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IPEMM - INTEGRATED PRODUCT DEVELOPMENT PROCESS MANAGEMENT MODEL, BASED ON SYSTEMS ENGINEERING AND SYSTEMATIC PROBLEM SOLVING

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ABSTRACT

In the last years of research on development processes a lot of different processes have been developed. Examples for newer development processes are the specific development processes for mechatronics and micro technology. The phases of these product development processes can be compared but they differ substantially with regard to the interactions and order of the single phases of the development processes. In the case of micro technology, for example, the manufacturing method influences already considerably the idea and the conceptual stage, because the production restrictions have to be known at this point of development. As a result of this, there exist several process models which are at some stage comparable. In other stages they are completely different. But this development does not meet the need of the industries for lean, standardized and comparable processes. Most of the specialized development processes are based on research in prescriptive process analysis. Out of this prescriptive research normative process models are deducted. The paper describes an integrated development process model as a reference model, from which specific development processes can be derived. One of the big advantages of this reference model is not being based on sequential development processes.
In general, product development can be seen as problem solving. In the product development process, problem solving has two dimensions: the overall life cycle and the problem solving dimension in single phases. This view defines the two dimensions of the product life cycle as the macro-logic and micro-logic problem solving process. The reference model for product development processes presented in this paper is based on these two dimensions, with a systematic integration of systems engineering and team management.

Keywords: management, product development process, design methodology, systems engineering, problem solving, knowledge management

INTRODUCTION

Over the last 40 years of research in innovation and product development processes, each decade was characterized by certain topics. The early product development and innovation research was dominated by the design methodologies. In the nineteen nineties, the development process research was more focused on management and economics e.g. Cooper and Kleinschmidt [6]. Since the nineties the research was focused again on certain development processes of systems and technologies: micro systems and mechatronics [11]. Additional to different technologies, development processes make differences in processes for radical and incremental innovations; market pull and technology push innovations. The reference process model is a process backbone for all development situations and does not separate certain development stages, as fuzzy front end approaches do. This reference model combines the strengths of each decade and focuses one integrated standardized process model for all innovation processes.

PRODUCT DEVELOPMENT PROCESSES

Product development and innovation processes have been researched by several different domains. Thus, different domains propagate and develop continuously new approaches. The most active actuators in the field of innovation and development processes are the management and engineering sciences. Many of these approaches have a special focus on their own domain. This fact can be clearly seen in the case of the design-methodical approaches. They start the development process with the clarification of the development task and the creation of the requirement specification. Many business management approaches, in contrast, end with the requirement definition [8]. In the 1990s especially Cooper had a decisive influence on the change from the design-oriented development processes to business management-oriented product development processes [5][6]. These domains were the result of two dimensions of a development process: design methodology and business management. The task of a development process is to manage the development project and to support the developers themselves during the development process. The success of a development process depends on the consistency and continuity of the single dimensions and stages. Prasad seizes this suggestion and divides the elements of a development process in different hierarchy levels – organization, product and process [15]. These dimensions of the product development process are characterized by the stage orientation, objectives and navigation through the development process itself. This view was founded by Blass, Franke, and Lindemann in the VDI-guideline 2221 [20], in which the stages of the development process are connected to a problem solving process. It is often used as the basis for the design of development processes. Gierhardt divides the model into process level, organization level, and product level, and turns his attention to a target and a knowledge level [10]. In brief, the development process can be divided into systems, methods, and processes, which again link targets, information / knowledge, and activities.

The approaches from Ottosson "Dynamic Product Development" and the approaches from Andreasen and Olesen made a fundamental step towards holistic integrated Development process under dynamic conditions. Ottoson has his focus on Team integration in to the development process, to control the un-order and chaos in the early stages of PDP, until the product concept is defined and lead into an ordered an structured development process [22]. Andreasen, Hein and Olesen also developed a successful approach to integrate the Design to X thinking in to the concept phase of PDP. There for Andreasen, Hein and Olesen developed a process in combination with a mental thinking model to integrate all phases of the PDP in to the concept Phase of the PDP [23].

Generations of Product development Processes

The main phases of development processes are basically similar throughout the generations of development process. The Phases can be reduced to five basic phases:

1. Strategy and planning
2. Ideas and Concepts
3. Development
4. Testing prototyping
5. Production and market launch

The main focus of all PDP (Product Development Processes) is the time reduction and the increase of quality. Especially for time reduction the approaches of Concurrent Engineering and Simultaneous Engineering lead to an enormous success during the 1990s. With these approaches the first step of the claimed 3rdgeneration of Product development processes (Figure. 1) from Cooper was realized [6]. The sharp separation between the stages was reversed. In regard to the quality of PDP, the information flow between the stages gained more and more importance. Close interaction between the stages and information integration of the other phases is one main success factor in development processes. With the core team management approaches, the specific knowledge of other phases was integrated in the process. The integration of core teams was one successful step. Indeed this method does not describe the information flow, it is only a method to provide the necessary information in the process through individuals. Up to now there is still a big demand to manage the fuzzy gates and the interaction of all phases in complex development processes (Figure 1).

Cooper describes the change of the development processes in three generations (Figure 2). In the first generation, the relation of the single stages is primarily a supplier-to-costumer relation. The further development of the process leads to the stage-gate approach of Cooper's second generation in which the single stages are separated by gates. The approach of the third generation is Cooper's request to replace the gates of the single stages by fuzzy gates. The difficulty with a process where the stage limits are eliminated is the coordination of the complex interaction of the stages and the establishment of a clearly defined lead process [6].

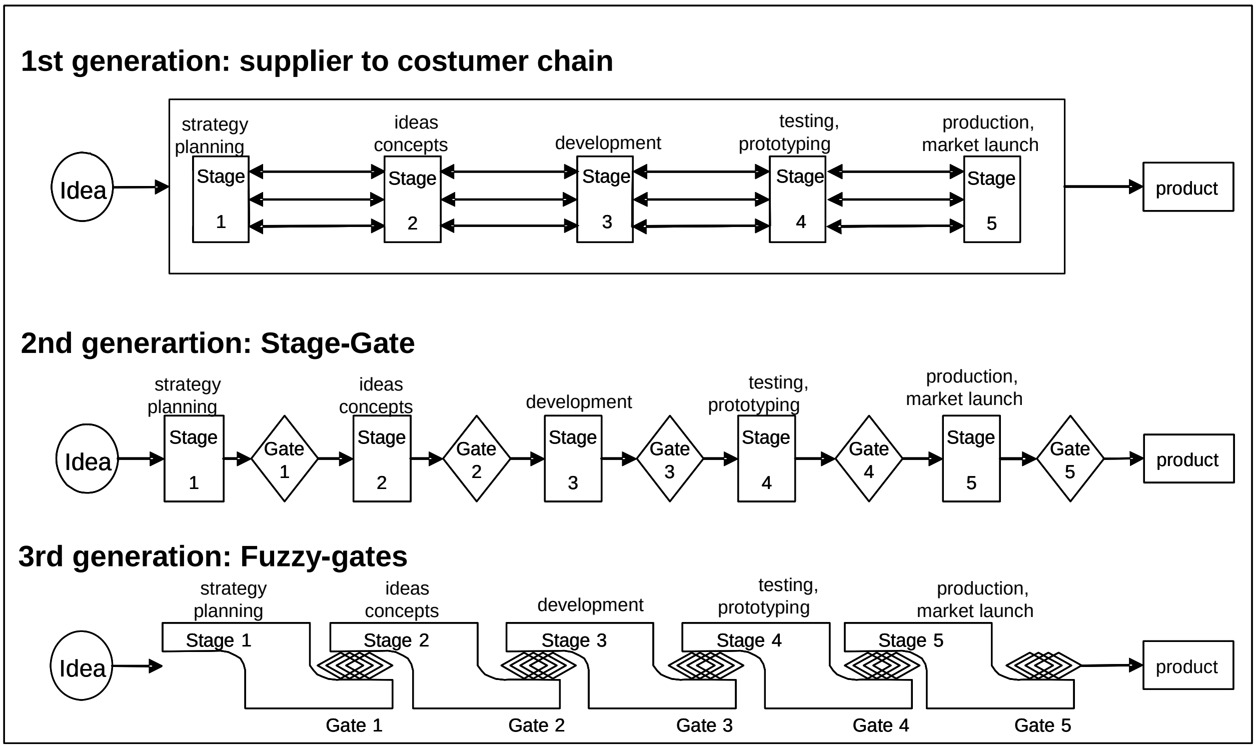

Figure 1. The three generations of product development processes

Requirements on integrated product development process

The success of a development process depends on the consistency and continuity of the single dimensions and stages and the support of the process itself. Also important for PDP process is a non-dogmatic and non-bureaucratic process model providing enough flexibility to react to a changing situation. Nevertheless the main objectives of the development process are well-focussed

Out of this analysis six important elements can be summarised as success factors of a PDP:

1. navigation of the developer through the process
2. provision of specific tools and methods during the Process
3. documentation of specific knowledge of project or process
4. integration of the management
5. initialization of strategic project decisions
6. standardization of the development process

Macro logic life cycle

Decisions in product development do strongly influence subsequent stages of a product's life cycle. Hence, transfer of knowledge to the design stage from subsequent stages, e.g. production or system integration, has to be enabled by integrating means of knowledge management.

As mentioned in the previous chapter, product development can be understood as problem solving. In the product development process, the problem solving has two dimensions: the life cycle from the profile phase to the recycling phase, and problem solving of the single stages from situation analysis to recapitulation and learning. This view defines the two dimensions of problem solving in the product life cycle as the macro-logic and micro-logic of the product development. Based on these different approaches, a reference model for the product development was created that displays the different dimensions and supports the different views and approaches [2][4][20] over the complete life cycle.

The VDI-guideline 2221 describes the process for development and design of technical system model in seven steps [20]. The process model of Pahl and Beitz reduces the process to four main stages [13]. Both process models start with the clarification of the development task; this step leads to the requirements, i.e. specifications that accompany the development process. These process models are sub steps of the product development process and separate development and design from the remaining product life cycle. In the nineteen nineties, it was recognized that the process steps in the development process are not sequential, but highly parallelized and with interlinking. Ehrlenspiel [8] resumes this approach and integrates personal, informational, and organizational aspects into the product development process; he establishes the "integrated product development". The product life cycle is described by means of systems engineering. The influences of all systems on the complete system, e.g. customer, product, production, human resources and methods, are examined holistically.

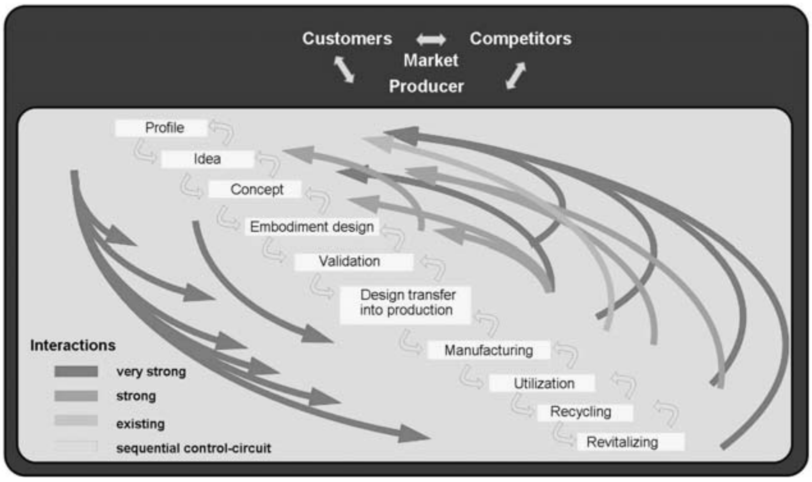

Figure 2. Stages of the product lifecycle (Albers et al. 2004)

The process model of Albers (Figure 2) displays the single stages of the life cycle and emphasizes the overlapping and parallelization of the stages. Thereby it describes the interaction of the single stages [3]. The market and its three players (customer, competitor, and producer himself) is the starting point. Albers incorporates the entire life cycle.

Micro Logic – problem solving process

Basically, a problem can be described as a delta between the target state and the actual state. Two kinds of problems can be distinguished: the emergency situation and the planning situation. In the emergency situation, the actual state declines and the target state remains the same, whereas in the case of the planning situation, the target state as objective is actively changed so that the actual state needs to be adjusted [4]. The most elemental problem solving process is the TOTE-scheme (Test-Operate-Test-Exit). The aim of this scheme is to achieve the target state or objective by changes or operations of the given actual state. This scheme can be considered as closed loop [17]. This closed loop is repeated in iterative steps, until the target state is achieved. For this purpose, a variety of problem solving cycles and models were developed. The problem solving process according to the VDI-guideline 2221 [20] has to be mentioned, which is substantially adapted to system technology or systems engineering. This process represents the stage-oriented procedure of product development, i.e. a macro process. Most problem solving models have not been established as standard processes. In practice, stringent problem solving methods for emergency situations are of a greater importance. Here, the VDA 8D-report is well-tried [19]. It supports e.g. SAP systems as standard process for customer complaints [16].

The developed SPALTEN-process (German: Spalten = to split, to decompose) is a holistic problem solving process. It describes a universal procedure for the solution of problems with different boundary conditions and complexity degrees. With its help, an effort and time minimization as well as a solution optimization and safety maximization for the problem solving can be achieved. The areas of application of the SPALTEN-method are the future-oriented as well as the spontaneously occurring problems. This problem-adjusted procedure enables an optimized benefit/effort relation. Here, the procedure is not to be applied dogmatically but pragmatically depending on the boundary conditions. (The seven steps of SPALTEN: 1. situation analysis, 2. problem containment, 3. finding alternative solutions, 4. selection of solutions, 5. analyzing the consequences, 6. deciding & implementing, 7.finally recapitulation & learning) [2].

Systems engineering – fundamental basics of the approach

The basics of problem solving and systems engineering was founded by Patzak [14] and Daenzer/ Huber [7]. Ehrlenspiel transferred the systems engineering approach to product development [8]. Describing a product, he refers it to a system of objectives, which is the sum of the objectives (requirements) and their relations. In the system of objectives, the requirements are hierarchically structured according to their importance and the chronology of the sub-requirements. The result is the requirement list and system specification, they are the basis of the evaluation of each developing object system and of the development or operation process. The market or the consumer that the product is manufactured for has of course a large influence on the system of objectives. Ehrlenspiel [8] defined these approaches, but he did not apply them consistently in practice. In the work of Negele, the systems engineering approach for the description of development processes was revived [12]. Negele developed the ZOPH-model (German: Ziel-, Objekt-, Prozess- und Handlungssystem, target system, object system, process system, and operation system) for product development. He divided the operation system defined by Ehrlenspiel into process- and operation systems. Steinmaier reduces this approach and combines operation system and process system again to one operation system [18]. In the systems engineering approaches, as well as in the problem solving processes, the system of objectives can be defined as target state and the object system as actual state. With these systems engineering approaches, the product development can be described as the transfer from a system of objectives, being still vague at the beginning of the product development, to a concrete object system. I.e. the core activity of the product development is the continuous expansion and specification of a target system, the creation of an efficient operation system and therefore the successful realization into an object system – the product.

The information of technical requirements is not adequate, especially in the early phases of PDP, the historical background of requirements in the development process is highly important. So, the requirements are only a subpart of the target system with all interferences and interactions. The target system describes not only the affordance and requirements of one phase the target system is also linked to affordance and requirements of all other phases. Through the emergence affect, a target system is more than the sum of requirements. If a product is only described through the requirement list this means for a development process it may not reach the original target system.

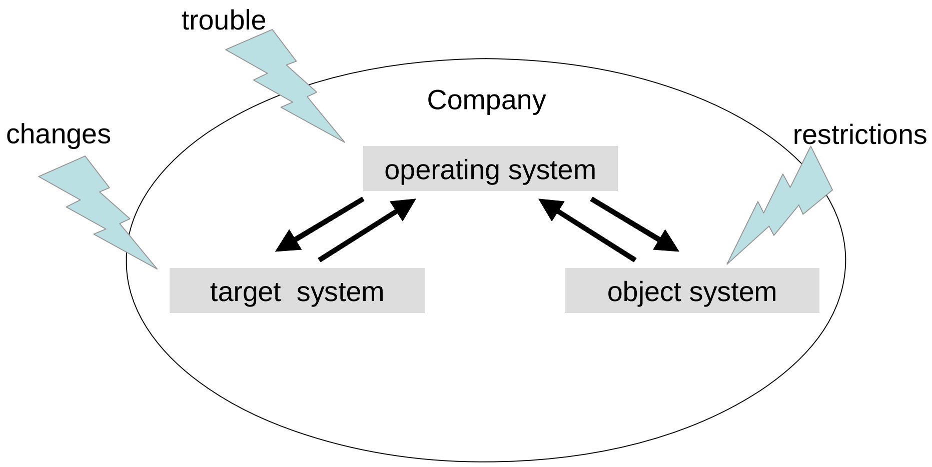

Figure 3. System model of PDP

Operating system

The operating system is a socio-technical system containing structured activities, methods and processes as well as the needed resources for the realization. The operating system creates the target system and the object system. The target system and the object system are only directly linked by the operating system; there is no other direct interdependency. Elements of the operation system are humans, organisation, materials, processes, methods and tools.

Target System

The target system describes the mental anticipated and planned attributes of the object system. The target system describes all relevant objectives, their dependence and boundary conditions [12], which are necessary for the development of the correct object system – outgoing from the current actual condition, up to the future actual condition – but not the solution it self. The target system is permanently extended and concretized over the complete life cycle. The correct, consistently and complete definition of the target system is the basis of the successful product development and a core component of the development activity.

Object System

The object system is the realized solution of the target system. The object system is completed, as soon as the planned specified condition of the target system corresponds to the actual condition. Object systems are not only material systems, also immaterial, e.g. software or services [8]. The object system also includes intermediate objects of the development process, i.e. drawings, models, prototypes etc. [21]. The elements of the object system are the subject and result of the operation system.

The SPALTEN Matrix – the core of the integrated development process model

The micro logic of development processes is the systematic problem solving SPALTEN. The micro-logic process SPALTEN (German: spalten = to split, to decompose) is a holistic problem solving process for complex problems. It describes a universal procedure for the solution of problems with different boundary conditions and complexity degrees. This problem-adjusted procedure enables an optimized benefit/effort relation. Here, the procedure is not to be applied dogmatically but pragmatically depending on the boundary conditions. (The seven steps of SPALTEN: 1. situation analysis, 2. problem containment, 3. finding alternative solutions, 4. selection of solutions, 5. analyzing the consequences, 6. deciding & implementing, 7.finally recapitulation & learning). The SPALTEN Process supports the controlled, purposeful procedure and the systematic way of working intended for solving all kind of problems. Unlike existing methods for problem solving the SPALTEN process makes it possible to provide the experience and the proceedings of users to optimize the problem solving process as a whole [4][2]. The integration of the SPALTEN process into the life cycle enables a new systematic classification of the problem. As shown in Figure 4 there the different kinds of problems concerning the complexity of problems: Simple problems, problems in a single step, difficult problems in a single phase and complex problems with focus on the complete life cycle. In addition to this systematic classification of problems in the PDP, it is now possible to get a specific view on the life cycle: micro-logic and macro-logic view.

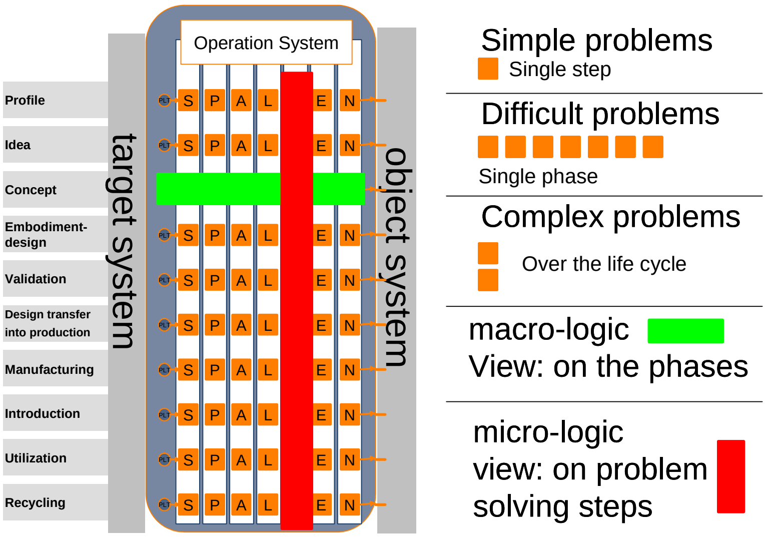

Figure 4. Systematic view on the different problem situation in PDP

The SPALTEN-process is in combination with the life cycle an effective tool for the implementation and documentation of troubleshooting in product development processes. Especially the standardized procedure enables the ability to interchange. The process step is the basis for a standard language for dealing with problem situations in different domains. The interactions of single phases of the product development process are controlled objective oriented with the SPALTEN-process, based on the system of objectives. If e.g. the problem containment of the idea stage identifies restrictions concerning the manufacturability for example, the situation analysis of the production planning is started; the results are replaced in all stages of the system of objectives and made available for all stages. Besides the systematic classification of the complexity level of the problems, the SPALTEN-matrix is the process backbone of the development processes (Figure 5). With this approach there is no fix sequential procedure through the life cycle. The navigation through the process is always indicated by a situation. The process model provides certain method for each single step and the documentation is also linked a single steps. With the systemic view over the life cycle it is now possible to initialize strategic process discussions with the view over the complete life cycle (Figure 5).

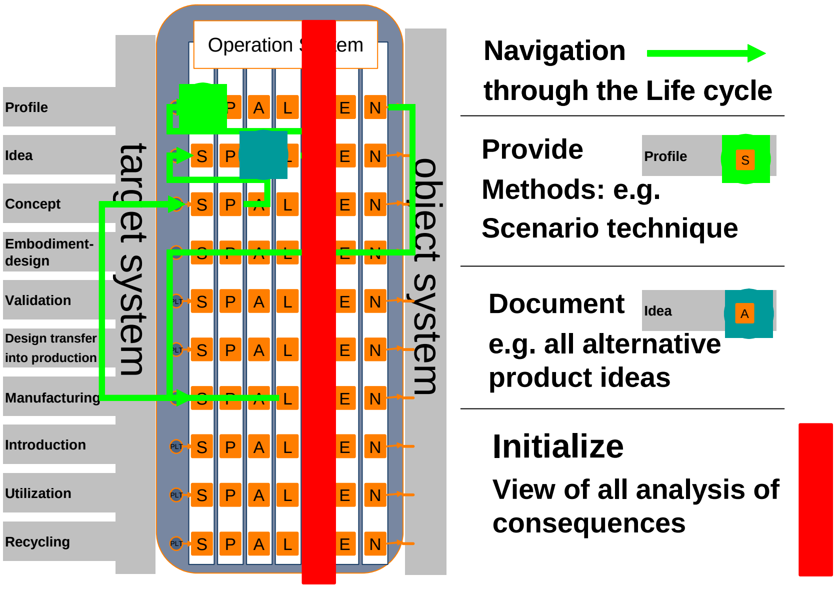

Figure 5. The SPALTEN-Matrix

This approach combines system engineering to the phases of the product development process and a systematic problem solving to one integrated model to handle complex product development processes. The SPALTEN-matrix is the process backbone and the cooperation, coordination and information platform for the product development process. This approach provides a long term planning and situation oriented problem solving during the product development process. With this model it is possible to support adaptation to development process and the model provides the necessary flexibility of the process.

Objective of a development process

The core element of this model is the holistic reference to the target system and fractal problem solving process SPALTEN during the entire product development process. The base of the process is the target system that specifies the objectives that describe the future, anticipated or planned target state. The target system describes all relevant objectives and their dependencies and boundary conditions that are relevant for the development of the right solution.

This reference model creates a problem-oriented process control, which is based on the target system and therefore protects the object and operation system during the entire life cycle. At the same time, all process steps are methodologically supported. The model enables a standard language on the micro and macro level in the product life cycle and standardizes stage- and domain overlapping views of the product development process. With this reference model Cooper's demand for a development process of the third generation is realized, stage changes and interactions are situation-specifically detected, implemented and protected by the problem solving process. With the documentation of the process model, the single steps of the SPALTEN-process cannot only be observed singularly in one stage, but also the entire life cycle. The reference model creates new possibilities in the methodical process support. Each step in the process, the cross point between micro- and macro logic can be provided with suitable auxiliary means accessible for the developers. The first studies demonstrated that the reference model offers many possibilities especially with its stringent separation between system of objectives, object, and operation system and the separation of the single steps of problem solving.

Integrated Process Integrated product development process model

To handle the SPALTEN-Matrix in a complete development process the model has to be linked to a time line with milestones and process gates. The core of the process model (grey box in figure 6.) is related to the operations management of the development process. The process model can be used as a management template to control the complete development process

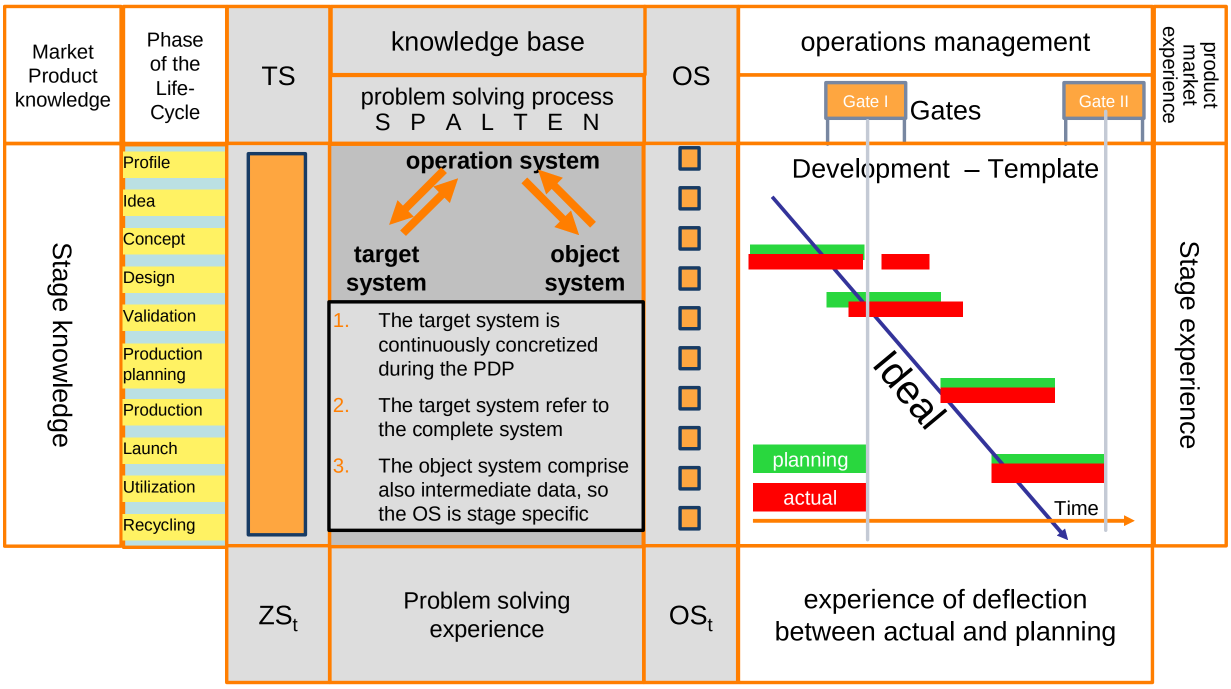

Figure 6. Integrated product development process model

CONCLUSION

The reference model creates a problem-oriented process control, with systematic focus on the objectives. Every step of the process is methodologically supported. The model enables a standard language on the micro level as well as on the macro level in the product life cycle and standardizes stage and domain overlapping views of the product development process. The reference model creates new possibilities in the methodical process support especially in multidisciplinary teams. With the help of this reference model it is possible to describe the independencies of the process and specific development processes can be derived from this model, with a standardized backbone process.

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