5TH INTEGRATED PRODUCT DEVELOPMENT WORKSHOP
IPD 2004 SCHÖNEBECK/BAD SALZELMEN b. MAGDEBURG
SEPTEMBER 23-24, 2004

ADAPTIVE SYSTEM MANAGEMENT

Thomas Naumann, Sándor Vajna

Keywords: System Theory, Product Development Processes, Sensitivity Analysis

1 Introduction

New approaches start mostly with the formulation of global objectives for the development of products, i.e. the reduction of development time and costs while improving the quality simultaneously. More precisely, these objectives are coming from industry in order to fulfil "customer needs". Linked to the formulation of these common objectives is primarily the assumption that they can be attained in general. Secondly, there is the request to science to provide approaches and solutions to these objectives.

This paper describes a new approach for planning and managing of the procedures in product development. Thereby, it is assumed that planning and managing can contribute to support and to optimise the product life cycle, e.g. by monitoring the search, identification, and realisation of solutions, and by dealing with conflicts of objectives. To introduce the problem, observations, usual models, methods, and supporting tools are briefly discussed. Beforehand, a differentiation is necessary.

The solution approach described here builds on the criticism of the discussed phenomena, models, methods, procedure models, and supporting tools. It shows how to create a new approach for planning and managing product development processes by considering new results from complexity research, psychology, and system theory. With this, a metamodel has been developed on which effect structures and control loops between action system and object system as well as processes can be projected. Further-more, it is described how the metamodel serves as a communication base and a knowledge base of the mediation process of product development, and how this can be included into a procedure model for planning and managing.

2 Differentiation

This paper focuses on product development as a part of the whole product life cycle. In product development, the characteristics of the product are defined and thus the later properties of the product are synthesised. Product development includes manufacturing preparation and it ends with the release to production.

The first hypothesis here is that product development processes are of chaotic and volatile character. This character can be seen on the level of an individual design process. It can not be completely depicted or reproduced, thus can be planned only in a limited way. Other hypotheses concern the management of processes, products, and organisations structures, which all include related hierarchical structures. However, they are managed separately. By their integration into one single system, a better understanding of the effect structures and the control loops could be possible, and new approaches and methods for a better support of product development processes could be realised. The human being with all his knowledge and his cognitive abilities should be the centre of such a system. The integration into a procedure model for planning and managing of product development processes will lead to more flexible processes and with it directly to better products.

3 Problem and Criticism

New products emerges by innovation needs, e.g. market requirements or customer demands. The creative human being synthesises the immaterial to material objects. Thereby creativity is an abstract characteristic of his cognitive abilities. Objects (products, the "what?") and action systems (the "who?") are structured in hierarchies and are related to each other. Also the processes (the "how?") are hierarchically described. Today's methods and procedures are not sufficient for the support of the complexity of product development. E.g. cognitive and social cultural influences remain unconsidered. Classical planning approaches (project and process management) increase the understanding of procedures and aims primarily at the mapping and the reduction of development time. However, certain development aspects are left out, because development structures are regarded as causal and deterministic. The elementary operational sequences of concept making and sketching (that are intuitive and chaotic) generally cannot be depicted.

4 Adaptive System Management

4.1 Requirements for a New Approach

From the previous critics and personal experiences of the authors the requirements for a new approach can be derived. For a suitable order the integrated approach of Integrated Product Development (IPD) (Burchardt 2001) is adopted. In the IPD, human beings, organisation, methods, and technology are regarded in an integrative way. The human being as a creative problem solver is the centre of product development. Organisation, methods, and technology complete this approach holistically. Therefore the requirements for a new approach can be clustered in the following manner:

Human beings

- Support of the management of (increasing) product and process complexity
- Consideration of the results of cognitive sciences, e.g. the description of opportunistic and creative/chaotic actions, the tendencies of planning, the handling of complexity, the (interim) storage of target characteristics and interim results, design techniques (sketching, modelling)
- Reduction of the uncertainty when passing through the solution space
- Supply of instruments for moderation and communication for the discussion and co-ordination of developed solutions
- Decision making aid for the planning of products and processes

Organisation

- Support of networks, e.g. supply chains, companies, or teams

Methods

- Provision of an adaptive planning where any planning level can be adapted to the respective execution level in a fast and flexible way
- Support of decentralised planning and management of product development processes so that all participants can integrate their own views and knowledge
- Consideration of an appropriate relationship of planning expenditure and benefits. Tasks of lower complexity must not planned.

Technology

- Integration into existing heterogeneous system environments (e.g. PLM, CAx as well as systems for process management and project management)
- Integration into an integrated data model that consists of all information of the product and its relevant processes

4.2 Description of the New Approach

The new approach describes in a systemic view the procedures of planning and realising within product development as a system. The systemic view is the basis for analysis and registration of all key factors of the system that are relevant to product and process. It is aimed to analyse and to register also qualitative key factors besides quantitative key factors. Especially it should be possible to mark the non-structured and intuitive episodes within product development in an indirect way. Their influences on the objectives of the product development (fulfilment of functions, reducing costs and time, increasing quality) should be evaluated as well.

Within the new approach, the procedures of planning and realising are the smallest elements of a process net, which describe ahead a new status of the complex and hierarchical product development system or realise a system change respectively.

The product development system is depicted by a metamodel that is made of several hierarchical sub-systems. These are, at the top, the superordinated natural, market, and social systems, at the bottom, the action system, the object system, and the processes with their respective hierarchical structures. All sub-systems are, according to System Theory, described by 20 to 30 key factors (Haken 1995). These key factors may be related to each other and may form so-called effect structures. An effect structure is created when a key factor has an influence on another key factor in a positive or negative way. A simple example is the influence of motivation onto the fulfilment of requirements. The higher the motivation is the better the requirements are fulfilled. But even at this simple example it could be criticised that the fulfilment of requirements is affected by other key factors also, especially by the applied knowledge, which leads to other influences and possible relations. Following this, an increasing imagination about the complex relations within the product development system comes into existence. Finally the systemic mapping of product development and the handling of the effect structures should be applied for communication as well for planning and managing.

Usually, planning and realising are individual thinking processes, which are ambitious and exhausting. Within these processes, primarily contradictory requirements for the product or for the process are recognised and solved. This procedure is strongly related to the cognitive abilities of a human being. It takes place in an interrelation between intuitive/unconscious and structure/methodical episodes (Hacker 1999). Even though the intuitive/unconscious episodes are only conditionally foreseeable due to their non-linear/chaotic character, they can be communicated! So the product development process can be understood particularly as a communication process for the solution of conflicting objectives.

Therefore the new approach primarily shows how to use the system model as a support for argumentation and decision-making. Secondly, a procedure model for planning and managing product development processes is laid out, in which project, process, and product data management as well as the system model of the product development are combined to an Adaptive System Management. By using the simulation of effect structures and the analysis and evaluation of control loops, an adaptive feedback planning and managing emerges within.

4.3 Description of the Metamodel

For the description of the metamodel a method was selected that can reduce complexity by applying cybernetic laws. The method follows three principles for the analysis of key factors, for the definition of the mutual influences between the key factors, and for the definition of effect structures. At first, the key factors of the system are described using the approaches of System Theory, where every system can be described with 20 to 30 key factors (Haken 1995, Vester 1999). Such a selection reduces the complexity of the product development to a manageable description.

During the construction of each hierarchical system model the description of the individual subsystems is decisive for the proximity to reality. The transitions between the subsystems are not arbitrary, but correspond to certain orders of magnitude e.g. product developer, team, company, company network within action systems. Thereby an interlaced system comes into existence, a fractal with particular structures.

The product development metamodel considers this structural integrity within the individual subsystems action, object, and process system. All subsystems are combined in a hybrid model. "Hybrid" means that there are no linear-deterministic relations between the different subsystems on a specific hierarchical level. The relations are manifold and have to be considered across several hierarchical levels. As an example, a product developer is responsible for the fulfilment of ergonomics and design as well as for the fulfilment of functions. While laying out the physical and geometric parameters (smallest elements of the product structure) the required properties of the product are synthesised. But in the process chain from manufacturing to the customer the cost of the product or its success on the market are massively influenced by the same decisions, too.

The product developer as a part of the action system and the individual design process as a part of the process network are situated on the lowest level of the metamodel of the product development system. Here, the analysis and the synthesis of product properties by of deciding on their respective characteristics takes place. Above this lowest level of individual design processes a level of overlapping design procedures in teams is situated, in which design methodologies and procedure models, just like VDI2221 can be found. On this level and at the next level above, activities related to projects were handled, which consider requirements to communication, market, customer, and manufacturing. On the level of companies and company networks (the next level above), the creation of products forms value adding sequences, which require continuous management activities (Andreasen 2002). All in all, four subsequent levels are described in relation to the company's process organisation structure, figure 1. Al-together, they have self-similar structures. But they are not reversible because their individual key factors are not reversible. Therefore, being a hierarchical product creation system, it fulfils the irreversibility as its main characteristic.

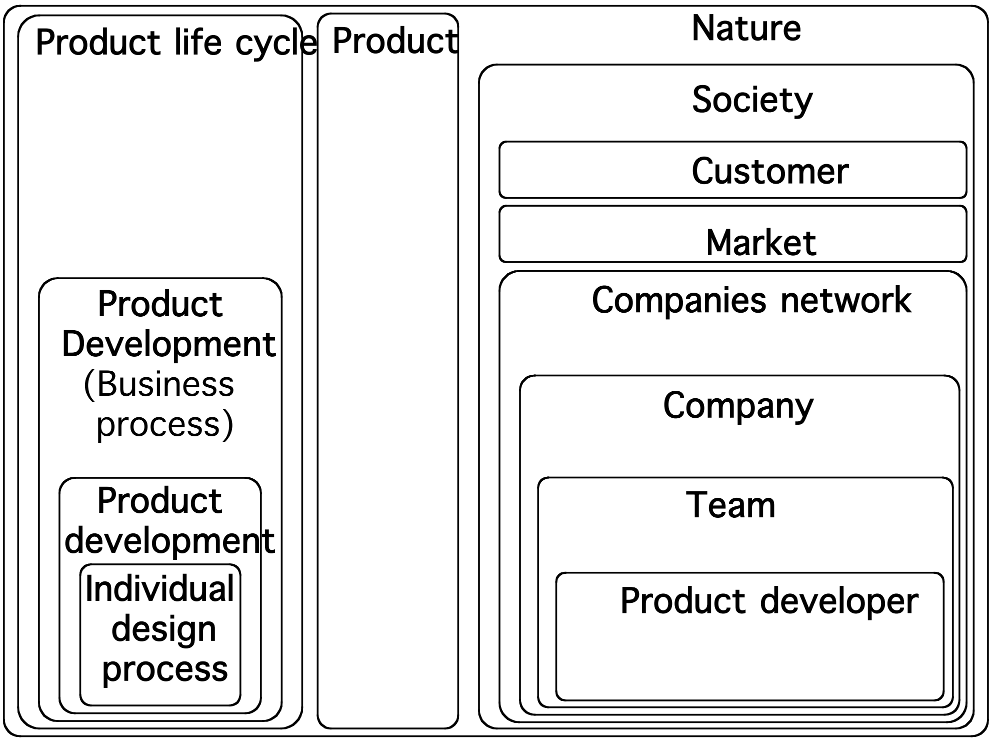

Figure 1. Metamodel of Adaptive System Management

However, with the consideration of the product creation process and the four levels of a company's process organisation, the metamodel would be incomplete and it would not make it possible to fulfil all requirements for the new approach discussed here. It will become really holistic by the view on the whole product life cycle and the integration of markets, customers, society, and nature. Each subsystem is described with about 25 key factors. The determination of the key factors results from the models of Hales (1987), Negele (2001), Frankenberger (1997) and Schroda (2000).

4.4 Effect Structures and Control Loops

After the description of the metamodel of the product development system with all its subsystems and key factors, they now can be networked together into effect structures. Only with this step a holistic picture of the complex system emerges, and statements can be made about the performance of the system. Figure 3 shows, as an example, an effect structure of the product development system.

Between the key factors aligned relations are depicted and their influences are visualised. As an example, the increase of the key factor competence/knowledge would lead to an increase of the key factor quality of solution search (+).

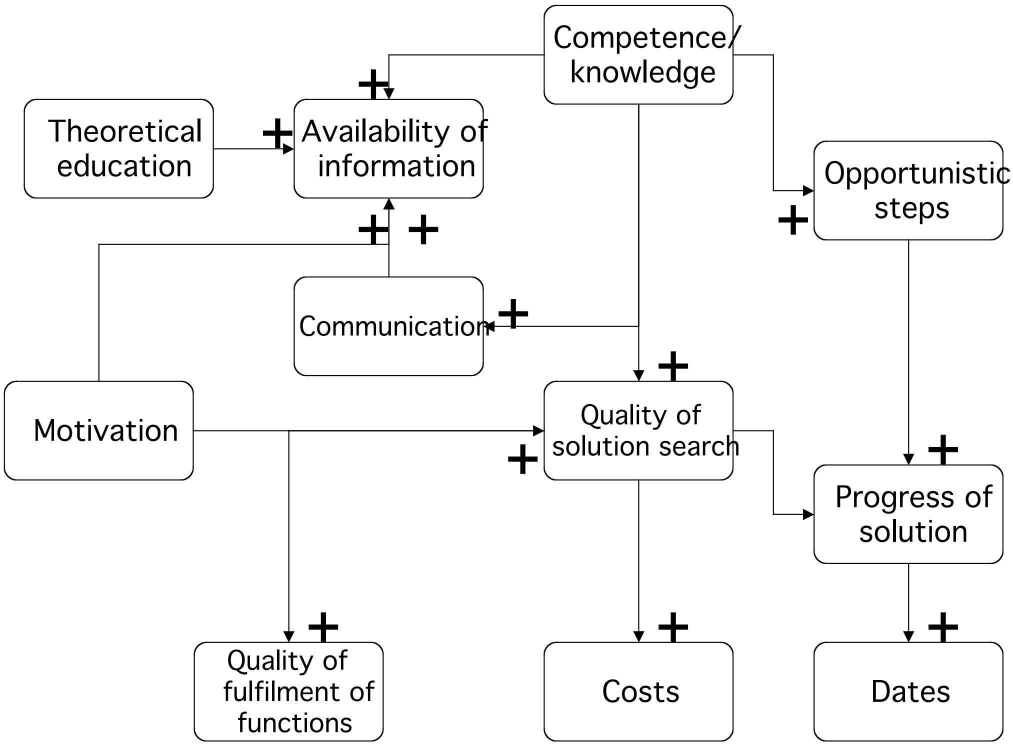

Figure 2. Effect structure of the product development system

However, within a complex product development system the quantity of effect structures rises above our abilities for analysing complex coherences. In particular, agglomerated procedures in the form of control loops show the requirements for new ways of thinking and new support forms.

4.5 Description of the Procedure Model of Adaptive System Management

With the mapping of the complex product development system the Adaptive System Management serves above all for the communication of all partners within the product life cycles, e.g. at the moderation of processes or the mediation (problem solution) of decisions. Its system environment constantly affects the product development system. These external disturbances, e.g. by new requirements of a customer, shift the entire system into an imbalance and activate change mechanisms that have effects across the hierarchies of the system. The courses within product development can therefore be understood as counterbalancing imbalanced conditions between the different subsystems.

A further substantial benefit results from the integration into planning and managing of product development processes. Depending upon time horizons, planning can be differentiated into strategic, tactical, and operational planning. For long-term strategic and tactical planning, methods like the scenario management and sensitivity analysis (Gausemeier 2000, Vester 1999) can be applied. For operational planning, a procedural model is suggested, in which the methods of conventional planning as well as project and process management are completed by the evaluation of effect structures and control loops.

When a planning problem arises, the key factors and parameters of the system model are analysed and networked into effect structures. Here the requirement is to connect also qualitative and quantitative key factors and parameters with each other, e.g. competence/knowledge and quality of fulfilment of functions. For the support of structured/methodical episodes within the development process, the work packages of a project can be extended in each case with certain key factors of the system model. As an example, the key factor competence/knowledge can be also assigned to a resource.

The mapping of the intuitive/opportunistic episodes cannot be done in reference to respective work-packages, because, as it was shown, they cannot be represented in that way. But they can be taken indirectly from the condition of the system. For example, the highly classified key factor for opportunistic steps expresses that within the process a less structured proceeding is necessary.

5 Conclusion

In this contribution, a new approach of an adaptive system management was described. The metamodel of the adaptive system management was developed as an abstract, phenomenal system model that connects the hierarchies of action system and object system as well as a process in a hybrid way.

A new basis for moderation and mediation of product development processes was created with the definition of key factors and the possibility of mapping effect structures between key factors. Furthermore, control loops can be depicted, which are integrated into the planning and the management of product development processes. All in all, the handling of complexity within product development is clearly simplified by improved communication as well as by the enhanced support of planning and managing.

References

[Andreasen 2002] Andreasen, M. M.: What shall engineers be taught about product development. Proceedings 3.IPD-Workshop 2002, Otto-von-Guericke Universität Magdeburg

[Burchardt 2001] Burchardt, C.: Ein erweitertes Konzept für die Integrierte Produktentwicklung, Dissertation, OvG-Universität Magdeburg, 2001

[Engelbrecht 2001] Engelbrecht, A.: Biokybernetische Modellierung adaptiver Unternehmensnetzwerke, Dissertation, University Hannover, 2001

[Frankenberger 1997] Frankenberger, E.: Arbeitsteilige Produktentwicklung, Dissertation, TU Darmstadt, 1997

[Gausemeier 2000] Gausemeier, J.: Kooperatives Produktengineering, Bonifatius Verlag GmbH, Paderborn 2000

[Haken 1995] Haken, H.: Erfolgsgeheimnisse der Natur; Synergetik – die Lehre vom Zusammenwirken, Rowohlt Verlag, 1995

[Hacker 1999] Hacker, W.: Zur Organisation der Entwurfstätigkeit: Opportunistisches Vorgehen mit geplanten Episoden. For-schungsberichte aus dem Institut für Allgemeine Psy-chologie und Methoden der Psychologie der TU Dresden. TU Dresden, 1999

[Hales 1987] Hales, C.: Analysis of engineering design process in an industrial context, Dissertation, University of Cambridge, 1987

[Negele 1998] Negele, H.: Systemtechnische Methodik zur ganzheitlichen Modellierung am Beispiel der integrierten Produktentwicklung, Dissertation, TU München, 1998

[Schroda 2000] Schroda, F.: „Über das Ende wird am Anfang entschieden“ Zur Analyse der Anforderungen von Konstruktionsaufträgen, Dissertation, TU Berlin, 2000

[Vester 1999] Vester, F.: Die Kunst vernetzt zu denken. Ideen und Werkzeuge für einen neuen Umgang mit Komplexität, dtv-Verlag München, 1999

Dipl.-Ing. Thomas Naumann

Chair of Information Technologies in Mechanical Engineering

Otto-von-Guericke University Magdeburg

Universitätsplatz 2

Germany

Phone: +49 (391) 67 18092
Fax: +49 (391) 67 11167
E-mail: Thomas.Naumann@mb.uni-magdeburg.de

Prof. Dr.-Ing. Sándor Vajna

Chair of Information Technologies in Mechanical Engineering

Otto-von-Guericke University Magdeburg

Universitätsplatz 2

Germany

Phone: +49 (391) 67 18793
Fax: +49 (391) 67 11167
E-mail: Vajna@mb.uni-magdeburg.de