts a digital planning validation method and deploys it in an engineering design environment, it is necessary to harmonize some relevant semantic information. It is first essential to define the interaction of a product and a resource. A screw does not “know”, where a screwdriver picks it up; nor does the screwdriver “know” how to join with the screw during the validation process. Semantical information of this type must be added prior to an automatic accessibility validation. Up to know, it is necessary to add these informations manually. As this simulation preparation is time consuming and susceptible to mistakes, another opportunity of defining these informations is using the assembly feature technology.

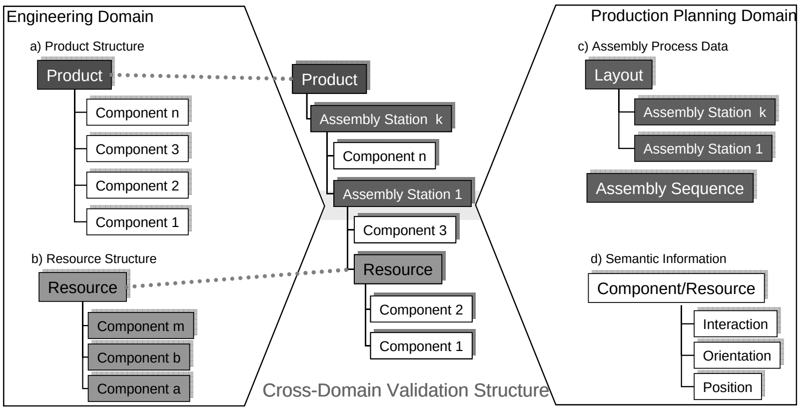

Figure 4. The Validation Structure in EDM as an Interface Between the Engineering and Production Planning Domains

4.2 Proof of Concept

In order to try out this concept, an available digital planning validation tool was adapted and the validation structure implemented in an EDM system. Figure 5 depicts how the method automatic accessibility validation is embedded in the engineering environment. Section 4.2.1 offers an overview of how a validation examination is established in principal. Advantages and disadvantages of this concept are then addressed in Section 4.2.2.

4.2.1 Performing an Accessibility Examination

For the accessibility examination, the cross-domain validation structure is initialized as described in figure 4. Then, the adapted digital planning validation tool is supplied with the validation structure. Depending on the validation scenario at hand, different scopes of the examination may be carried out. Thus far, two use cases have been developed, namely validating the reachability of clips and pins and the accessibility of assembly joints such as screws and bolts. After performing an examination, a report file is generated. This file can be stored back in the validation structure in order document the results of the validation.

4.2.2 Advantages and Disadvantages of the Concept

Once the validation structure is initialized, the validation examinations become easily adaptable to the investigation range. Depending on the issues to be addressed, a validation scenario might contain one single mounting device or as many as several assembly stations. Thus, the method works in a broad variety of use cases, for example, as a quick self-check for an engineering designer or for the examination of larger assemblies before reaching certain quality gates. The usage of an EDM system as source and sink of the method yields yet another advantage. Once a validation scenario is created and documented in the EDM system, an examination becomes reproducible. The architecture of this CAx/EDM concept ensures that every examination is based on up-to-date, approved product and resource data.

To cite the main disadvantage, however, the prototypical implementation shows that additional effort is necessary to initialize the validation structure. As the validation structure merges data from different domains, the degree of complexity is very high. An appropriate administration of the validation structure is therefore necessary and organizational adjustments might be helpful to control this complexity. The adapted application shows some potential for optimization. The accessibility checks are almost static examinations. While, for example, the kinematic behavior of mounting devices, which is important, can be considered, the preparation of such an enhanced examination scenario is time consuming.
Thus, this prototypical implementation meets the requirements formulated in chapter 3.2.

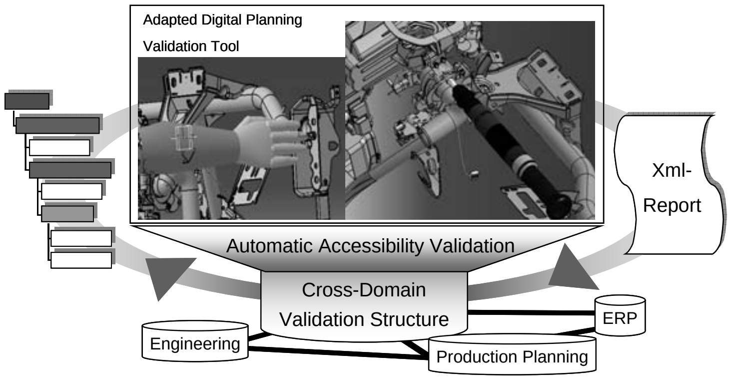

Figure 5. Automatic Accessibility Validation Based on the Cross-Domain Validation Structure

5. Conclusion

This contribution introduces a new CAX/EDM concept based on a maturity map.Validation methods and applied tools were used to classify different maturity levels and different views of the maturity of a product. These maturity classes and views were arranged and fitted into a digital maturity map. A digital maturity map of the assembly process chain delivers the motivation and requirements for the development of a new validation method. Thus, a digital planning validation method was adapted and a cross-domain validation structure was conceptualized. A first prototypical implementation proofs the suitability of the concept and concludes the main part of this contribution.

5.1 Discussion of Results

Despite the successful prototypical implementation via the adaptation of planning applications it is not clear yet whether the enhancement of DMU applications in a sense of process DMU, for example, is the more promising approach. Anyhow an open question remains: how do we harmonize product, process, and resource validation methods without redundant work. The answer is through the use of adaptive, scalable, and reusable validation methods as well as seamless data management across the domains involved.
This contribution introduces a concept using distributed as well as relational data structures in EDM. Other approaches are promoting just one master structure and different views on it in order to supply downstream processes. Both ways may lead to positive results, thus the first approach seems to be more complex. Nevertheless, as it is more flexible and holistic quite promising and therefore in the scope of further investigations.

5.2 Outlook

Yet, there is a further need for validation methods that can be used in earliest stages of the product development process and meet certain requirements, namely focusing production-oriented or, more general, x-oriented ones. As requirement management deals with similar problems like unknown or moving targets [Andersson 2004], it should be interesting to implicate further research on maturity, validation and requirement management.

It will be interesting to observe how both the industry and research handle the maturity topic in the future. Maturity is established as a helpful concept for monitoring, tracking and controlling product development processes. However it often fails, as engineering or management elements try to express complex technical situations as simple numbers. Besides the harmonization of the digital validation processes and project controlling and tracking activities it is the interaction between the hardware and the digital world that should be into the focus for further research. In this contribution, the concept of maturity opens a new view on old problems, delivering promising insights and is therefore motivation for further research.

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