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DEFINING AN ADAPTIVE PRODUCT DEVELOPMENT METHODOLOGY

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1. Introduction

In the last decades various theoretical models of the engineering design process have been proposed, such as by Cross, Hubka and Eder, Pahl and Beitz [Pahl/Beitz 1996], Ullman and VDI 2221. These prescriptive models typically give a systematic sequence of stages or activities, and recommend certain methods for specific steps in the design process [Blessing 1996]. This combination of a systematic approach and methods is expected to improve product development. Unfortunately prescriptive models tend not to be based on extensive descriptive studies. Most of these models draw on the experience and perception of their authors, and represent typically the implicit intent to provide prescriptions of models applicable to any kind of industry, developing any type of product although it is obvious that product development differs distinctly due to the changing context. “In fact, the same enterprise may follow different processes for each of several different types of development projects.”[Ulrich et al. 2003] The result is that, in spite of their good intentions, these models from the literature are rarely appropriated to be used as the basis for practical product development.
Due to a number of development context factors, for example the company structure, the market size, the composition of the development team and pressures on lead time, different activities are carried out and different methods and tools have to be applied. Furthermore the choosen methods and tools have to be adapted to the context to go with the project specific environment
The concern of the approach described in this paper will be to establish the most appropriate development practices to adopt in specific circumstances. Key influence factors that define the nature of engineering design and product development processes have to be captured and their relationship to the various elements of engineering design and product development practice must be ascertained.

2. Design and Product Development Methodologies

2.1 Engineering Design Models

Design models are basically derived from the conventional ways of perceiving and solving engineering design problems. The models commonly include the assumptions that design should proceed from the general and abstract to the particular and concrete and that complex problems should be broken down into sub-problems. In general, three main stages can be distinguished [Blessing 1996]: a problem definition stage, a conceptual design stage and a detail design stage resulting in a full product description. This structure of engineering design models has met with criticism. One is that they have been developed with the focus on new, innovative products and therefore the conceptual design phase is oversized in relation to the following phases. The provided methodical assistance seems to be too complicated, theoretical, time consuming and inflexible. Further points of criticism are the missing empiric basis and the not supported division of labor.

2.2 Product Development Models

The changing context of product development demanded adaptations of product development practice. In the past, the increasing complexity of products led to the separation of planning tasks and executive tasks and as a result to the emergence of company sections and departments. Products were developed in sequential steps by taking intermediate results from one department to the next. In the 1980s increasingly competitive markets demanded higher quality and higher performance products, in shorter development cycle times, and at lower cost. To respond to these pressures and to eliminate the disadvantages of the sequential strategies approaches such as concurrent engineering (or "simultaneous engineering") were developed. The development team, consisting of representatives from the participating areas, is in the centre of product development. The activities of development and introduction of a product to the market have to overlap.

Today in practice organisational, controlling and informational activities have meanwhile come to outweigh actual design work [Badke-Schaub, ,Frankenberger 2004]. The increasing variety of the activities of the designers led to the term "product development". This term has more of a business approach than "engineering design", as it also incorporates things like market studies and issues like knowledge management, collaboration and others [Marxt 2004].

Integrated Product Development (IPD) arose from the idea that product development cannot be carried out in the best possible way if it is segmented into different areas of specialisation, areas of activity, or areas of responsibility [Andreasen, Hein 2000]. Therefore IPD combines topics like company structure, simultaneous/concurrent engineering, teamwork, manufacturing and product life cycle. The core ideas are to determine simultaneously the product properties and the production process, to bring together experts from all departments, and to aim for a holistic optimisation of the product.

3. Influences on Product Development

Designers are influenced by the society in which they live and their decisions depend on political, social and financial pressures. The technological environment and the accelerating rate of change is a characteristic of modern times. Changing conditions produce new needs and thereby encourage new developments, innovation is rewarded and new artefacts are created. Some products require design activity on a far larger scale than others.

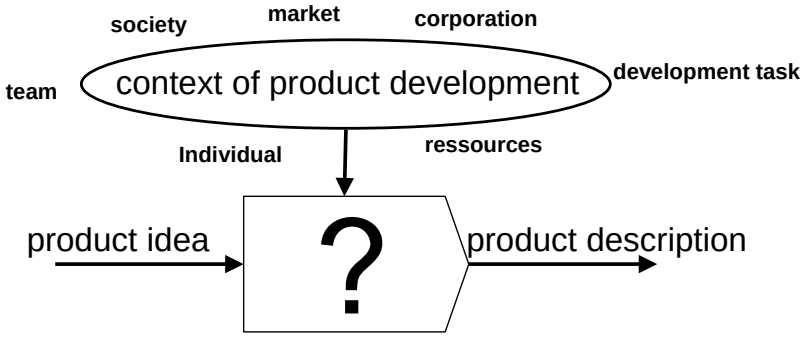

Figure 1. The context of product development

Huge one-off products such as power plants or oil platforms require an immense and skilfully organised design operation. Less complex products as hand tools or toys can be designed by a single person. These different design tasks generate contrasting design situations within which designers operate. The designer could be working in a small company, carrying a variety of responsibilities including the marketing, design and manufacturing of the product. Or he is working in a larger company were many people work on a single design project with specified areas of activity and a hierarchy of responsibilities.

To what extent product development processes have to distinguish depending on the context, seems obvious. The determining context factors that influence the organisation of product design processes

authoritatively must be found. Whithin a preliminary study the authors questioned executives from eleven german companies, which are involved in product development, about most influencing context factors to serve as basis for adapting the product development process (Figure 2). Characteristics of the design task seem to be the key factors as represented by the proposals from the literature, which are introduced in the following section.

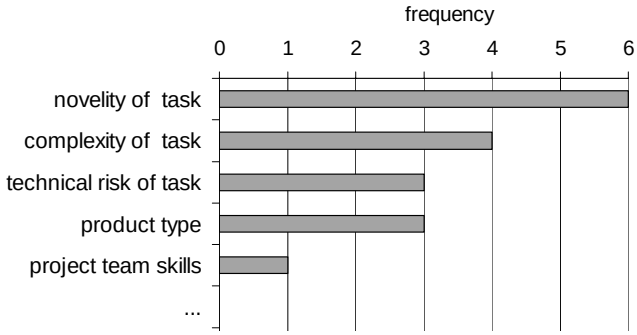

Figure 2. Context factors influencing the development process

3.1 Classification of Design Tasks

Pahl and Beitz [Pahl/Beitz 1996] list up task characteristics and give hints about their influence on the design process (Table 1).

Table 1. Characteristics of design tasks [Pahl/Beitz 1996]

Origin	Organisation	Novelty	Production	Branch	Complexity	Goals
Product planning, customer, design task, field test	product-, problem-, design phase-oriented	original, adaptive, variant design	one-off/small batch, large batch/mass production	mechanical, electro-mechanical, chemical, etc.	plant, machines, assemblies and parts, sizes	Optimisation of function, minimisation of cost, etc.

Müller [Müller 1990] uses personality characteristics and problem characteristics as a base to identify six problem types (Figure 3).

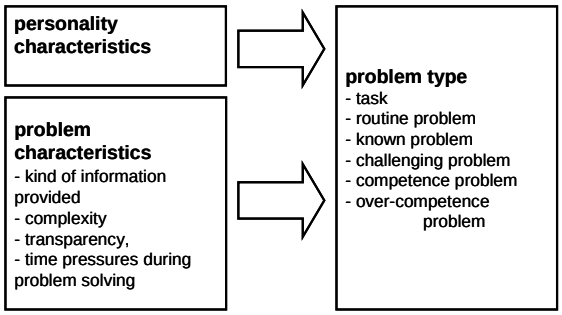

Figure 3. Determination of problem type [Müller 1990]

For each problem type he describes the problem situation, challenges and possible support for problem solving.

Schroda [Schroda 2000] constructed a questionnaire system to support the planning of design processes. This is done by categorising the design problem and by the assessment of its demands. The system is based on five criteria that influence the difficulty experienced by designers when solving the

problem: Complexity, Transparency, Degrees of Freedom, Dynamic, Necessary Knowledge. Two or three questions measure each aspect.
Ulrich and Eppinger [Ulrich, Eppinger 2003] remark that the definition of a generic development process described in their book is most like the process in a "market-pull" situation when a market opportunity causes the development of new products. Variants of the development process depend in their opinion on different kinds of products to be developed and correspond to technology-push products, platform products, process-intensive products, customised products, high-risk products, quick-build products and complex systems. They provide short descriptions of the resulting process types and list up distinct features and examples.

3.2 Consideration of the Entire Development Context

The following approaches represent a broader view on the context of product development. Nevertheless the number of considered factors is limited, due to the complexity of the development context it would be too time-consuming for the practical application to generate a complete picture of the context landscape.
Hales and Gooch [Hales, Gooch 2004] state that "the successful management of engineering design projects requires an understanding of the context within which the project takes place". To provide a framework for mapping the context Hales defines five levels of resolution: Macroeconomic, Microeconomic, Corporate, Project, Personnel. He proposes a "Design Context Checklist" together with an associated "Design Context Worksheet" to identify key influences on design projects.
Maffin et al. [Maffin et al. 1995] define a contextual typology for the classification of companies, their strategic policies and key project variables. The company's characteristics are classified regarding the dimensions "company structure" (ownership, autonomy etc), "market environment" (market type, complexity, size and share etc), "process" (complexity, flexibility, production volume etc), "product" (type, variety, status etc), "supplier environment" (collaboration, degree of control etc) and the "local environment" (local labour market, skills, training etc). The strategic policies are distinguished in reference to the "business focus", "critical success factors" and the "product development strategy". The consideration of project variables covers the "project type", the "project innovation" and "key suppliers".

3.3 Approaches towards an Adaptation of Process Models

Skalak et al. [Skalak et al. 1997] propose a concurrent engineering methodology that is based on three design types: original, evolutionary, and incremental. Using assessment criteria, the proposed design methodology can be tailored to fit a project. Their model was based on the models of Pahl and Beitz [Pahl/Beitz 1996] and the VDI Guideline and expanded to represent the entire development process. Since not every product needs to go through the entire process they developed three major design models for original design, evolutionary design and incremental design.
Ponn and Lindemann [Ponn, Lindemann 2005] use process modules which base on the process modelling technique SADT (Structured Analysis and Design Technique) to adapt the process to characteristics of design situations. They propose to generate an adapted process by recombining predefined process modules which are derived from the munich procedural model.

3.4 Selection and Adaptation of Methods

A further important aspect regarding the adaptation of product development methodologies is the selection and adaptation of methods and tools to support the development process. There exist a large number of approaches with to enable a task specific or situation specific selection of methods. For instance Sales de Araujo [Sales de Araujo 2001] provides a general descriptive model to explain the acquisition of development method and tools in practice.
There are also some approaches about the adaptation of methods. One example is the work of Zanker [Zanker 1999] He splits methods up into basic parts and allocates these parts to elementary tasks. These works mention the influence of the product development context, but a methodical approach for using the context information for an adaptation of methods is missing.

3.5 Conclusion: The Need for an Empiric Basis

The introduced approaches propose different sets of context factors to consider influences on product development. Because sets differ distinctly it is not possible to integrate them within a clear defined consensus model. The definitions and choice of context factors base on the experience and perception of their authors as well as on literature, but not on extensive empirical research. To find the key factors for adapting processes and their methodical support, an empirical basis is needed.
The authors [Meißner et al. 2005] used a questionnaire for a preliminary empiric investigation regarding the correlation between the context profiles of product development projects and the choice of methods and tools. By conducting a cluster analysis the 173 respones from different companies could be divided up into three cluster, depending on context factors. For instance it could be shown that companies with few product developers which develop products with a short life time more frequently use the method benchmarking. A statistical proof that the specific choice of methods within a cluster resulted in success could not be conducted. A continuative investigation is currently prepared.

4. Defining an Adaptive Product Development Methodology

The consideration of a large number of context factors for the improvement of product development requires a flexible adaptation of product development processes and their methodical support. The proposed approach should facilitate the transformation of context information into actions for adaptation.

4.1 Requirements for an Adaptive Product Development Methodology

Besides requirements regarding the adaptability, basic requirements have to be met regarding the effectiveness, efficiency, learnability, traceability, practicability and flexibility of the development process and the included procedures, methods and tools. Compared to adaptability flexibility means the ability to react to new situations without increasing the product development effort.
When the context is used for the adaptation the context factors must be differentiated in terms of their weight and of their dynamics. Long-term constant factors which do not change for month or years need not to be considered as often as short-term factors changing within days.
An individualisation of the methodology on an operative level to optimise the methodical support demands for more concrete product development models appropriate to a specific context. If they are built from top down according to the company organisation, the approach is less complex and the management is involved at an early stage [Mendes et al. 2003]. A quite small number of methodology modelers can be specially trained for their job and for supporting tools.
The problem is that it will be difficult to match the daily reality of the company's development practice to this generally abstract model. A flexible, short-term reaction on a changing development context will hardly be possible. An alternative is to let all people involved in product development work decentrally on the adaptation. If the model is built bottom up, local practitioners can be involved in the construction and will bring credibility to the model. The information contained will be up-to-date; the effort for adapting the methodology is limited, because it is shared by many individuals. The problem here is that the model is created from local perceptions and it will be difficult to establish a holistic view of the process. Interfaces between departments can not be considered sufficiently. A middle course must be found including the top down and the bottom up view of the development process.

4.2 A Modular Approach

A modular approach seems to be an adequate solution to fulfil the requirements discussed above. The modularisation of the methodology can be defined as a decomposition of the development process into modules with specified interfaces, driven by company specific reasons. The main objective of the modularisatin is not to built up new processes by recombining modules like building blocks, but to subdivide the process of adaptation. For a reasonable partition of the methodology the modules should be derived from combinations of sub-tasks of the development process. The module set should

represent the whole range of possible product development tasks. Through the context-related adaptation only the necessary modules are selected. The modular architecture is used for the following reasons:

- By considering parts of the process the complexity to be handled gets less and local practitioners can be involved to reach a detailed degree of adaptation and a fast reaction on new situations. By elaborated module interfaces assigned local teams can individualise their part of the development process with a high degree of autonomy.
- An essential condition for the improvement of the product development process is the creation of transparency. By using modules which are embedded in a generic process framework the detailed view on the process can be assigned to the local practitioners while the holistic view is provided by the generic framework.
- With integrated methods for evaluation and improvement modules can be carried out and improved separately from other parts of the process.
- The modular architecture facilitates changes to processes once introduced. Due to the partitioning of the development process and the consideration of sub processes a reduction of integration and complexity is possible.
- The modular architecture supports by defined information interfaces a concurrent planning of development projects.
- The definition of module boundaries and of the information interfaces facilitates outsourcing.
- If a process framework serves as platform the methodology can be adapted based on a stable architecture.
- If particular context constellations occur repeatedly, adapted modules may be saved and reused.

An illustration of the methodology-module is presented in Figure 4. Modules represent sub- processes with several inputs and outputs. In Figure 4 the input and output information is summarised to the incoming sub-problem and the outgoing description of the sub-solution. Besides the regular input information disturbances as suddenly changing context factors have to be considered, e.g. changed requirements or ill team members The sub process within a module fulfils a certain function. The sub-procedure is supported by acquired methods and tools and guides the practitioner through the process. Each module should contain a guideline to explain the module and the application of contained methods. For the application of a module, besides the input information further preconditions (available human and financial resources, skills, tools etc) have to be fulfilled.

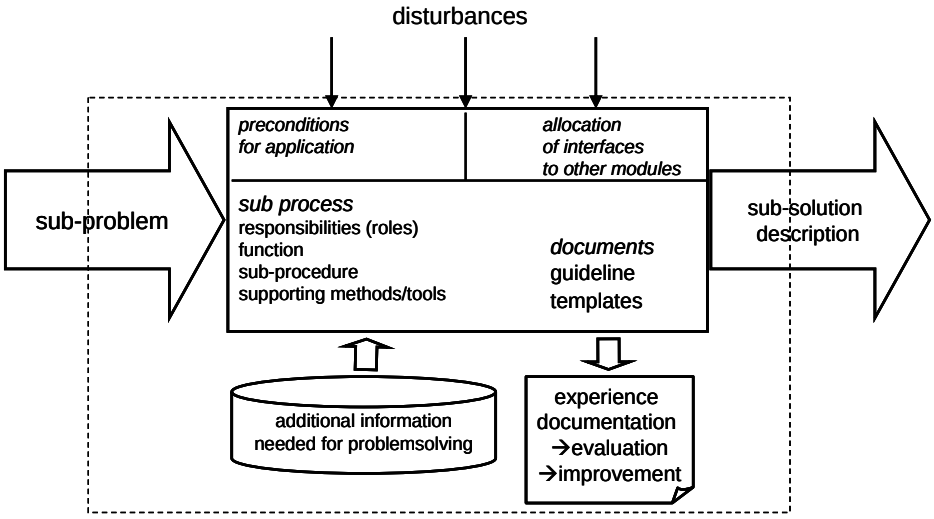

Figure 4. Definition of a methodology module

The allocation of interfaces to other modules help to integrate the module into the development process network. As integrated part the documentation of experiences and the evaluation of the sub-process enable the continuous improvement of the self-contained module.

Several requirements for the module boundaries have to be considered:

- A limitation for the modularisation of the development process is the volume and complexity of module interfaces. On the one hand, the number of interactions between modules will fall with a growing number of modules and therefore module interfaces will become less complex. On the other hand the total number of interactions within the development process will rise if the number of modules gets too high.
- To allow for autonomy for modelling the contained sub-process a module should consist of reasonable combined activities and not divide up strongly interrelated tasks.
- For a distinct latitude in configuration by local practitioners clear and firm interfaces should be predefined.
- Modules could be mapped by a Gantt chart. To support concurrent engineering their beginning and end times should overlap. If there are preassigned steps, phases or milestones defined by a reference process framework, the module boundaries should be in line with them.
- For the adaptation of the methodology, the modules may be allocated to local teams. Hence the working areas of these teams affect the module boundaries.
- If the company applies outsourcing of development tasks, the combination of outsourced activities within one module could be reasonable.

Table 2 contains an exemplary proposal for a set of modules for the development of complex mass-products. The modules were derived from literature and from process descriptions and project documentations of three German manufacturers. When a new project is planned, modules are chosen, linked and adapted in detail. Some Modules (as the Modules "Milestone", "Design Review and Verification") may be repeated during the project.

Table 2. Example for a Set of Modules

Modules	
Identify Needs	Evaluate Concepts
Find Product Ideas	Define Engineering Specs
Elaborate Product Ideas	Detail Design
Project Proposal	Prototyping
Process Design	Manufacturing Validation/Preparation
Process Adaptation	Production Validation/Preparation
Milestone	Pilot Production
Project Planning (plan task)	Production
Define Product Specification	Beta Testing
Define Product Architecture and Assign Sub-Teams	Field Trials
Generate Concepts	Product Review
Virtual / Physical Modelling	Design Review and Verification

4.3 The Process of Adaptation

Maffin et al. [Maffin et al. 1995] observed that many context factors within the company structure, the local environment or the supplier dimension can be considered as being relatively constant. For a high efficiency of the adaptation process only changed context factors should be considered for a new adaptation. Context factors that will not change within some years may be involved in planning of product development on the strategic level. Context factors which do not change within the duration of a development project may be considered while planning a project. The most dynamic part of the

context, i.e. factors which change within days or hours, may be included in project planning if future changes can be predicted. Otherwise a flexible adaptation of the product development process is necessary. Hence three categories of context factors are proposed for the adaptation:

- Long-term factors are the basis for a generic model of the product development process which is adapted from top down and serves as stable architecture for the methodology and as basis for product development strategies.
- Medium-term factors including project-context factors serve for the adaptation of the methodology while planning the project.
- Short-term factors which occur during the project and can not be predicted (for example if product requirements are changed or team members fall ill) initiate suddenly necessary adaptations.

Corresponding to this classification of context factors the adaptation of the product development process should be carried out on three levels (Figure 5). The three clusters of context factors (long-term, medium-term, short-term) determine the adaptation.

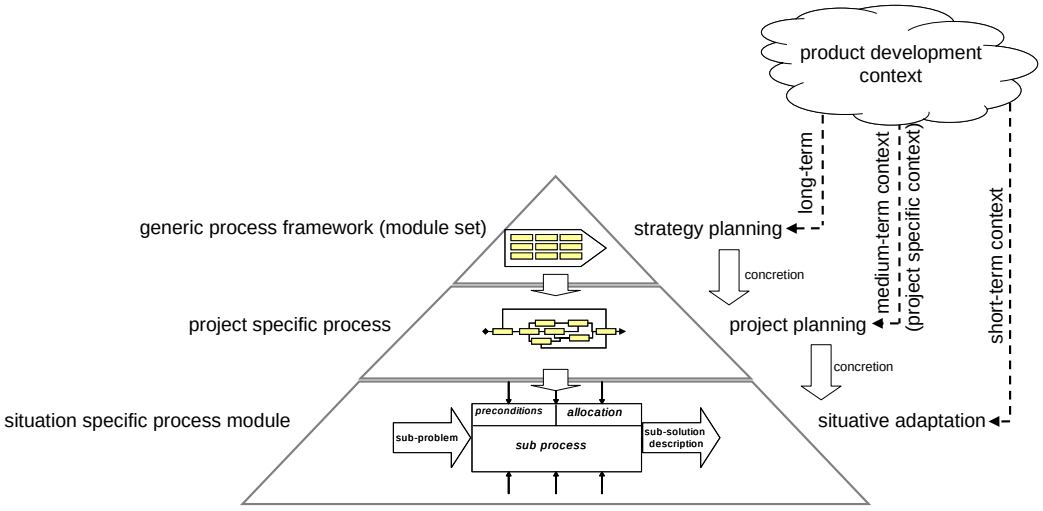

Figure 5. The process of adaptation

On account of the potential complexity of product development, the more abstract company process framework provides a holistic view on product development and serves as basis for the more concrete project-related adaptation. The long-term context should be used for this first step of adaption to allow for long-term strategic planning. This framework may be used for defining milestones and to support the management while planning and controlling development projects.

This process framework contains all company-specific modules which are available for the project-specific adaptation. After this company-specific adaptation on the first level the methodology is adapted to the medium-term context on the second level, including the project-context and characteristics of the design task.

Modules are chosen and then adapted in detail. On the second level (project planning) local practitioners should be involved to enable them to bring in their experience. The selection of modules can be made by a checklist which determines the necessary activities. For the detailed adaptation, i.e. the selection and adaptation of methods and tools, methods will be needed as described in section 4.2. On the third level (situative adaptation) the methodology is adapted to situations while working on the project. The iteration symbol indicates re-occurring situations which may possibly demand an adaptation.

5. Conclusions

The accelerating appearance of new technologies and the related change and increase of customer demands create a faster moving context of product development. The importance of context factors for the adaptation and improvement of product development respectively has been shown by several contributions in literature. An empiric basis for implementing context factors into the adaptation of processes and supporting methods is missing.

The proposed approach towards an adaptive methodology allows a more dynamic and more detailed adaptation to the development context. By assigning local teams to adapt as practitioners their part of the methodology helps to match the daily reality of practice. To allow this break down of the product development methodology it is decomposed into modules. To apply the proposed approach in practice reasonable suggestions for the adaptation relating to specific context factors have to be generated. This will be done by empiric research during the next months.

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