FORMAL METHOD FOR VALIDATION OF PRODUCT DESIGN THROUGH KNOWLEDGE MODELLING

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Abstract: The aim of production-oriented product validation methods is to ensure the consideration of production requirements during the product design phase and to validate the product specification against these requirements before launching further steps. This work focuses on a formal method for product design specification by using techniques from the knowledge modelling and management. The solution developed within the EU project MyCar, in collaboration between the IMI institute of Karlsruhe and the Research and Advanced Technology Group of Daimler AG, is based on the example of the body shop in the automotive industry. A solution based on the Production-oriented Product Validation Platform gathers the relevant production requirements and makes it available in a structured form to assess the product design with respect to its ability to be produced on the production equipment.

1 INTRODUCTION

In the recent years the number of product variants that are offered to the customer in automobile industry increased enormously. At the same time the product variety and the individualisation of the products increase. This leads to more and more complex products that are often facing conflicting requirements, e.g. costs, quality or production.

A possible solution of the mentioned challenges is an increase of the manufacturing flexibility. Flexibility can be understood as adaptation of the production to changing demand in term of order variation and multiplication of different models. Yet, other arguments, specific to each company, enforce this trend like among others: the necessity to optimize the use of existing resources, the limited space allocated to production equipments, and the reduction of the product lifecycle leadtime. In that, flexibility is not only a matter of adaptability but also a strategy for the reduction of production costs by optimally using or reusing existing equipments.

In order to make it possible to produce on the same line several different products simultaneously, an overall concept is necessary, which links the product development with the production planning. During the whole product development process the product has to be validated, if it can be manufactured on an existing production line. For this, a methodology supported by a software tool is being developed by the Institute of Information Management in Engineering of the University Karlsruhe and the Daimler Research Group.

In this context the challenges are primarily the identification of suitable information models for the IT-supported integration of all the relevant information, processes and methods and the relationships between them.

2 RELATED WORKS

During the whole product development process design engineers have to consider a lot of different product requirements which can be summarised by the term “Design for X” (Weyand, et al., 2008). “Design for Production” takes the requirements of the production already during the design phase into account, in order to reduce the production cost and development time as well as to raise the manufacture

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quality (Pahl, et al., 2007). For checking if all requirements are fulfilled the products have to be validated during the whole product development process considering the certain aspects. In this context a X-orientated product validation must be defined (Müller, 2008).

To support different kinds of digital validation, the context has to be described more in detail. Svensson (Svensson, et al., 1999) defined an Engineering Information Management System (EIMS) which is divided into four views: process, information, system and organisation. All of them are linked with each other, as shown in Figure 1.

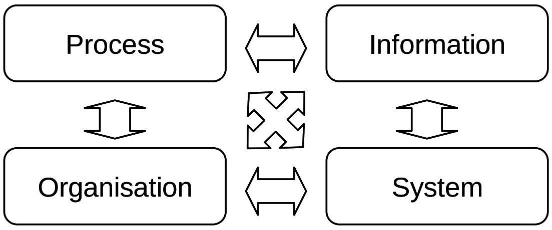

Figure 1: Engineering Information Management System, according to (Svensson, 1999).

On the basis of the Engineering Information Management System Burr (Burr, et al., 2007) derived the six views of the EIMS (see Figure 2).

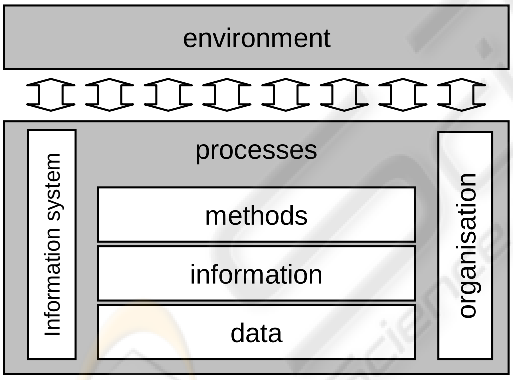

Figure 2: Engineering Information Management System, according to (Burr, et al., 2007).

According to Müller (Müller, 2007) a framework for x-oriented product validation can be described with the engineering information management system showed in figure 2. This framework contains all relevant influencing factors that are interacting during digital validations.

3 POPV PLATFORM

In order to meet the industrial challenges in this area a platform for production-oriented product validation is being developed within the framework of the EU-funded project MyCar. Figure 3 illustrates the overall framework.

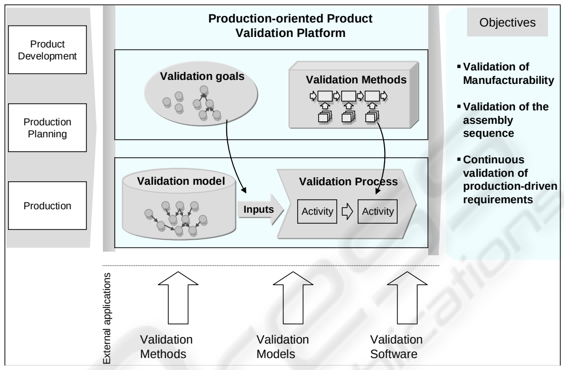

Figure 3: Production-oriented Product Validation Concept.

Input for the platform is taken from the new developed product, the process that executes the product and the respective production facility. The core of the framework is an integrated validation model (knowledge base), which describes the relevant product, process and production information by means of knowledge engineering techniques. Based on this information model the validation method can be instantiated as a process and executed in order to check if a product can be produced on a production line.

The validation process itself can be performed either based on the information specified in the validation model or by the user of an external application (Müller, 2007). This is usually the case if some facts are missing in the knowledge base or if there is a need of complex algorithmic calculations in order to check the design. However in both cases the user will be lead by the validation methods since this information is modelled into the knowledge base.

4 VALIDATION METHOD

The developed production-oriented product analysis method aims at giving a comprehensible evaluation of product specifications for manufacturing purposes. Therefore, the method developed for production-oriented analysis is applied to evaluate product manufacturability. In order to apply the method, information regarding the product, the resources, the manufacturing process and the relations between these entities must be provided. After this the respective information is being modelled and evaluated based on methods from the knowledge engineering followed by the last step of the method where the identification of appropriate solution takes place.

4.1 Basic Definitions

An appropriate formalism concerning product-, process- and resource-specifications must be defined, whereupon the product specification can be validated by means of the algorithmic evaluation of the method.

For this purpose the following formal definitions are needed:

An attribute of a product, process or resource is a geometrical, structural, physical, chemical, mechanical or other characteristic that can be represented formally through mathematical formulas.

Let P be the set of attributes, which specifies a product. Then P is finite and there exists a set of attributes $P' \subseteq P$*, which contains the production oriented analysis attributes of a product. The number of attributes* $|P'|$ *depends on the application domain and may vary.*

The most used product attributes for production-oriented analysis using the example of body shop in automotive industry are the product structure, product geometry, number of parts, type of material, type of joining elements.

A resource can be defined as follows:

Let R be the set of attributes, which specifies a resource. Then R is finite and there exists a set of attributes $R' \subseteq R$*, which contains the production oriented analysis attributes of a resource. The number of attributes* $|R'|$ *depends on the application domain and may vary.*

The most used resource attributes concerning a production-oriented analysis using the example of body shop in automotive industry are resource geometry, resource structure, footprint, manufacturing technology.

The formal specification of a process is given analogously to the product/resource definitions:

Let A be the set of attributes, which specifies a process. Then A is finite and there exists a set of attributes $A' \subseteq A$*, which contains the production oriented analysis attributes of a process. The number of the attributes* $|A'|$ *depends on the application domain and may vary.*

The most used process attributes for production-oriented analysis using the example of body shop in automotive industry are process structure, process sequence, flow of material and additional process characteristics such as cycle time, operating cost, etc.

Let $V = \{P', R', A'\}$ *be the set of relevant product, process and resource attributes. For all* $v \in V$ *the function* $dom : v \mapsto dom(v)$ *defines the co-domain for every attribute. A function* $\tau : B \to \bigcup_{v \in B} dom(v)$ *over a set of attributes* $B \subseteq V$ *with* $\tau(b) \in dom(b)$ *for all* $b \in B$ *that assigns each attribute to a feasible value* $\tau(b)$*, is called* ***Assignment*** *of B.*

In order to define compounded attributes, which are inter-related with other attributes, a calculation must be defined.

Let F *be the set of any partially defined functions* $f : P(V) \to V$ *of finite arity over the power set of* V*, which assigns every set of attributes to an attribute by a definite and calculable operator. If* $f \in F$ *is such an assignment and if* $f(B) = c$ *is true for* $B \subseteq V$ *and* $c \in V$*, then* f *is called* **calculation** *model for the attribute* c *over* B*.*

By means of this definition the product structure (bill of material) attribute of a product component can be defined as a binary relation $\to_{BOM} \subseteq V \times V$, for which $b \to_{BOM} c \Leftrightarrow \exists B \subseteq V : b \in B, BOM(B) = c$ is true. Thus, a directed graph can be derived. The relation $\to_{BOM}$ directly induces the graph's edges and the nodes are the referenced attributes, which represent structures of other components on their part, as well.

4.2 Modeling and Evaluation

Based on techniques from the knowledge engineering the modelling and evaluation is described in this paragraph.

Based on a mathematical model, the new method should perform algorithmized evaluations of the product specification regarding manufacturability. For this purpose an algebraic structure over the set of relevant attributes is required, which allows the algorithmized performance of the method.

Let G *be the set of any calculable logical terms of finite arity over* $B \subseteq V$*. Then* $g \in G$ *is referred to as a condition or predict regarding* B*. The set of all conditions along with the set of calculation models build algebra of terms over a set of attributes. If in a condition g every free attribute is assigned to a value by* τ*, then the condition results in a calculable term, which can be evaluated directly by* $g_\tau : B \to \{0,1\}$*. This logical condition is correct if the term evaluates to 1.*

In order to evaluate the product manufacturability on a particular production resource, it is sufficient to prove the correctness of the conditions over the attribute set of the respective production process. Such conditions are characterized as process assertions as shown in the table below.

Table 1: Process assertions as logical requirements.

Process assertion	Description
Manufacturing sequence is correct	Is the entire manufacturing sequence correct?
Manufacturing method is applicable	Is the manufacturing method applicable?
Flow of material is consistent	Is the process' flow of material consistent?

Due to the complex relations and interdependencies between relevant information regarding the products, resources and processes these emerge between the assertions as well. Using the example of concrete assertions in Table 1 the consistence of flow of material, the applicability of joining method and the compatibility of manufacturing sequence represent the premise for the assertion "Manufacturing sequence is correct". Concerning this form of knowledge representation, the most appropriate logical representation of knowledge is the one given by rules and facts (Gottlob et al., 1990). The rules are characterized by $\text{IF}\, G_{pre}\, \text{Then}\, G_{post}$, whereby the logical premises or preconditions are expressed by G_{pre} and the logical assertions are expressed by G_{post} (Puppe, 1991). Thus, if the premises are correct, then the assertion is correct as well. In turn, the preconditions consist of the correlation of the rules and facts set, which are necessary for the production oriented analysis of a component, are characterized as validation model as shown in the table below.

Table 2: Exemplary rules for production-oriented analysis.

Rule 1	IF	Conditions to Rule 1
	THEN	Manufacturing sequence is compatible
Rule 2	IF	Conditions to Rule 2
	THEN	Manufacturing method is applicable
Rule 3		Conditions to Rule 3
		Flow of material is consistent
Rule Final	IF	Manufacturing sequence is compatible
		Manufacturing method is applicable
		Flow of material is consistent
	THEN	Manufacturing sequence is correct

For the evaluation of such rules the backward chaining inference method is best-suited, since it aims at proving a given assertion. If the proof cannot be executed automatically (e.g. due to some rule which is not included in the knowledge base) this fact must to be queried by the user (Winston, 1993). This feature is particularly appropriate with respect to the integration of external tools (e.g. tolerance analysis), which implement assertion methods of high mathematical effort.

4.3 Identification of Solutions

By use of the presented method for production oriented analysis it can be analyzed, whether the product can be manufactured on a resource. If not, the sections of the production resource are identified in this step, which are not able to manufacture the particular product component, due to technological and process-related restrictions. First, the emerging failure within specification is exactly analyzed. Therefore, the attributes, which caused the failure and the particular components, must be identified.

Let $\rightarrow_f \subseteq V \times V$ be a binary relation over the set of attributes V regarding a calculation model f and $b \rightarrow_f c \Leftrightarrow \exists B \subseteq V : b \in B, f(b) = c$ are true. Then given an attribute $b \in V$ by means of the transitive closure $b \rightarrow_f^+ c$ of $\rightarrow_f$ it is possible to find all attributes c, which are influenced directly or indirectly by a change of b.

A requirement evaluating in a wrong way, indicates to an incorrect specification of a particular component. The corresponding attributes are included in the condition directly or via a calculation model and can be derived by means of the transitive closure $\rightarrow_f^+ \subseteq V \times V$ of $\rightarrow_f \subseteq V \times V$.

Afterwards, all the conditions must be derived, which are influenced by change of altered attributes and thus are not potentially satisfiable. Let $g \in G$ be a defective condition over $B \subseteq A'$ and $V_g \subseteq V$ be the set of attributes, on which g is directly or indirectly dependent. Then the set of conditions G_g depending on attributes, which determine g, can be derived as follows:

$$G_g = g \cup \{h \in G \mid \exists a \in V_g, b \in def(h) : a \rightarrow_f^+ b\} \qquad (1)$$

Thus, affected components with respect to product and resource can be identified, which feature a defective specification. Identifying a solution is carried out by browsing a solution catalogue, which includes alternative resource configurations. After having indentified the defective component by the means of the described approach, action alternatives can be defined manually by appropriate engineers based on their implied knowledge. Afterwards, another iteration loop of production-oriented analysis must be executed in order to ensure technologically manufacturability of the particular component. This iterative process is then executed for each action alternatives. In doing so, multiple iterations can be performed until a proper solution is available. Therewith, possible resource configurations are the result of the proposed method, which ensures the manufacturability of a product component at an existing production system.

4.4 Application Scenario

The following paragraph describes an application scenario of the introduced validation method. The main application is to support the product development process when developing a new car that should be manufactured on an existing production line. In the context of this challenge the validation method can be applied for continuous validation of the product specification thorough the different phases of the product lifecycle.

The core of the framework is the validation method that is executed in the frame of a validation procedure. In case that the validation procedure is positive, the new developed product can be manufactured on the existing production line. In case the result is negative, an engineer needs to change either the product design or the production resources. At this the validation tool suggests the possible action alternatives.

To react accordingly on changing requirements from the production planning, the product specification needs to be validated iteratively through the whole product development process. With the progress of the product development process the product design gets more mature and more information can be regarded for the validation. In the early stages of the development process the materials are specified. Already at this point of the development process the engineer should check if the product materials can be joined using the technology on the production line.

Later in the development process the product geometry, joints, functions are defined. These are the base for further validations (i.e. accessibility checks). At this point the validation can be done either by using internal validation methods or using external ones.

5 CONCLUSIONS

Due to an increasing customer-individualisation and the growing complexity of the production systems the integration of new products on existing production facilities is getting more important. This work presents an integrated method for validation if a product component can be manufactured on a given production line. This is performed by modeling and evaluating the respective product, resource and process informaion based on knowledge engineering techniques. The application of this method in the industry ensures time reduction between introducing a new product to the market and also creates an important improvement of the decision security for all responsible personnel.

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REFERENCES

Weyand, L., Bley, H., Kaiser, J.-M., Meißner, R., Bär, T. 2008. *Production Oriented Design-Check in Car Manufacturing – Not Only a Question of Powerful Validation Tools*. In: *Intelligent Computation in Manufacturing Engineering*, 6th Conference, Neapel.

Pahl G, Beitz W, Feldhusen J, Grote K-H (2007): *Konstruktionslehre Grundlagen erfolgreicher Entwicklung. Methoden und Anwendungen*, Springer Verlag. Berlin Heidelberg New York, 7th Edition.

Müller, M., 2007. *Reifegradbasierte Optimierung von Entwicklungsprozessen – am besonderen Beispiel der produktionsbezogenen Produktabsicherung*. In: Bley H, Weber C (eds.) *Schriftenreihe Produktionstechnik*. Saarland University, Saarland.

Svensson, D., Malmström, J., Pikosz, P., Malmqvist, J.: *A Framework for Modelling and Analysis of Engineering Information Systems*. Proceedings of ASME DETC '99, 1999. Las Vegas, USA.

Burr, H., Müller, M., Vielhaber, M., 2007. *EIMS – A framework for engineering process analysis*. In: *Proceedings of the International Conference on Engineering Design*, ICED '07, Paris.

Winston, P. H., 1993. *Artificial intelligence*, Addison-Wesley Reading. 1st Edition.

Puppe, F., 1991. *Einführung in Expertensysteme*, Springer Verlag. Berlin Heidelberg, 1st Edition.

Gottlob, G., Frühwirt, T., Horn, W., 1990. *Expertensysteme*, Springer Verlag. Wien, 1st Edition.