IV.B

Product Planning

CHAPTER 48

Planning and Integration of Product Development

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1. INTRODUCTION

1.1. Overview

Today's market is characterized by keen international competition, increasingly complex products, and an extremely high innovation dynamic. Parallel to the shortening of innovation cycles, the life cycles of products and the time until investments pay off are decreasing.

Thus, time is presently the most challenging parameter. Fast, successful positioning of new products on the market has become vital for a company, and the development of innovative products needs to be accelerated. The production of prototypes is significant for a rapid product development (RPD) process.

One feature of this process is the coordination of work tasks within the distributed teams. It will become increasingly important to bring together the different experts. Effective and efficient project management is the basis for the way a team functions. The early integration of different experts serves as a means to develop innovative products. This is also an important factor concerning costs because the main part of the end costs are determined in the early phases of product development. To facilitate the integration of different experts and enhance the efficiency of the iterative phases, prototypes are used as cost-efficient visual models.

1.2. New RP Technologies

Generative prototyping technologies, such as stereolithography (STL), reduce prototyping lead times from a few hours to up to three months, depending on the quality required. These prototypes can serve as visual models or as models for follow-up technologies such as casting.

Handbook of Industrial Engineering: Technology and Operations Management, Third Edition.

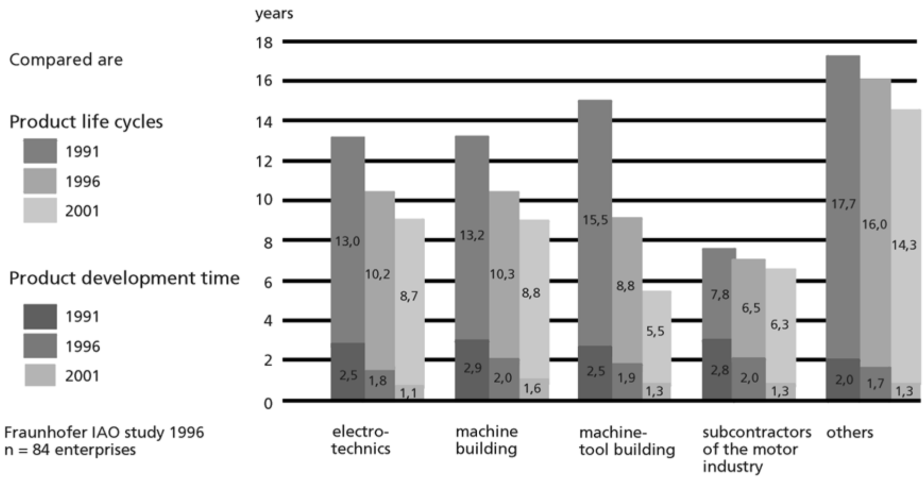

Figure 1 Product life cycles and Development Times.

New, powerful CAD technologies make it possible to check design varieties in real time employing virtual reality tools. The use of virtual prototypes, especially in the early phases of product development, enables time- and cost-efficient decision making.

1.3. Communication Technologies

ATM (asynchronous transfer mode) networks (Ginsburg 1996) and gigabit ethernet networking (Quinn and Russell 1999) enable a quick and safe exchange of relevant data and thus support the development process tremendously. The Internet provides access to relevant information from all over the world in no time, such as via the World Wide Web or e-mail messages. Communication and cooperation are further supported by CSCW tools (Bullinger et al. 1996) like videoconferencing and e-mail. The distributed teams need technical support for the development of a product to enable synchronous and asynchronous interactions. Furthermore, the Internet provides a platform for the interaction of distributed experts within the framework of virtual enterprises. The technologies used support the consciousness of working temporarily in a network, which includes, for example, the possibility of accessing the same files. All these new technologies have been the focus of scientific and industrial interest for quite a while now. However, the understanding how these new technologies can be integrated into one continuous process chain has been neglected. Combining these technologies effectively enables the product-development process to be reduced decisively. Rapid product development is a holistic concept that describes a rapid development process achieved mainly by combining and integrating innovative prototyping technologies as well as modern CSCW (computer-supported cooperative work) tools.

Objectives of the new concept of RPD are to:

- Shorten the time-to-market (from the first sketch to market launch)
- Develop innovative products by optimizing the factors of time, cost, and quality
- Increase quality from the point of view of the principle of completeness

2. CHARACTERISTICS OF RAPID PRODUCT DEVELOPMENT

2.1. The Life Cycle

Simultaneous engineering (SE) considers the complete development process and thus carries out the planning on the whole. RPD, on the other hand, considers single tasks and the respective expert team responsible for each task. SE sets up the framework within which RPD organizes the rapid, result-oriented performance of functional activities. The mere application of SE organization on the functional level leads to a disproportionate coordination expenditure.

The overall RPD approach is based on the idea of an evolutionary design cycle (Bullinger et al. 1996). In contrast to traditional approaches with defined design phases and respective documents, such as specification lists or concept matrices, the different design phases are result oriented.

The whole cycle is subject to constraints from the project environment, such as market developments, legislation, and new technologies. Late changes in customer requirements (Thomke and Reinertsen 1998) make necessary research and development (R&D) management that is able to handle these uncertainties efficiently. Furthermore, the execution of the cycle is not necessarily sequential. For example, results from the generation of prototypes can be directly incorporated into a new design phase.

The idea of evolutionary design means that previously unrecognized product requirements or technological progress be considered and incorporated. This issue leads to an important feature of RPD, namely, the abandonment of a homogeneus definition of a product throughout the project. Each product module has an individual definition. The initial concept is conceptualized for the complete product as well as the final integration of the modules. In between, changes are made through new design methods and tools.

The RPD approach will become more transparent by comparing it to the concept of SE (Bullinger and Warschat 1996). The influencable and controllable parameters of a company will serve as a frame for the comparison (see Table 1):

- Organization
- Processes
- Human and technical resources
- Product

2.2. The Organization

Organizational changes, rearrangement of processes, investment in new machines, and training of staff, as well as new solutions for product structures, are necessary to increase the effectiveness and efficiency of the product-development process.

The organization of a company defines its structures, such as the formation of organizational units and the coordination between the units. Project management, as a method that uses certain tools, influences organizational change to a large extent. Whereas SE exhibits a more or less formalized frame with milestones, RPD requires a reactive project-management methodology. The apparent plan precision within phase-oriented approaches such as SE becomes increasingly inaccurate with proceeding project progress. Hence, it will be replaced by a result-oriented approach, where the plan inaccuracy decreases with the progress of the project. For both development approaches, integration of tasks is needed, with labor being planned, controlled, and steered by one responsible person or team.

TABLE 1 Simultaneous Engineering vs. RPD

Parameter	Element	SE	RPD
Organization	Project management	Formalized	Reactive, individual
	Planning	Product-neutral plan with decreasing accuracy	Result-oriented plan with increasing accuracy
	Labor	Integrated approach	
Process	Structure	Full-process orientation	
	Innovation source	Initial product concept	Continuous improvement and redefinition of concepts
	Development cycles	Avoidance strategy	Active process element
Resources	Data integration	Static	Dynamic
	Communication and coordination media	Short paths and SE teams	Short paths and SE teams and CSCW and ASN
Product	Documents	Unique approval by responsible source	Continuous testing and redefinition of concepts
	Definition	Homogeneous according to modularization	Individual according to project progress
	Data management	Standardized product and process data (STEP)	
	Learning/experiences	For next/from previous project	Within the project

In the early phases of product development, those decisions are made that are relevant for the creation of value. The organization needs to be flexible enough to provide appropriate competencies for decisions and responsibilities.

2.3. The Process

RPD concentrates on the early phases of product development. SE already achieved the reduction of production times. RPD now aims to increase the variety of prototypes through an evolutionary iterative process in order to enable comprehensive statements to be made about the product. The interdisciplinary teams work together from the start. The key factors here are good communication and coordination of everyone involved in the process. Thus, the time for finding a solution to the following problems is reduced:

- There are no customer demands. Therefore, without any concrete forms many solutions are possible, but not the solution that is sought.
- The potential of new or alternative technologies results from the integration of experts, whose knowledge can influence the whole process.
- The changing basic conditions of the development in the course of the process make changes necessary in already finished task areas (e.g. risk estimation of market and technology).

These possible basic conditions have to be integrated into the RPD process to reduce time and costs of the whole process.

The application of processes determines the product development and its effectiveness and efficiency. Product data generation and management process can be distinguished. Hence, it is important for the SE as well as the RPD approach to achieve a process orientation in which both product data generation and management process are aligned along the value chain. In a traditional SE approach, innovation results from an initial product concept and product specification, whereas the RPD concept will be checked and redefined according to the project progress. RPD therefore makes it possible to integrate new technologies, market trends, and other factors for a much longer period. Thus, it leads to highly innovative products. Design iterations are a desirable and therefore promoted element of RPD. The change of design concepts and specifications is supported by a fitting framework, including the testing and the most-important evaluation of the design for further improvement.

2.4. The Human and Technical Resources

Common SE approaches are based on standardized and static product data integration, whereas RPD requires dynamic data management in semantic networks in order to enable short control cycles. Short paths and multidisciplinary teams for quick decisions are essential for both approaches. Moreover, RPD requires team-oriented communication systems, which open up new ways of cooperation. They need to offer support not only for management decisions, but also for decision making during the generation of product data.

In RPD, the people and machines involved are of great importance. The people involved need free space for the development within the framework of the evolutionary concept, and well as the will to use the possibilities for cooperation with other colleagues. This means a break with the Taylorized development process. The employees need to be aware that they are taking part in a continually changing process. The technical resources, especially machines with hardware and software for the production of digital and physical prototypes, have to meet requirements on the usability of data with unclear features regarding parameters. They have to be able to build first prototypes without detailed construction data. The quality of the statements that can be made by means of the prototypes depends on how concrete or detailed they are. For optimal cooperation of the single technologies, it is important to use data that can be read by all of them.

2.5. The Product

The results of the product-development process are the documents of the generated product, such as product models, calculations, certificates, plans, and bills of materials as well as the respective documents of the process, such as drawings of machine tools, process plans, and work plans. The aim of all documentation is to support information management. A documentation focusing on product and process data guarantees project transparency for all the persons involved. The standardization of the whole product data is a basic prerequisite for evolutionary and phase-oriented approaches. STEP (standard for the exchange of product model data), as probably the most promising attempt to standardize product data and application interfaces, offers applicable solutions for quite a few application fields, such as automotive and electronic design, rapid prototyping, and ship building. Documents reflecting parts of the complete product data generated, such as specifications, bills of materials, and process data, represent an important difference between SE and RPD. Whereas in an SE documents are synchronized at a certain time (e.g., milestones), the RPD process documents are subject to persistent alteration until a certain deadline. Thus, figures can be changed or agreed upon and boundaries narrowed. The RPD approach only sets rough boundaries within which the modules mature individually. This yields in specific project-management questions, such as (re)allocation of resources or synchronization of the overall process, which are presently still subject to research (Malone and Crowston 1994). Therefore, the RPD process focusses specifically on the management of variants and versions.

3. ELEMENTS OF RAPID PRODUCT DEVELOPMENT

3.1. Process Planning

The goals of RPD are to speed up these iteration cycles, on the one hand, and promote learning within the cycle, on the other. The whole development process involves cooperating development teams that are increasingly distributed globally. The functioning of the cooperation between these teams is essential for the success of the development process. This can only be realized by effective coordination of the partial plans of each of the distributed development teams that are part of the overall product-development chain.

The decentralization of decisions and responsibilities enhances the flexibility and responsiveness of development teams significantly. Hence, planning tools used to coordinate the tasks of development teams have to fit the characteristics of a development process. Consequently, a tool that is designed for central planning approaches will not fit the requirements of a decentralized structure. Specifically, issues needed for RPD, such as coordination of decentralized teams or learning within each cycle, are not supported.

Based on the understanding of planning as the initial step for scheduling diverse processes, the planning of processes involved in complex R&D projects must be possible. The planning system has to be suitable for use in surroundings that are characterized by decentralized and multisited operations. A high grade of expression of the generated plans is based on the ability to process of incomplete and inconsistent data. Therefore, support of documentation and planning has to be integrated, too. Because separate development teams have different tasks, adaptability to the type of the development task and consideration of specific situations have to be ensured. For this reason, open and standardized data storage is fundamental for the planning system. Therefore, the team-oriented project planning system (TOPP) has been developed.

In order to ensure a high grade of expression of the plans, time relations as proposed by Allen (1991) have been used for the phase of plan definition. Logical and time-connected relations between tasks to be planned have to be described within the plan definition phase. Based on 13 Allen time relations, the results of each task are described dependent on the relations to other tasks. Therewith all necessary constraints between related tasks can be represented. This is why TOPP differs from critical path methods. This method only uses the start and the finish to describe time relations.

Each distributed team can define the relations between the tasks to be planned within their responsibility by Allen time relations (internal relations). External relations (interfaces) to other distributed development teams can also be defined. These external relations are additional constraints for the backtracking-planning algorithm that forms the basis for calculating the optimal plan.

Further, the planner uses disjunctive relations to define the constraints between tasks in order to take the requirements of uncertainty into account. For example, the planner can determine whether a task A has to start at the same time as task B, or whether task B can start at the same time as task A is finished.

If all other constraints, such as available resources, can be met, each disjunctive relation will lead to one possible plan alternative. The required resources and the expected duration of the task are added to the task to be planned in order to consider the limits of resources adequately.

The first reason for this approach is the high uncertainty and complexity of R&D and RPD projects. The definition of rules forms the basis for the use of automatic resource assignments. Therefore, abstractions and simplifications are needed, which cannot easily be obtained from complex systems such as R&D or RPD projects. Second, planners are subject to cognitive and mental limitations. Hence, the planning system has to support the planner by giving him the ability to compare plan alternatives under various circumstances.

A typical problem in multiattributive decision making is the proposed selection of one plan out of a limited number of plans characterized by specific figures. Since the figures show ordinal quality, the process of selecting the optimum can be supported by using the precedence sum method.

Planning as a complex task can normally not be solved optimally, due to the limited mental capacities of human planners. The use of models to plan projects offers many advantages:

- From a statistic point of view, the probability of finding the optimal plan increases with the number of plans.
- The comparison of plans based on specific figures offers possibilities for finding advantages and disadvantages of each plan. Additionally, the planner is not limited to one plan.

- Failures within obscure and complex structures typical of RPD are detected rather than anticipated.
- Since sensitivity for the different figures increases, there is a support mechanism with regard to the knowledge about the situation.
- The evaluation of plans based on quantifiable figures contributes to the achievement of plans.

Five different scenarios have been implemented in TOPP. A particular planning aspect is emphasized by each scenario. The scenario is defined via characteristic figures such as process coordination, process risk, and process logics. Hence, the planner is given the ability to judge all possible plans from a specific point of view.

According to the scenario, the calculation of the order of precedence always takes place in the same manner. First plans are evaluated in view of first-order criteria (FOC). If plans still show the same ranking, second-order criteria (SOC) are taken to refine the order. If a final order of precedence is still not possible, the ideal solution, defined by the best characteristic numbers of all plans, determines the order. The plan with the least difference from the optimal plan will be preferred.

Decentralized planning within rapid product development involves more than simple distribution of partial goals. Since development teams are distributed and are responsible for achieving their partial goals, different coordination mechanisms are necessary. The coordination of TOPP is based on planning with consistency corridors, an integration of phase-oriented and result-oriented planning and task-oriented planning.

By the use of characteristic numbers and planning scenarios, a new approach has been presented to support the selection of the optimal plan within complex R&D projects and rapid product development (Wörner 1998).

In general, TOPP offers a way to support planners coordinating global engineering projects of rapid product development and R&D.

3.2. Physical Prototyping

3.2.1. Rapid Prototyping

In addition to the conventional manufacturing of physical prototypes (e.g., CNC milling) the rapid prototype technologies (RPT) are gaining more and more importance. RPT makes it possible to produce a physical artifact directly from its CAD model without any tools. Thus, it is possible to build the prototype of a complex part within a few days rather than the several weeks it would take with conventional prototyping.

In the past, great effort has been put into developing RPTs, improving their processes, and increasing the accuracy of the produced parts. The most common techniques today, like stereolithography (STL), selective laser sintering (SLS), solid ground curing (SGC), and fused deposition modelling (FDM), are mainly used to produce design or geometrical prototypes. They are used primarily for aesthetic, ergonomic, and assembly studies or as pattern masters for casting or molding processes. However, up to now current materials and process limitations have hindered their use as technical or functional prototypes. To accelerate the development process, technical and functional prototypes are of great importance. Therefore, it is necessary to develop powerful technologies for rapid production of prototypes with nearly serial characteristics, for example, material or surface quality. In addition to new or improved RPTs, there are promising developments in the field of coating technologies and sheet metal and solid modeling, which will be a valuable contribution.

3.2.2. Rapid Tooling

In addition to rapid prototyping, rapid tooling has become increasingly important in recent years. It offers the possibility of building functional prototypes. Here, the material and the process of the series product is used. With rapid tooling it is possible to build tools rapidly and inexpensively for prototypes parallel to the product development process. Rapid tooling technologies help to make the process from the first sketch to the final product more efficient. A range of technologies is available, from cutting to generative methods and from milling to the direct or indirect metal laser-sintering process.

3.3. Digital Protoyping

Physical prototypes are often time and cost intensive and thus need to be reduced to a minimum. By the combining of CAD technologies, rapid prototyping, virtual reality, and reverse engineering, prototypes can be produced faster and more cheaply then before. The employment of virtual prototypes in the early phases of product development, in particular, optimizes the whole development process (Thomke and Fujimoto 1998). The strategic advantage of digital prototyping is the advancement of decisions from the test phase with physical prototypes to the early phases of product development with digital prototypes. Thus, the process of product development and testing can be considerably ameliorated. The digital demonstration allows early modification and optimization of the prototype. Furthermore, it leads to a cost-saving increase in the variety of prototypes. By means of virtual prototypes product features can be easily verified and thus development times can be reduced enormously. Also, faults concerning fabrication or the product itself can be detected in the early development phases and thus be eliminated without great expenditures. This makes it possible to start product planning at an early stage. Due to the early overlapping of development and fabrication, additional synergy effects can be expected. Prerequisites for digital prototyping are the following three areas: CAD, simulation, and virtual reality. Simulation (Rantzau and Thomas 1996) and CAD data produce quantifiable results, whereas the connection with VR technologies enables a qualitative evaluation of the results (Figure 2).

An important component of digital prototyping is the digital mock-up (DMU), a purely digital test model of a technical product. The objective of the DMU is the current and consistent availability of multiple views of product shape, function, and technological coherences. This forms the basis on which the modeling and simulation (testing) can be performed and communicated for an improved configuration of the design. This primary digital design model is also called the virtual product. The virtual product is the reference for the development of a new product, specifically in the design and testing phase. The idea is to test the prototype regarding design, function, and efficiency before producing the physical prototype. Thus, effects of the product design can be detected in a very early phase of product development. This way, possible weaknesses of the physical prototype can be detected and corrected in the design phase, before the physical prototype is built. An enormous advantage of the DMU is the shortening of iteration cycles. The decisive changes in the digital prototype are carried out while the physical prototype is being built. During this period, the DMU process can achieve almost 100% of the required quality by means of corrections resulting from the simulation processes. The development process without DMU, on the contrary, requires further tests

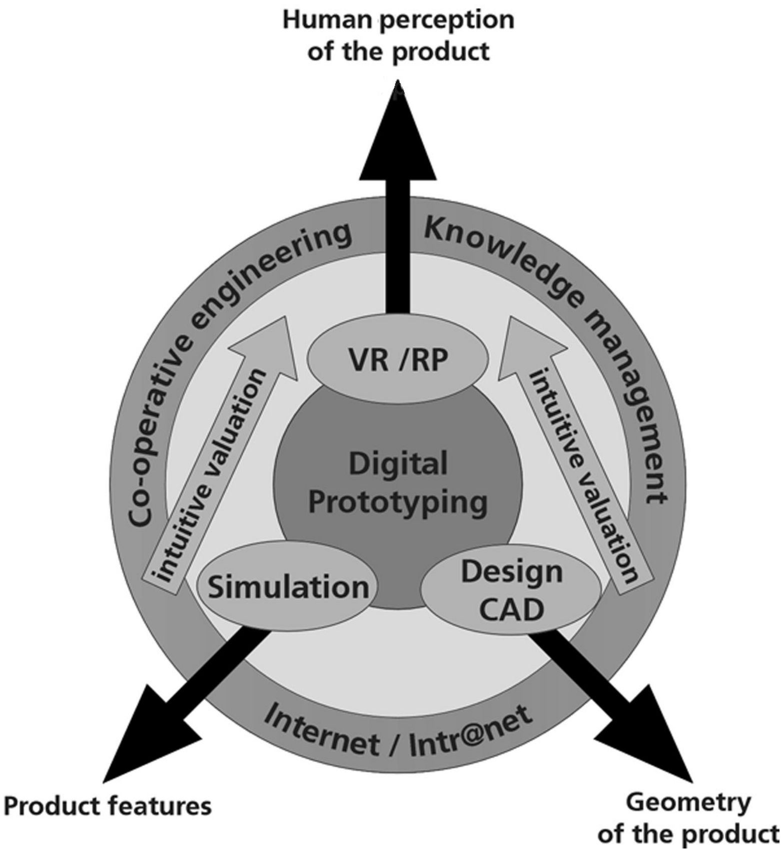

Figure 2 Application Triangle.

with several physical prototypes before the end product can be produced. This means that employing the DMU considerably reduces the time-to-market. The DMU platform also offers the possibility for a technical integration of product conception, design, construction, and packaging.

Digital prototyping offers enormous advantages to many different applications, such as aircraft construction, shipbuilding, and the motor industry. Fields of application for digital prototyping in car manufacturing are, for example:

- Evaluation of components by visualization
- Evaluation of design variations
- Estimation of the surface quality of the car body
- Evaluation of the car's interior
- Ergonomic valuation with the aid of virtual reality

To sum up, creating physical or virtual prototypes of the entire system is of utmost importance, especially in the early phases of the product-development process. The extensive use of prototypes provides a structure, a discipline and an approach that increases the rate of learning and integration within the development process.

3.4. The Engineering Solution Center

The use of recent information and communication technology, interdisciplinary teamwork, and an effective network is essential for the shortening of development times, as we have demonstrated. The prerequisites for effective cooperative work are continuous, computer-supported process chains and new visualization techniques. In the engineering solution center (ESC), recent methods and technologies are integrated into a continuous process chain, which includes all phases of product development, from the first CAD draft to the selection and fabrication of suitable prototypes to the test phase.

The ESC is equipped with all the necessary technology for fast and cost-efficient development of innovative products. Tools, like the Internet, CAD, and FEM simulations, are integrated into the continuous flow of data. Into already existing engineering systems (CAD, knowledge management, databases, etc.) computer-based information and communication technologies are integrated that support the cooperative engineering effectively. Thus, the engineering solution center offers, for example, the complete set of tools necessary for producing a DMU. A particular advantage here is that these tools are already combined into a continuous process chain. All respective systems are installed, and the required interfaces already exist. An important part of the ESC is the power wall, a recent, very effective, and cost-efficient visualization technology. It offers the possibility to project 3D CAD models and virtual prototypes onto a huge canvas. An unlimited number of persons can view the 3D simultaneously. The power wall is a cost-efficient entrance into large 3D presentations because it consists of only one canvas.

Another essential component of the ESC is the engineering/product-data management (EDM/PDM) system. The EDM encompasses holistic, structured, and consistent management of all processes and the whole data involved in the development of innovative products, or the modification

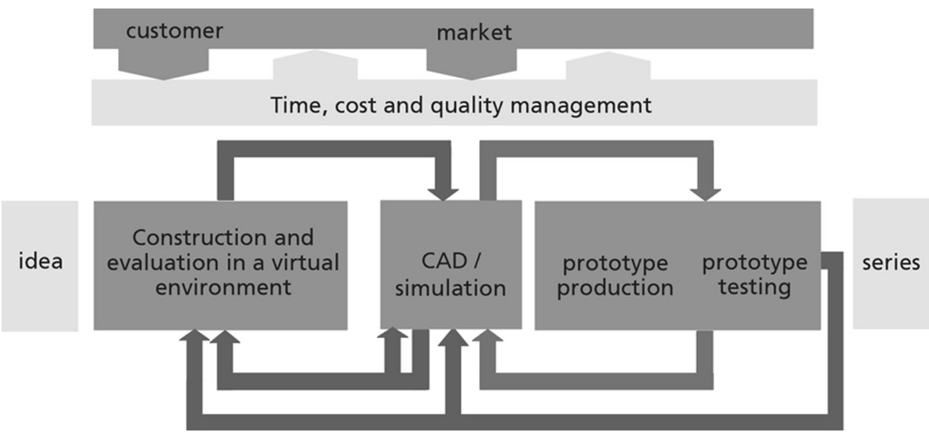

Figure 3 Digital Prototyping in the Product-Development Process.

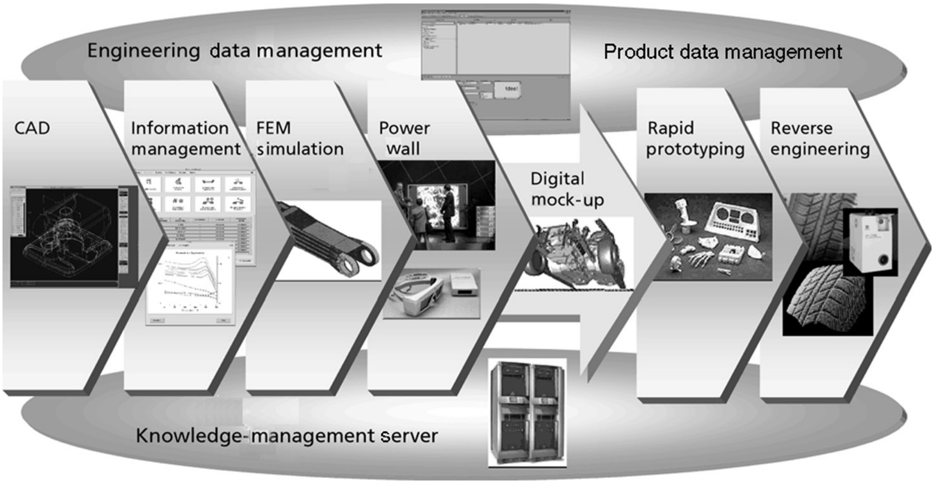

Figure 4 The Engineering Solution Center (ESC).

of already existing products, for the whole product life cycle. The EDM systems manage the processing and forwarding of the produced data. Thus, these systems are the backbone of the technical and administrative information processing. They provide interfaces to CAD systems and other computer-aided applications (CAX), such as computer-aided manufacturing (CAM), computer-aided planning (CAP), and computer-aided quality assurance (CAQ). This way, these systems enable a continuous, company-wide data flow. Inconsistent or obsolete information stocks are reduced to a minimum through the use of EDM.

The innovative approach realized here is what makes the engineering solution center so special. The ESC integrates recent technologies into a continuous process chain. By the use of virtual prototypes the time- and cost-intensive production of physical prototypes can be considerably reduced. The interplay of all methods and technologies makes it possible to achieve high development quality from the first. The virtual product, together with all the applications of virtual technologies and methods in product development and testing, is a necessary reaction to the rapidly changing requirements of the market.

4. KNOWLEDGE ENGINEERING

4.1. Communication and Cooperation

Communication is a further basis for cooperation. It guarantees the continuous exchange of data, information, and knowledge. Particularly dynamic processes, like the development of innovative products, demand great willingness to communicate from the development partners, especially when the partners have not worked together before. Project partners often complain about the great expenditure of time for meetings, telephone calls, and the creation and exchange of documents. If partners are not located nearby, resource problems mean that small and medium-sized companies can arrange personal meetings at short notice only with great difficulty. Nevertheless, face-to-face communication is important because it helps the partners to build up trust and confidence. An information exchange via phone or fax is an insufficient substitute. Especially for small companies, trust is an important factor because it gives them the ability to reduce burdensome expenditures such as frequent coordination and comprehensive documentations. The dynamic in a network of cooperating partners requires a higher degree of communication than most companies are used to because spontaneous agreements concerning the further development process are often necessary. Above all, the manner of communication between the partners has to be altered. Continuous advancement in knowledge and the time pressure put on the development of new products make quick feedback necessary if any deviations from the original planning emerge.

How can communication be improved for the movement of knowledge? There is a difference between explicit knowledge, which is documented, such as on paper or electronically, as language, sketch, or model, and implicit knowledge, which exists only in the heads of the employees.

Another distinction to be made regarding communication is that between the synchronous exchange of knowledge, where partners can communicate at the same time, and the asynchronous exchange, where the transmission and the reception of the message do not happen simultaneously, such as the sending of documents via e-mail.

In most cases of cooperation, exactly this relation is made: implicit knowledge is exchanged synchronously via phone or face to face, and explicit knowledge is exchanged asynchronously via documents. As a consequence, implicit knowledge remains undocumented and explicit knowledge is not annotated. This is a great obstacle to rapid reception of knowledge. Support here is offered by telecooperation systems, which allow communication from computer to computer. Besides documents, pictures, sketches, CAD models, and videos, language can also be exchanged. This way, documents, pictures, and so on can be explained and annotated. By using special input devices, it is possible to incorporate handwritten notes or sketches. This facilitates the documentation of implicit knowledge.

These systems have a further advantage for the integration of knowledge. Learning theory tells us that the reception of new knowledge is easier if several input channels of the learner are occupied simultaneously.

Knowledge-intensive cooperation processes need coordination that is fundamentally different from conventional regulations and control mechanisms. A particular feature of knowledge-intensive processes is that they can hardly be planned. It is impossible to know anything about future knowledge—it is not available today. The more knowledge advances in a project, the higher the probability that previous knowledge will be replaced by new knowledge. Gaining new knowledge may make a former agreement obsolete for one partner. As a consequence, it will sometimes be necessary to give up the previous procedure, with its fixed milestones, work packages, and report cycles, after a short time. The five modules of RPD can be of great help here:

1. Plan and conceive
2. Design
3. Prototyping
4. Check and
5. Evaluate

However, they do not proceed sequentially, as in traditional models. A complete product is not in a certain, exactly-defined development phase. These development projects have an interlocked, networked structure of activities. Single states are determined by occurrences, like test results, which are often caused by external sources, sometimes even in different companies. Instead of a sequential procedure, an iterative, evolutionary process is initiated. But this can function only if the framework for communication is established as described above.

Traditional product-development processes aspire to a decrease in knowledge growth with preceding development time. According to the motto "Do it right from the start," one aim is usually to minimize supplementary modifications. New knowledge is not appreciated; it might provoke modifications of the original concept. RPD, on the other hand, is very much knowledge oriented. Here, the process is kept open for new ideas and changes, such as customer demands and technical improvements. This necessitates a different way of thinking and alternative processes.

Knowledge-integrated processes are designed according to standards different from those usually applied to business process reengineering. The aim is not a slimming at all costs, but rather the robustness of the process. The motto here is "If the knowledge currently available to me is not enough to reach my target, I have enough time for the necessary qualification and I have the appropriate information technology at my disposal to fill the gap in my knowledge."

The knowledge-management process has to be considered a direct component of the value-added process. According to Probst et al. (1997), the knowledge-management process consists of the following steps: setting of knowledge targets, identification of knowledge, knowledge acquisition, knowledge development, distribution of knowledge, use of knowledge, and preservation and evaluation of knowledge.

For each of these knowledge process modules, the three fields of organization, human resource management, and information technology are considered. After recording and evaluating the actual state, the modules are optimized with regard to these mentioned fields. The number of iterations is influenced by the mutual dependencies of the modules (Prieto et al. 1999).

From the experiences already gained from R&D cooperation projects the following conclusion can be drawn: if the knowledge-management modules are integrated into the development process and supported by a suitable IT infrastructure, the exchange of knowledge between team members becomes a customer–supplier relationship, as is the case in the value-added process itself. This enables effective and efficient coordination of the project.

4.2. Knowledge Integration

For distributed, interdisciplinary teams it is of great significance that the different persons involved in a project base their work on a common knowledge basis. The cooperating experts have to be able to acquire a basic knowledge of their partners' work contents and processes and their way of thinking in only a short time. Function models and design decisions cannot be communicated without a common basis. Knowledge integration is therefore the basis of communication and coordination in a cooperation. Without a common understanding of the most important terms and their context, it is not possible to transport knowledge to the partners. As a consequence a coordination of common activities becomes impossible. Growing knowledge integration takes time and generates costs. On the other hand, it meliorates the cooperation because few mistakes are made and results are increasingly optimal in a holistic sense. A particular feature of knowledge integration in R&D projects is its dynamic and variable character due to turbulent markets and highly dynamic technological developments. Experiences gained in the field of teamwork made clear that the first phase of a freshly formed (project) team has to be devoted to knowledge integration, for the reasons mentioned above. The task of knowledge integration is to systematize knowledge about artifacts, development processes, and cooperation partners, as well as the respective communication and coordination tools, and to make them available to the cooperation partners. The significance of knowledge integration will probably increase if the artifact is new, as in the development of a product with a new functionality or, more commonly, a highly innovative product. If the project partners have only a small intersection of project-specific knowledge, the integration of knowledge is also very important because it necessitates a dynamic process of building knowledge.

To find creative solutions, it is not enough to know the technical vocabulary of the other experts involved. Misunderstandings are often considered to be communication problems, but they can mostly be explained by the difficult process of knowledge integration.

Which knowledge has to be integrated? First, the knowledge of the different subject areas. Between cooperating subject areas, it is often not enough simply to mediate facts. In this context, four levels of knowledge have to be taken into consideration. In ascending order, they describe an increasing comprehension of coherence within a subject area.

1. Knowledge of facts (''know-what'') forms the basis for the ability to master a subject area. This knowledge primarily reflects the level of acquiring ''book knowledge.''
2. Process knowledge (''know-how'') is gained by the expert through the daily application of his knowledge. Here, the transfer of his theoretical knowledge takes place. To enable an exchange on this level, it is necessary to establish space for experiences, which allows the experts to learn together or from one another.
3. The level of system understanding (''know-why'') deals with the recognition of causal and systemic cohesion between activities and their cause and effect chains. This knowledge enables the expert to solve more complex problems that extend into other subject areas.
4. Ultimately, the level of creative action on one's own initiative, the ''care-why,'' has to be regarded (e.g., motivation). The linkage of the ''care-why'' demands a high intersection of personal interests and targets.

Many approaches to knowledge integration concentrate mainly on the second level. Transferred to the knowledge integration in a R&D cooperation, this means that it is not enough to match the know-what knowledge. The additional partial integration of the know-how and the know-why is in most cases enough for a successful execution of single operative activities. The success of the whole project, however, demands the integration of the topmost level of the care-why knowledge. A precondition here is common interests between the project partners. This is also a major difference between internal cooperation and cooperation with external partners. In transferring internal procedures to projects with external partners, the importance of the care-why is often neglected because within a company the interests of the cooperation partners do not differ very much; it is one company, after all (Warschat and Ganz 2000).

The integration process of the four levels of knowledge described above is based on the exchange of knowledge between project partners. Some knowledge is documented as CAD models or sketches, reports, and calculations. This is explicit knowledge, but a great share of knowledge is not documented and based on experience; it is implicit.

This model, developed by Nonaka and Takeuchi (1997), describes the common exchange of knowledge as it occurs in knowledge management.

5. SUMMARY AND PERSPECTIVE

The RPD concept is based fundamentally on the early and intensive cooperation of experts from different disciplines. This concept therefore makes it possible to bring together the various sources of expert knowledge in the early phases of product development. Thus, all available sources of information can be used right from the beginning. The initial incomplete knowledge is incrementally completed by diverse experts. Cooperation within and between the autonomous multifunctional teams is of great importance here. The selection and use of suitable information and communication technology are indispensable.

Information exchange is considerably determined by the local and temporal situation of cooperation partners. If the cooperating team members are situated at one place, ordinary, natural communication is possible and sensible. Nevertheless, technical support and electronic documentation might still be helpful. In case cooperation partners are located at different places technical support is indispensable. For this, CSCW and CMC (computer-mediated communication) tools are applied, such as shared whiteboard applications, chat boxes, electronic meeting rooms, and audio/videoconferencing. The currently existing systems make it possible to bridge local barriers. However, they neglect the requirements of face-to-face communication and cooperation. For instance, it is necessary to establish appropriate local and temporal relations among team members. The communication architecture, therefore, should enable the modeling of direct and indirect interactions between individuals. Because of the dynamic of the development process, these relations change. The system should therefore possess sufficient flexibility to enable keeping track of the modifications. Furthermore, the communication basis should be able to represent information not as isolated, but as in the relevant context.

During product development, especially within creative sectors, frequent and rather short ad hoc sessions are preferred. This form of spontaneous information exchange between decentralized development teams requires computer-mediated communication and cooperation techniques, which permit a faster approach and lead to closer cooperation between experts. This results in a harmonized product development, which maintains the autonomy of decentralized teams.

Along with the short iteration cycles, the interdisciplinary teams are an essential feature of the RPD concept. They operate autonomously and are directly responsible for their respective tasks. Additionally, the increasing complexity of products and processes requires an early collaboration and coordination. Thus, it is necessary to make knowledge of technology, design, process, quality, and costs available to anyone involved in the development process.

Conventional databases are not sufficient for an adequate representation of the relevant product and process knowledge. On the one hand, current systems do not consider the dynamic of the development process sufficiently. On the other hand, it is not possible to assess the consequences of one's definition. However, this is a fundamental prerequisite for effective cooperation.

To cope with the given requirements, it is necessary to represent the knowledge in the form of an active semantic network (ASN). This is characterized by active independent objects within a connected structure, which enables the modeling of cause-and-effect relations. The objects in this network are not passive, but react automatically to modifications. This fact provides the possibility of an active and automatic distribution of modifications throughout the whole network. In contrast to conventional systems, ASN contains, in addition to causal connections, representations of methods, communication, and cooperation structures as well as the knowledge required to select the suitable manufacturing technique. Furthermore, negative and positive knowledge (rejected and followed-up alternatives) are stored therein. These acquired perceptions will support the current and future development process. The ASN should exhibit following functions and characteristics:

- Online dialog capability
- Dynamicness
- Robustness
- Version management
- Transparency

All in all, the ASN makes it possible to represent and to manage the design, quality, and cost knowledge together with the know-how of technologies and process planning in the form of the dynamic chains of cause and effect explained here. Thus, the ASN forms the basis for the concept of RPD.

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