AN ONTOLOGY-BASED APPROACH TO SUPPORTING DEVELOPMENT AND PRODUCTION OF MICROSYSTEMS

Process-Related Documentation for Process and Application Knowledge Management in Microsystems Technology

Markus Dickerhof[1], Oliver Kusche[1], Daniel Kimmig[1] and Andreas Schmidt[1, 2]
[1]*Forschungszentrum Karlsruhe, Institute for Applied Computer Science Hermann-v.-Helmholtz-Platz 1, D-76344, Germany*

[2]*University of Applied Sciences Karlsruhe, Dept. of Computer Science and Business Information Systems*
Moltkestraße 30, D 76133 Karlsruhe, Germany

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Abstract: Knowledge about relations among process steps or dependencies of materials, technologies, designs, tools, and machines is mostly stored in the product developer's mind. This also happens when it is talked about product-related knowledge and the respective technological requirements. This knowledge is lost, if the person leaves the company. The present paper describes a knowledge management approach for a product-independent description of microsystems processes and outlines a data modelling concept for process-related information.

1 INTRODUCTION

Planning development and production today means to proceed along economic and technical parameters derived from product requirements and customer-oriented business processes. During the last few years, many efforts were taken to push "knowledge management" in industry. The result often represented not more than a new type of document management with additional "meta" information on top to meet the requirements of a company's quality management. Documentation of technological capabilities in microsystems technology (MST) often leads to a non-reusable, product-specific documentation of a production design according to the quality management guidelines. Hence, a lot of information about the subjacent fabrication know-how or relations among application requirements, physical effects, technological constraints, and costs is not documented or documented in an insufficient manner. Insufficient in this context means irretrievable or only customer project-related so that it cannot be reused for new projects in terms of Nonaka and Takeuchi's Seci model (Nonaka and Takeuchi, 1995). Knowledge of the relations among process steps or dependencies of materials, technologies, designs, tools, and machines is mostly stored in the product developer's mind. The same also applies to product requirements and technological capabilities. The knowledge is lost, if the employee leaves the company. A fortiori especially know-how in a key technology like MST transfer is extremely expensive and time-consuming for a company..

The present paper describes an approach to overcoming some of the limitations in present MST product development by providing a specific, holistic modeling approach for microsystems technology.

2 KNOWLEDGE MANAGEMENT FOR MICROSYSTEMS PRODUCTION

The terms "knowledge" and "knowledge management" are frequently used in information technology in many respects. Their scope of use ranges from the mapping of simple structural knowledge to the representation of knowledge by

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means of semantic networks or methods of artificial intelligence.

Application of these approaches certainly is feasible in an enterprise and useful in various fields, where enterprise knowledge is generated. The pre development or fabrication knowledge and in particular on the necessary process know-how in the Microsystems Technology context. As MST is an interdisciplinary field of technology, special attention in the early product development phase has to be paid to influencing factors resulting from application requirements, which have to be related to the constraints of the already existing manufacturing technologies.

2.1 Knowledge and Knowledge Management in the MST Development and Production Phase

The basic idea of the process modeling concept to be presented in this paper is to support product developers in the early production phase, through a decision support while the identification of an appropriate the technological approach that fits best to a given product requirement.

Industrial activities in this field are discussed in white papers and other documents (Bouwstra et al., 2003). Scientific activities like the pretzel model comprise models for the subset of silicon-MST field (Wagener et al., 2002) which unfortunately cannot be transferred easily (Brueck et al., 2007). Other scientific approaches for the sub-group of precision technologies mainly concentrate on a feature-based approach, which primarily focuses on the relations between geometrical primitives and technical capabilities/constraints. They do not consider the relation between technologies and the corresponding application properties that are of relevance in the product development context.

2.2 Technical Aspects and Competences for the Description of MST Knowledge

As microsystems typically are parts, components or subsystems integrated in macrosystems, it is useful to distinguish between parameters that are of relevance to the "macro world" product and production oriented parameters of a technology itself. The former mostly include economic constraints or describe capabilities of a technology, e.g. related to the physical effects to fulfil the task given (e.g. surface roughness as a factor influencing optical properties). The latter allow the user to investigate the technology itself (material, technology, design, equipment, tools, etc.).

- Process parameters describe technical factors that can be achieved in a reliable manner (material parameters, milling tool size, feed, milling velocity, etc…)
- Product properties represent the resulting capabilities, e.g. resulting minimum grooves, surface roughness, which again correlate with application-specific requirements resulting from physical effects often utilized in sensor or actuator applications.

So far there exists no direct description of the relation between process capabilities and application requirement. Information on a descriptive level often is stored in "Design rules" allowing for a basic assessment of relations almost for a very narrow range of tasks.

2.2.1 The ProWiDa Modeling Approach

At Forschungszentrum Karlsruhe, a new modeling approach has been developed to allow for a full description of the key influencing factors in MST. The basic concepts were defined in the ProWiDa approach (Dickerhof et al., 2004). In the ProWiDa terminology, these elements are designated as *technological aspects* for the characterization of *process related parameters.* An analysis of the most influencing production factors led to the definition of five (six) factors of influence for microsystems technology:

- Materials (two: substrates plus layers)
- Procedure
- Geometry
- Machines
- Tools

Material, procedure, and geometry are almost sufficient for a definition of parameter sets that may be compared approximately with the design rules already known from silicon MST. These parameter sets are of relevance to the design engineer or marketing department to identify the feasibility of a customer's request.

Each technological aspect can be refined by a taxonomy. For instance, the procedures on the next lower hierarchy level can be divided into coating methods, subtractive methods, etc. In this case, an is-a relation is used as a basis. This also applies to all the other technological aspects.

A schematic overview of the relations between the technology-oriented aspects and the subsequent technological properties is given in Figure 1.

Hence, the ”technological aspects“ form a number of taxonomy trees or hierarchies. In this context, each parameter in such a tree will be assigned to a node in the hierarchical tree. A technical parameter consists of a designator, an optional (mostly numerical) default value or (partial) interval, and the respective unit.

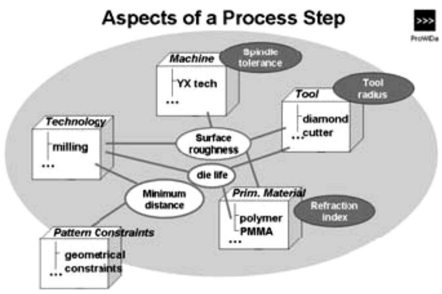

Figure 1: Technology-oriented “aspects” of a process step.

As a rule, a technical parameter refers to either the product to be manufactured (what exactly is manufactured - product-related) or to the production itself (how is it produced - production-related). In the individual hierarchy trees, the technical parameters are inherited along the is-a relations. This means that a technical parameter does not only apply to the concrete node in the hierarchy tree, but also to all of its subnodes. This is in agreement with the classical structural inheritance known from object-oriented programming languages.

In the inheritance hierarchy, the given value (or interval) of a technical parameter and, hence, the underlying unit may change from node to node.

To fulfill the requirement of linking technological aspects with the product requirements not only a single specific aspect becomes of relevance. Furthermore, the combination of all aspects leads to a “real world” view, comparable to what one could define as a companies “know how”.

As the combinations of the major influencing aspects finally describe the company’s technological know how of producing a specific micropart, component or subsystem, the resulting n-tupel is referred to in the ProWiDa methodology as “competence“. Such a competence consists of additional, more product-related parameters for the description of the resulting product properties.

A competence can be also seen as a product independent generalization of the above mentioned product specific “design rules” in MST production today. For instance, the combination of a process, the material to be processed, and the processing machine describes a competence by the product property parameter “surface roughness”.

In analogy to the technological aspects, a competence may be enriched by additional parameters that cannot be derived from the individual hierarchy trees of the technical aspects.

2.2.2 Corresponding Data Model

Due to the high dynamics of the processes, machines, and materials used in MST, static modeling of the technical aspects and parameters in the form of a class hierarchy (technical aspects) with the corresponding attributes (technical parameters) cannot be applied.

Instead, these artefacts have to be modeled on a Meta level. This allows for the dynamic adaptation/extension of these aspects at runtime. Figure 2 shows an excerpt from the underlying metamodel of the application, which models the relationships presented in Figure 1.

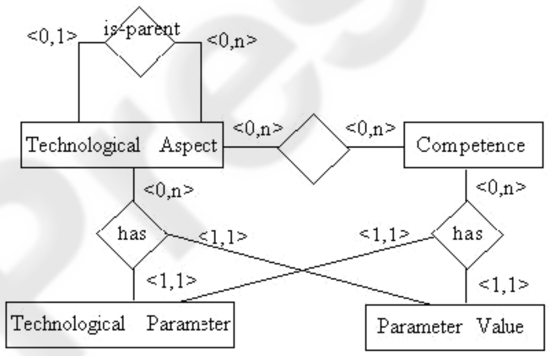

Figure 2: ER model of the ProWiDa metamodel.

Together with the “is-parent” relation, the entity “technical aspects” forms the generalization hierarchies for the technical aspects (procedure, material, …). Consequently, each entity that does not refer to a corresponding parent node is considered to be the root of a taxonomy. Hence, the requirement of flexible taxonomies is fulfilled.

The technical parameters that are related to the technical aspects via the relation “has” allow for an allocation of the production- and product-specific parameters to the technical aspects. According to the semantics of the application, the technical parameters of the technical aspects are inherited to all specializations (child nodes in the taxonomy tree).

Separation between the technical parameter and parameter value allows for the variation of the given default value (or interval) for a technical parameter in the individual taxonomies.

The “competence” entity is related to the technical aspects via an n:m relationship. This means that a “competence” consists of n technical aspects. Vice versa, a technical aspect may occur in n “competences”. However, this n:m relationship is subject to a semantic constraint that cannot be expressed by the ER model: Since the technical aspects on level 1 of the tree form independent taxonomies, a competence may only be related to such technical aspects that do not have a node as a common parent (i.e., that originate from different taxonomies). Thus, it is ensured Together with the “is-parent” relation, the entity “technical aspects” forms the generalization hierarchies for the technical aspects (procedure, material, …). Consequently, each entity that does not refer to a corresponding parent node is considered to be the root of a taxonomy. Hence, the requirement of flexible taxonomies is fulfilled.

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2.3 Knowledge about Relations among and Constraints of Process Steps

State-of-the-art process documentation typically is performed in line with the requirements of a quality management system which usually describes product specific processes on an organizational level. The ProWiDa methodology aims at showing the relations among the process steps in a more transparent and with that transferable manner, which also allows for an improved reusability of the product specific production information. These meta parameters are additional or different properties resulting from the combination of single process steps in a process sequence or process chain.

2.3.1 Modeling of Technological Parameters along the MST Process Chains

The modeling component allows for a simplified modeling of MST processes (sequential and parallel). Three major elements serve to describe a complete production process:

The *process chain* element represents an order/product-specific set of process sequences. It is equivalent to the model of a product or customer-related production process.

The *process sequence* represents a characteristic of a basic technology.

A *technology* is represented by a set of *process steps*. The process step itself is the smallest modeling element (represented by a competence) which represents a subtask that has to be executed when processing a technology.

The complexity of such a process chain directly depends on the complexity of the MST system to be produced. MST parts may consist of a small amount of process sequences, while complex MST subsystems, e.g. a sensor, comprise larger numbers of process sequences, completed by additional sequences for assembly and manufacturing.

2.3.2 Corresponding Data Model

To model the workflow functionality, a simple, but flexible model is selected (figure 3), as described in the section above. The key component is the “activity” that is given by the above specializations of “process chain”, “process sequence”, and “process step”. Any complex hierarchical workflow can be modeled by the two types of relations of “hierarchy_relation” and “flow_relation”. The basic element to generate the workflow, however, must be an activity entity of the type “process step” that is related to a “competence”. Consequently, the “competences” defined above are the basic elements of the workflow. In analogy to the “technological aspects”, adding of additional “technological parameters” is possible.

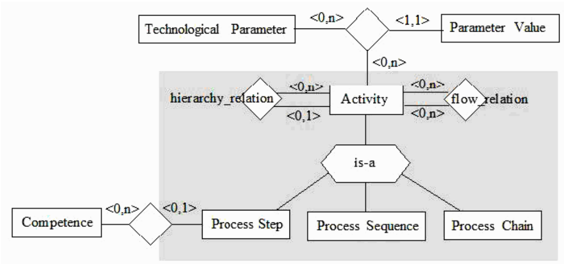

Figure 3: Workflow model.

Remark: The focus of this first stage modeling approach has been set on the ability to identifiy process-step overlapping relations. This primary goal was achieved through a reduction of modeling options. For an enhanced modeling of process chains, modeling methods with a strong focus on economic aspects like Petri nets, workflow modeling or event-driven process chains may be more adequate and will be considered in future versions of ProWiDa.

3 SUMMARY AND OUTLOOK

The paper basically describes a knowledge management approach for MST production technologies. It allows for a product-independent definition, storage, and retrieval of design rules, business rules, and process parameters for the development of microsystems products according to the customers' needs. The approach is based on a generic database concept for the flexible combination of parameter sets attached to product- and fabrication-relevant aspects. First prototype interfaces to enterprise information systems and components for the analysis of data collected in this specific manner have been implemented or are under development. They will allow for the import of measuring data from production and, hence, for a continuous optimization of business rules/design rules based on "real-world" process data. A first prototype of a process chain analyzer for identifying the most appropriate solution path related to a specific task given has been developed and shall be improved in the next years.

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