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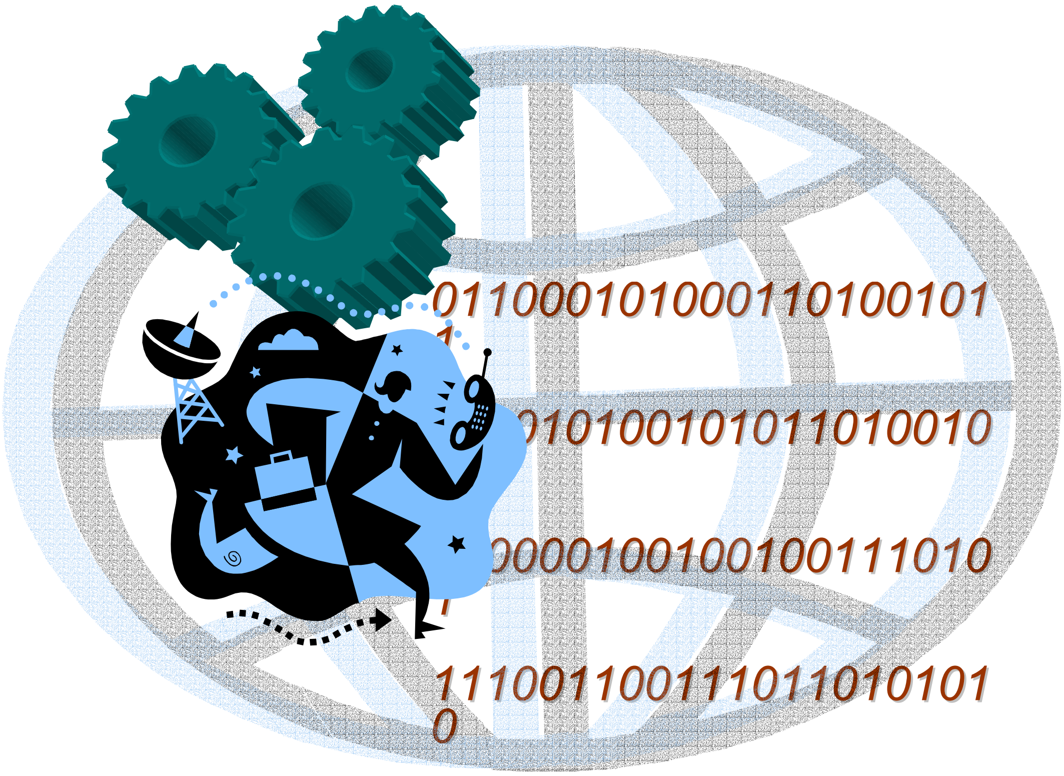

Challenging global competition: tune up your product development

Kari Leppälä
Provisec Oy

Jukka Kääriäinen, Juha Takalo & Pekka Savolainen
VTT Electronics

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tel. växel 020 722 111, fax 020 722 4374

VTT Technical Research Centre of Finland, Vuorimiehentie 5, P.O.Box 2000, FI–02044 VTT, Finland
phone internat. +358 20 722 111, fax +358 20 722 4374

VTT Elektroniikka, Kaitoväylä 1, PL 1100, 90571 OULU
puh. vaihde 020 722 111, faksi 020 722 2320

VTT Elektronik, Kaitoväylä 1, PB 1100, 90571 ULEÅBORG
tel. växel 020 722 111, fax 020 722 2320

VTT Electronics, Kaitoväylä 1, P.O.Box 1100, FI–90571 OULU, Finland
phone internat. +358 20 722 111, fax +358 20 722 2320

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Abstract

Maturing electronics industry and global scale of operations create a new and challenging business environment. Production capacity is available on a competitive base; it will no more be a strategic advantage for product-based industries. Thus, it can be seen that the product itself is becoming the new competitive factor. Product developing companies seeking for competitive advantage push product performance and functionality, often with the help of advanced technology. All the product-related activities will increase in demand: numerous technologies, skills, and competencies are required in the development section. The companies have to search for new methods and tools to manage their sophisticated products, and they also must learn to rely on resource networks and co-operation partners.

Techniques, models, methods, standards and best practices related to systems engineering and improvement of product-life-cycle management, in particular targeted to development of advanced and mass-produced consumer products, are hard to find. The scope of necessary activities is wide, and there is a specific need for experience reports and application cases. Thus, we propose to develop a framework for collecting, evaluating, maintaining, and distributing an expert knowledge base of the topic. This knowledgebase will include techniques, templates, and methods to support practical process deployment tasks. The knowledgebase shall not contain just static "one-type-of" method chains, but provide the pool of methods which can be searched according to the needs of various improvement activities, cumulatively updated to keep the company's process knowledge that has been built during the development.

Keywords
systems engineering, product life cycle management, PLM, product creation processes

Activity unit
VTT Electronics, Kaitoväylä 1, P.O.Box 1100, FI–90571 OULU, Finland

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Executive summary

Maturing electronics industry and global scale of operations create a new and challenging business environment. Production capacity is available on a competitive base; it will no more be a strategic advantage for product-based industries. Thus, it can be seen that the product itself is becoming the new competitive factor. Outsourcing of production is common, and *product development* becomes the core industrial process. Product developing companies seeking for competitive advantage push product performance and functionality, often with the help of advanced technology. All the product-related activities will increase in demand: numerous technologies, skills, and competencies are required in the development section. The companies have to search for new methods and tools to manage their sophisticated products, and they also must learn to rely on resource networks and co-operation partners.

Also the product concept is changing. Products become smart products. Microprocessors and software are a flexible way to implement new features. As the cost of processing and distributing information is becoming insignificant, in the near future most new smart products access and utilize external information resources. This progress means that companies, which previously concentrated on more traditional engineering, will be increasingly tied to software technologies and multi-discipline system development practices. When new product concepts are planned, it is no longer an internal issue. New infrastructures and service concepts have to be created, and products need to be designed to be compatible with these infrastructures. Third-party vendors provide supplementary applications and services, thus creating added value for the core product.

Product-developing companies establish product and technology platforms, which are collections of designs, design templates, software libraries, and product modules. Platforms provide building blocks to create new products. A related concept is business platform, which ties together the basic product and the numerous supporting products (a.k.a. enhancements), services, technologies, and information contents, which may be delivered by third-party companies. In contrast to product platforms, which are usually proprietary and controlled by the hosting company, business platforms often come from multiple vendors.

Product and technology management are guided by business, product and technology strategies. A modern product management and product development process needs also to take into account the business environment, and the product's whole life cycle must be covered, from the definition up until after sales and disposal. This need for new, holistic methods for product creation and management calls to re-vitalize viewpoints and applications of system sciences. Systems engineering has already proven success records in the development and acquisition of large one-of-a-kind technical systems in the defence and aerospace sectors. The increasing complexity of common product development environment requires application of concurrent engineering principles: collaboration and stakeholder participation. The systems engineering methodology also provides a framework for concurrent engineering, and thus can be seen as a viable approach to support networked design and production of mass-produced consumer products.

Planning and deployment of systems engineering and product life cycle management is challenging. It is a common belief that the systems engineering and product life cycle models are restricted to support creation of very large and complicated one-of-a-kind systems. In fact, the issue is not the systems engineering concept, which is actually a rich and flexible framework for all kind of engineering and development work. The challenge resides in how to create the company-specific and efficient implementations for the complicated real-life situation.

Deployment or improvement of product creation processes requires knowledge and practices of information system development, process improvement and project management. The contemporary industrial-scale product development environment is rich and sophisticated: it includes various design environments and tools, information management systems, requirements for new products, co-operation networks, and management processes, to schedule and monitor the activities and their results. The resulting complexity is beyond "a single system/process deployment". Various models and standards exist to help to assess, rationalize and develop business processes, for example, ISO 9001, TQM, EFQM, ISO 15504, CMM, and CMMI.

Techniques, models, methods, standards and best practices related to systems engineering and improvement of product-life-cycle management, in particular targeted to development of advanced and mass-produced consumer products, are hard to find. The scope of necessary activities is wide, and there is a specific need for experience reports and application cases. Thus, we propose to develop a framework for collecting, evaluating, maintaining, and distributing an expert knowledge base of the topic. This knowledge base will include techniques, templates, and methods to support practical process deployment tasks. The knowledgebase shall not contain just static "one-type-of" method chains, but provide the pool of methods which can be searched according to the needs of various improvement activities, cumulatively updated to keep the company's process knowledge that has been built during the development. Tool support is needed to provide easy-to-use searching, filtering, and selecting of practical methods from knowledgebase, and packaging the knowledge, or methods, into an exploitable format.

Contents

Common acronyms

CAD	Computer Aided Design
CASE	Computer Aided Software Engineering
CE	Concurrent Engineering
CMM	Capability Maturity Model
CMMI	CMM-Integration
CSCW	Computer Supported Cooperative Work
ERP	Enterprise Resource Planning
GPS	Global Positioning System
GSM	Global System for Mobile Communications
HW	Hardware
PDM	Product Data Management
PLM	Product Lifecycle Management
Pri^{2}mer	Practical process improvement for embedded real-time software
RDF	Resource Description Framework
RM	Requirements Management
SCM	Software Configuration Management
SE	Systems Engineering
SW	Software
TQM	Total Quality Management
XML	Extensible Markup Language

1. Introduction

Moving factories and production lines into countries of low cost level is now a reality which impacts also electronics and communications industries. In this case this phenomenon also reveals the maturity level of electronics industry: manufacturing capacity is a service commercially available, and product development is now the main industrial competition factor.

The aim of this document is to address the secret of efficient product development. Our basic message is that product development has to be seen as the core business process, with two main characteristics: 1. the development process has to take into account the entire product life cycle, and 2. all stakeholders including business networks, service providers and end users should be involved with the process.

In practice such a holistic viewpoint means efficient deployment of systems engineering and life cycle management. Setting up a comprehensive, smoothly running and efficiently managed product process requires combined skills of information system development, process improvement, and effective project management. In the literature and in professional journals it is possible to find a large number of theories, techniques, models, methods, standards and best practices. However, it is a challenging task to select, define and implement process deployment and improvement activities, which are appropriate with regard to company specific product technology, resources, business situation, and timescales.

The document starts with the discussion of changing industrial setting that brings in demand for new holistic methods for product creation and management. Then fundamental concepts in product creation and life cycle management are introduced and challenges for planning and deploying product creation and life cycle management determined. Finally, an improvement initiative is introduced.

2. Changing industrial setting

2.1 Change as we see it – and beyond

Industry is going through a change process. Superficially we see and name this process as globalization, moving factories and production lines into countries where work cost is low. It is indeed true that technology and industry are no longer a protected privilege for old industrial countries. However, this phenomenon is really new only within electronics and communications industry. The similar change has taken place decades earlier in many other industrial branches, including basic steel making, home appliance industry, car industry, and even with semiconductor industry.

Outsourcing electronics manufacturing capacity has been so shocking in Finland, because significant electronics industry is a rather new phenomenon. The trend to relocate production facilities on the global scale will persist, due to the removing barriers of international trade and co-operation. However, there is also another far-reaching change going on, shadowed by manufacturing outsourcing: the focal point of *industrial competition is moving from production to products and services*.

Mass-production has been the heart of industrial revolution. Companies which have been able to create cost-efficient manufacturing facilities with sufficient technology and quality level have prospered. During the last decades production has become a well-understood and controlled activity. As a result, production capacity is becoming an abundant commodity, which is available on competitive base. Production capacity that is free-for-all is no more a strategic competition advantage, and the competition moves to new activity sectors. As noticed above, the product itself has become the new success factor. The winner in the game is the one who has the capability of creating attractive products; products that win the hearts of the customers. As the product is now moved into the focal point, *product development has become the core industrial process*.

2.2 Impacts on products and product development

Because product has become a competition factor, product developing companies seek for competitive advantage by pushing forward product performance and functionality, often with help of advanced technology. Thus, products show a tendency to become more and more complicated. At the same time, product development activities become more demanding: numerous technologies, skills, and competencies are required. Companies have to seek new methods and tools to manage their sophisticated products, and they also have to rely on resource networks and co-operation partners.

The standard method to manage products and technologies of continuously increasing complexity is the modularisation of the product. The concept of modularity can be derived from basic design theories, which decompose the product function into sub-functions and allocate an implementation module for each function. In integrated or "coupled" design one module may implement a number of functions, while in the modular design there are more modules but less functions per module. The general rule in design is that integrated design – several functions per one module – are more efficient in terms of material and energy use and more economical in mass production, but also more expensive to develop and difficult to modify. The lesson learnt is that complicated products should be modular.

The modularity can be either visible, products may even be re-configurable, or the modularity may as well be concealed from the product's users. Modularity supports creation of product families – visibly differing products having many features in common – and product variation in time by copies of successful models with some features enhanced. Economic interest is gained by designing the same advanced but expensive components as parts of multiple differing products, thus making the manufacturing lots larger and sharing the development costs among the different product models.

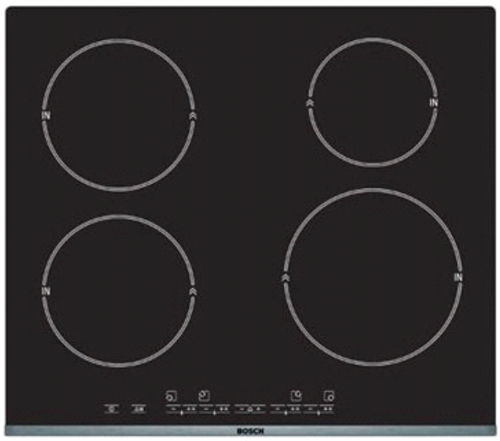
Modern electronics products are complicated multi-technology artefacts. The use of software has increased in many different product types. Even the traditional products, those which were earlier based on pure mechanical and electronics parts, today include software components, not only in their embedded control core, but also in the user interfaces. For example, nowadays the development cost of software in the industrial-robot industry is about two thirds (Crnkovic et al. 2003). This progress has meant that many companies that previously concentrated on more traditional products have become increasingly tied to software technology and system development practices.

The shift from pure hardware development to integrated product design including software engineering has not always happened without problems. Software is an example of technologies where modularity is intensively utilized (although it can be claimed that over-extensive use of modules and loosely controlled production of new versions of modules is also a source of quality and efficiency problems in software production). In computer products, and increasingly in mobile products, the modularity is not totally concealed from products' users. Although it makes the products much more flexible and allows third party vendors to create added-value software modules for users, modularity can also challenge users by making product user interfaces complicated and confusing.

Product design that is based on modularity is also called *platform design*. A product platform is a collection of designs and other technical items needed for a set of different present and future product models. A platform may support one or several product families or product lines. An extensive product platform is an important resource and technology depository. Platform's lifespan is much longer than that of a single product. In platform-based design product development is normally decomposed into platform projects and product projects. Planning the platform projects is a strategic issue, as platform items should serve several products and cater also for future needs.

2.3 Trends with new intelligent products

As companies aim to create competitive advantage with new products, they introduce more performance, improved functionality, and better user-friendliness. Electronics components and especially microprocessors are becoming basic building blocks of contemporary products, and software is a flexible way to implement new features. Products are becoming smart products. This trend does not concern only traditional information products like mobile terminals and television sets, but products like cars and diverse home appliances (like in Figure 1) have become software-enhanced.



- Electronic front-mounted touch controls
- 17 temperature settings for each zone
- Electronic digital readout of selected temperature stage
- Touch control on / off switch for each zone
- Touch control main on / off switch with indicator light
- Timer for all zones
- Memory function
- 2 stage residual heat indicator for each zone: 'H' residual heat sufficient to keep items warm, 'h' residual heat insufficient to cook but zone still hot enough for caution
- Boost setting for all zones
- Child lock
- Safety shut off

Figure 1. A smart cooker.

Application of microelectronics and software in products makes them more versatile and user friendly. Furthermore, there is another, fairly new phenomenon: products capable to access and utilise external information resources. So, not only new kinds of products are appearing, but also the way how these products and the required technological infrastructures are created is changing.

Information is a very special commodity. The development of society has progressed parallel with information processing: art of writing, dissemination of printed books and magazines, and finally the transition to electronic forms of information – the dawn of a new era we are just living with. Information technologies consume only little energy and material resources, and we can be quite sure that, due the continuing progress of microelectronics, costs of storing, processing, and distributing information will soon be insignificant. So what matters now and in the future is how we deal with the information: how we create it, how we shape it into the form of identifiable contents and services, and how we do business with it.

It seems unavoidable that in the near future practically all new smart products are dealing with information resources. This is not only an issue with mobile terminals, which are already capable of accessing existing internet-based resources and electronics mass media, but other consumer-appliances as well. For example, transportation systems will be able to provide navigation and traffic control resources to help the driver, and also entertainment and commercial service catalogues for passengers.

All media products have certain common features. They need some source of information and access to the communication infrastructure, so that consumers can utilize the information resources. The success of new products is critically dependent on access to the external information, and creation of the logical packages to distribute the information: applications and services. To implement these product ideas it may be necessary, to reshape the embodiment of the "product". The product functionality is no longer concentrated in the physical device, which the user carries with him, but shared between the user's device and the environment where the application is used. For example, consumers could only carry along some identification device, which would then allow them to use private or public media applications.

2.4 Infrastructure and business platforms

After discussing product related issues, we will re-consider the platform concept from a global business viewpoint. Contemporarily, information-enhanced products also require established and mature infrastructure. From the technological point of view, there has to be commercially available components, tools, and services for the key technologies, in addition to well-selected company specific, and thus proprietary, development work and technology. As we have pointed out, modern product design is complicated and elaborate. In order to develop new product models and product families rapidly and in a cost-efficient way, product companies establish product and technology platforms. A platform is a collection of reusable design modules, design templates, software libraries, and product modules, which can be used as building blocks to create instances of new product models.

Another interesting concept is business platforms – although this concept is more complicated and more difficult to conceptualise. A business platform ties together the basic product and the numerous supporting products, services, technologies, and information contents from third-party companies. In contrast to product platforms, which are usually proprietary and controlled by the product company, business platforms often come from multiple vendors (Wonglimpiyarat 2004). Examples of business platforms are the Internet, Windows Operating System, game consoles, and the Symbian software platform. Perhaps the most fundamental form of business platform is a concept standard, for example GSM or GPS (Global Positioning System).

When we discussed modern, information-enhanced products, or media products, we pointed out that use of those products is critically dependent on the availability of information (the content) and the information delivery channels. Thus, launching such products is possible only when the overall infrastructure is present. Business platforms are central elements of such infrastructures. Although business platforms are often formed through gradual evolution and are available from multiple vendors, companies also strive to create and control business platforms to gain competitive advantage. For example, 3G mobile phone standards are controlled by patents: the leading companies holding major patents gain cost advantage, as competitors have to license key technologies for accessing the platform.

Developing new products is not only a technical issue. The products need infrastructure and information contents. On the other hand, companies have interest in cooperating with the other vendors of the infrastructure for several reasons. It is advantageous to accelerate the formation of the infrastructure and provision of third-party contents and services. It is also necessary to make the own product and product platform compatible with the needs and objectives of information distributors and content and service providers.

2.5 Need for holistic methods for product related processes

Product development is one element in a comprehensive set of activities: product and technology management, guided by business, product, and technology strategies. The purpose of product management is not only to create new products, but also to create the knowledge and competence to cope with product and technology related activities. At the same time, it is necessary to participate in the formation of the network, which creates the necessary infrastructure and business structure for marketing and utilization of the products.

A modern product management and product development process needs to take into account the business environment which is interested in the new product type (see Figure 2). There is also a need to cover the entire product life cycle, from concept definition through design phases and manufacturing, up to after sales activities and disposal. Product platforms, product roadmaps, and business platforms must also be included into the scope of product management.

The need for new, holistic methods for product creation and management calls to re-vitalize viewpoints and applications of system sciences. The fundamental principles of systems analysis are not new, and they have also been applied in engineering and engineering management. *Systems engineering (SE)* and *concurrent engineering (CE)* have been applied successfully in the development and acquisition of large one-of-a-kind technical systems in the defence and aerospace sectors worldwide. Also, various product life cycle management solutions have been developed to support traditional product development. Now the increasing complexity of product business requires application of those same principles in design and production of mass-produced consumer products.

A good starting point to re-consider product-related processes is to consider the following principles of concurrent engineering:

1. All product interest groups should participate in the product development process. These parties include the internal functions of the company, main partners and contractors, the stakeholders of relevant business platforms, and consumers.

2. The product development process must be transparent: product-related information, including the discussions and contributions of product interest group members should be visible to the participants of the product process – taking into account requirements of confidence.

There are good sources of information and guidance for planning and running product development activities (see for example Ulrich & Eppinger 2000). Our intention is not to repeat this material, but to complement it through the process viewpoint: how to define and implement these proved techniques and practices as well defined and controllable business processes.

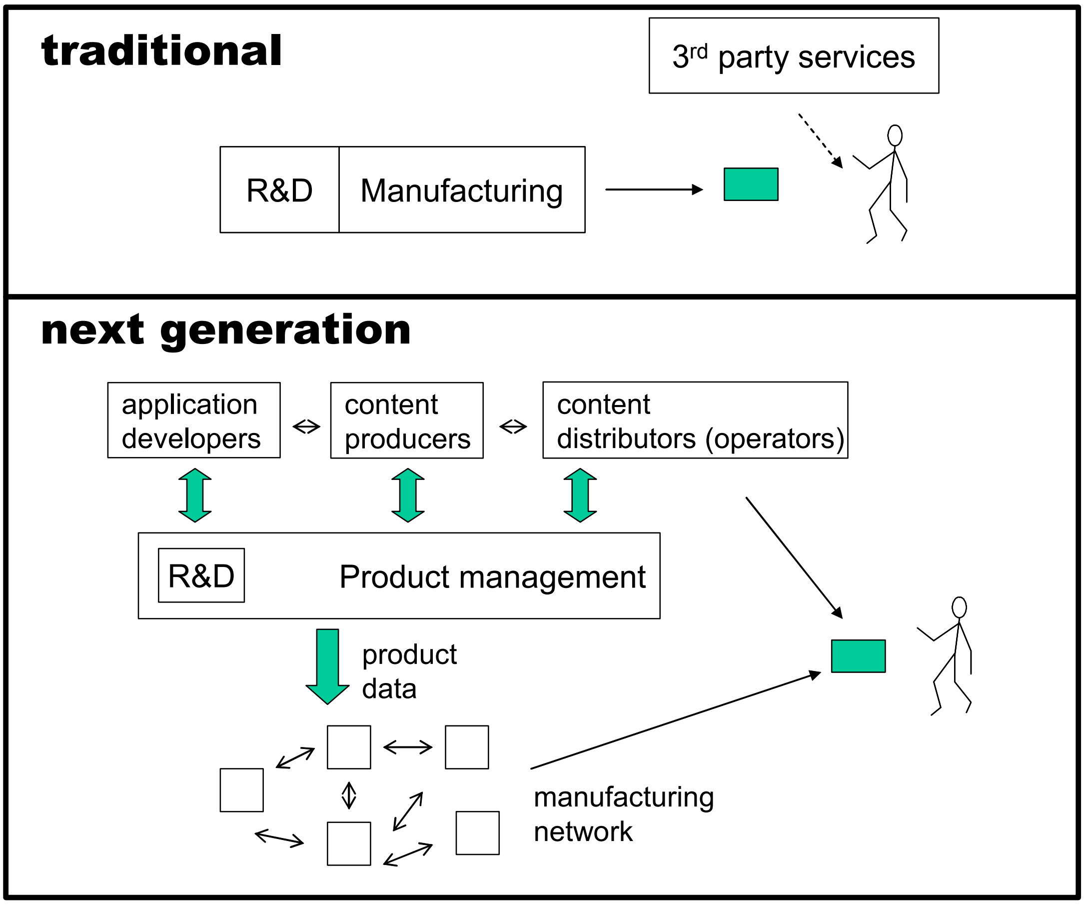


Figure 2. Next generation of development and manufacturing of consumer products.

3. Fundamental concepts in product creation and life cycle management

In this section we discuss some fundamental concepts in product creation and life cycle management. Our aim is to illustrate reasons for the complexity of product creation process. We also discuss controlling, organizing, and visualizing the elements of the process.

3.1 System thinking and systems engineering

In design and engineering, systems theory approach aims at understanding, analysing and explaining technical objects. A system is seen as a collection of entities, which interact with each other and with the environment. The critical aspect is to recognize the system's boundaries. The concept of boundary is more or less artificial, and depends on the viewpoint. Sometimes there are no natural boundaries, for example in the case of organisational and social systems. In product engineering it is usually fruitful to analyze the product boundary: what in the environment is interesting as regards to the product, and what kind of interactions there are or should be. When analyzing a product, it is also useful to distinguish three different systems: the technical system (the product), the physical product environment and the human activity environment. An advanced analysis aspect is to consider the service that the product provides as a system.

An approach that brings together the different skills, disciplines, development stages, and stakeholders during product development is called *systems engineering* (SE). Stevens et al. (1998) define systems engineering as follows:

The technical and control actions associated with the processes in the system and capability development processes.

We can understand systems engineering as a rational and holistic model to create a design, so that all the aspects of the design are taken into account: (1.) all components of the artefact which have to be designed; (2.) the environment, where the future artefact is to be used and utilized through its life cycle; and (3.) the organisation of the human activities which create the design. Thus, it actually provides a full model for creating new products.

The core part of the SE model consists of the technical life-cycle processes. They comprise a sequence of constructive activities, which refine and transfer the requirements of a future product into a description of the product structure. It also includes a verification track, which assures by several kinds of tests that the design is correctly made in the technical sense, and that it fulfils the requirements originally set.

Also an analysis track is included to apply formal methods to ensure integrity and soundness of the designed parts before they are realized as prototypes. The model considers the product as a system, in reality a collection of subsystems defined according to their functions. The product is decomposed according to the technical disciplines: for example, divided into mechanical, electronic, software, thermal, electromagnetic, industrial design, and usability domains. A decomposition of the technical life cycle processes is illustrated in Figure 3.

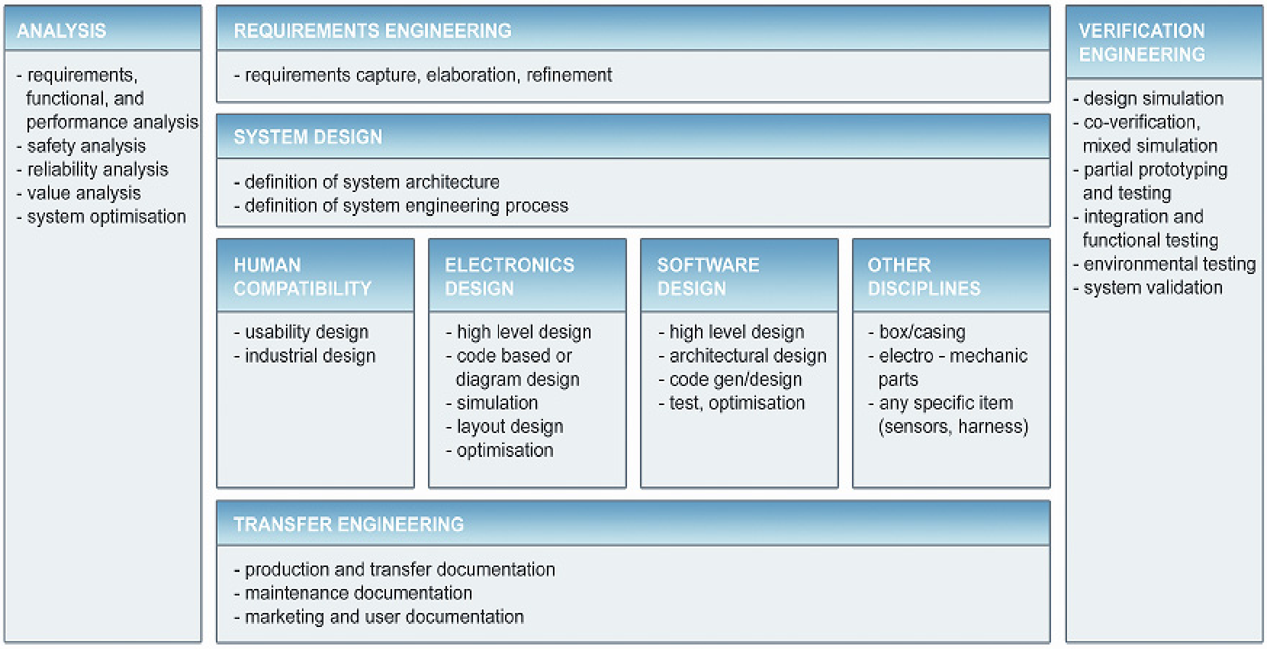


Figure 3. Technical product design life cycle processes (Leppälä et al. 2003).

Discipline-specific engineering approaches focus on their own special area, providing mechanisms to support design in that area. SE, on the other hand, provides a framework for the work on each engineering discipline alone and several of them together, still remaining independent of each discipline or product type. Stevens et al. (1998) state that the role of SE depends on the ability to communicate across the disparate groups involved in a development. On large systems it is performed at multiple levels throughout the development and by every discipline (Stevens et al. 1998).

The development of complex products is dispersed into several concurrent design processes, including HW, SW, and other discipline specific processes. One special characteristic in this type of development is the parallel development of HW and SW, also called co-design. ITEA Technology Roadmap for Software-Intensive Systems (2004) lists the following challenges for systems engineering: evolutionary design, product line engineering, automation in verification and validation, system architecture trade-off analysis, and hardware/software co-design.

The systems engineering cycle is finalized by so called transfer engineering phase, where information is produced to utilize the end product: information for production, maintenance, training, and user guidance.

3.2 Comparing systems engineering and concurrent engineering

Figure 4 is a high level domain representation of a systems engineering process, highlighting engineering techniques and disciplines. It assumes an overall activity flow from top to bottom, but it does not tell how to organize, execute and control these activities. Implementing an engineering process means that the elements of designing are organised into a coordinated and controlled effort. Process management it the compound act of planning, executing, and controlling the systems engineering process ensemble.

While the systems engineering approach aims to take into account the environment where engineering is conducted and managed, it has to include a number of auxiliary processes. This is reflected in the established systems engineering standards, like the ISO/IEC 15288 Systems Engineering reference standard and the CMMI-SE/SW/IPPD/SS process assessment standard for Systems Engineering, Software Engineering, Integrated Product and Process Development, and Supplier Sourcing.

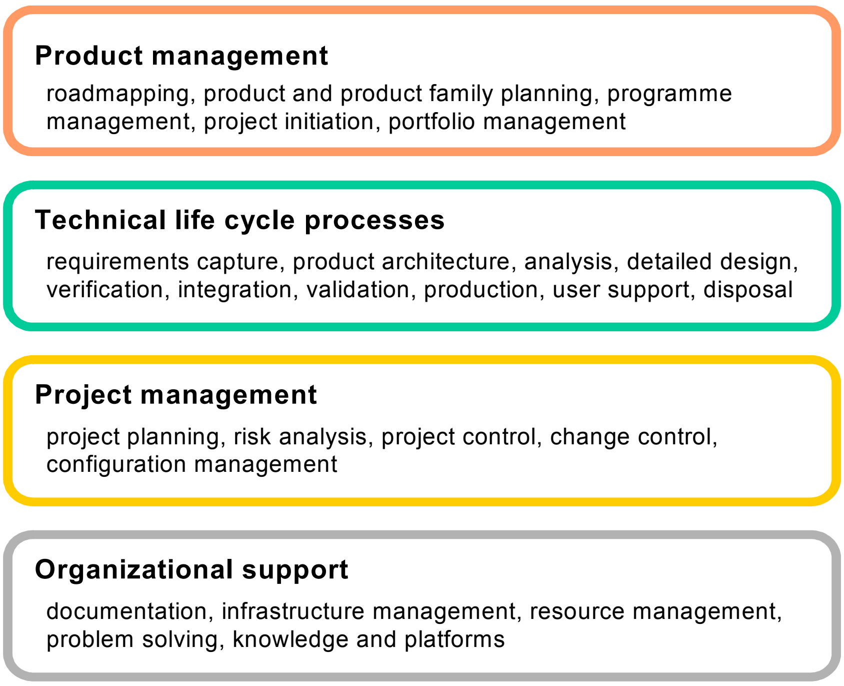


Figure 4. Processess within the scope of systems engineering.

Figure 4 illustrates the multitude of organizational processes within the scope of systems engineering (though simplified, i.e. not directly adopted from the above-mentioned standards).

The advantage of process management disciplines is addressing both the performance and the content of activities. The processes describe the actual activities performed within the organisation. They have the capability to bypass functional and hierarchical – more or less artificial – superstructures, and allow focusing on the essentials.

This discussion of systems engineering is completed by relating it with concurrent engineering interpretations. The first interpretation is communication: all important product stakeholders should participate into the process. As systems engineering highlights environment and management of engineering processes, it clearly includes the processes and the control functions for this participation. The second interpretation is: concurrent engineering aims at speeding up product engineering by organizing it into parallel activities. This is also a natural property of systems engineering, which can be described as an ensemble of concurrent processes. We can conclude that *the systems engineering model is a viable framework for implementing concurrent engineering principles.*

As we pointed out in chapter 2, companies create and maintain technology platforms – collections of designs – which are building blocks for the present and future products. So the development projects are often distinguished between platform projects and product projects. When product line and product family thinking is advancing, product development is actually performed in many parallel design projects, which can be coordinated applying SE principles. An interesting issue is how to implement the parallelism in the technical lifecycle processes, because the sub-processes within the life cycle have strong mutual dependencies. Actually, different models of parallelism define different technical life cycle models, which we will discuss next.

3.3 Exploring the technical life cycle processes

The traditional design life cycle emerged during the first half of the 20th century. It took the shape of a linear and progressive sequence, from the definition and refinement of the requirements to construction and testing a prototype. NASA adopted this model for aerospace projects and introduced an important improvement: the phased project planning method, PPP. The design process was decomposed into sequential phases, and after each phase there was a review. Only after a successful review and resolution of review issues was proceeding to the next phase permitted. This linear design sequence, which is generally also known as "the waterfall model", is quite natural for very large projects. It provides the basic principle for application of managerial control over design processes.

The linear model for system development divides the development life cycle into two main sections. The first section is used to define what is to be build (*definition (requirements / architecture)*). The second section is used to integrate and verify what has been built (*integration/verification*). Another view to system development is to enhance the traditional sequential model by adding horizontal links between *definition* and *integration/verification* sections. This produces a model called *V-diagram* (Figure 5). Kotonya & Sommerville (1998) and Stevens et al. (1998) state that after system level requirements specification, architectural design divides and assigns system level requirements into sub-system level entities, which further are specified and divided into smaller entities. This specification takes place on various levels during system decomposition, in co-operation with architectural design, until the sufficient practical implementation level has been reached. Hooks and Farry (2001) emphasize coordination and requirements traceability between these levels to ensure that all requirements are flowed from the top and through all the refinement levels.

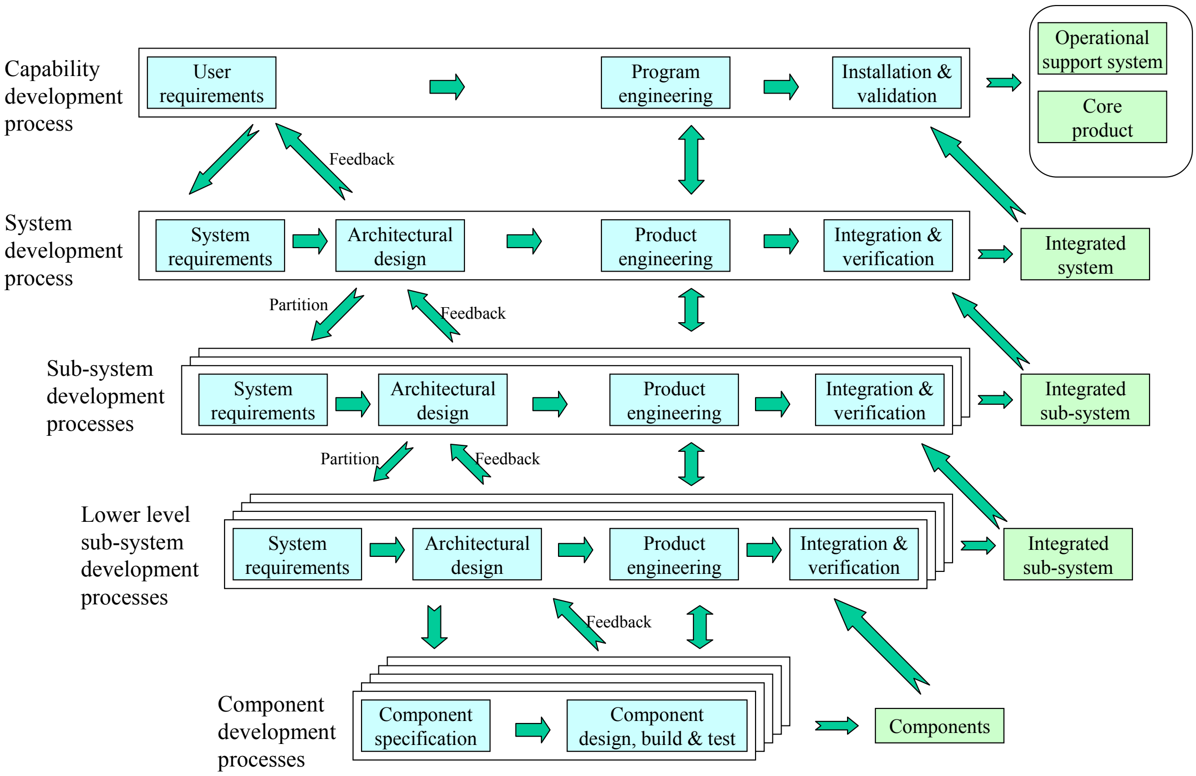


Figure 5. Development approach based on V-diagram (Stevens et al. 1998).

Stevens et al. (1998) suggest that the”customer-supplier” relationship applies at each level. E.g. the system level process agrees the specification for a sub-system level and asks for a set of components from the sub-system level. Thus, the system level (customer) negotiates with the sub-system level (supplier) and sub-system levels negotiate further with their suppliers. Stevens et al. (1998) also state that the architecture defines the components that must be supplied from lower level and therefore it actually shapes *the managerial structure* of product development. It is noteworthy that in this kind of approach, the total number of interactions between upper and lower level teams and processes is significant. Thereby system engineers must keep a holistic viewpoint to the system development.

Although the V-model engineering process illustrates basic design concepts and issues, it has been claimed to be insufficient to be applied as such. In reality, the design process may have to be repeated, once or several times, to improve the results. This cyclic arrangement is called spiral model design. Even the spiral model is unsatisfactory in most practical cases. In an improved, iterative, model, the product is designed through a series of small design steps and modifications, iterated if necessary to produce the requested sub-component. This is a feasible model especially for software, where building non-physical prototypes for testing is a fast and automated process. Many design projects are actually improvement projects, where only some modules of the product are redesigned.

3.4 Managing the product process

As we have seen, the product creation process is actually an ensemble of concurrent processes (see Figure 3). In a product development project, the project starts with a planning phase, which considers what kind of engineering and supporting processes are to be involved. Management processes are included in the systems engineering model, taking control of executing and scheduling the technical life cycle activities.

Project management appears to be one of the most general and uniform industrial processes. It was originally developed for large construction projects, to control and schedule multiple activities and their mutual dependencies. However, project management appeared to be useful to control any bounded activity, especially if the task is non-trivial, risky, and unpredictable. This is why product design is usually performed within the project envelope.

A product development effort is planned as a project – or often as an ensemble of projects. More precisely, it is decided up front what elements of the engineering model are included, and how the elements are sequenced and scheduled. This implementation is then compiled into a project plan. In addition to the planning and scheduling of technical design tasks, also the technical documentation structure has to be include: requested documents describing the design, and required control documents.

Management activities are also needed, like status review meetings and technical reviews.

Product program management is a comparable technique; it can be understood as an application of multi-project management. In product development, programmes implement product roadmaps. They consist of projects which are necessary to create elements for product platforms. Individual projects then create individual products or members of product families.

3.5 Product life cycle management

Systems engineering is a discipline that creates and organizes the key information that defines the system. An approach that captures, manages, and distributes product related information created on systems engineering domain is called Product Lifecycle Management (PLM). PLM emphasises a holistic view to the product information management and is not specifically tied to any engineering discipline. The term PLM has emerged from the term Product Data Management (PDM), which has a stronger connection to specific tool category called PLM-tools. Sääksvuori & Immonen (2004) define PLM as follows:

PLM refers to the wider frame of reference of Product Data Management (PDM), especially to the life cycle perspective of information management.

According to CIMData (a world-class PDM consulting company) (Sääksvuori & Immonen (2004)):

PLM is a group of systems and methods with which the development, manufacture and management of products is made possible at all the stages of the product life cycle.

The important aspect of the above definitions is the conception of PLM as a generic frame of reference for systems and methods that are needed for managing all product-related data during the product's life cycle. It does not refer to any individual software or method (Sääksvuori & Immonen 2004). Some PLM literature tends to treat PLM just as an extension to PDM but it should be considered in its wider sense as described above.

Nowadays, there are different kinds of disciplines and information processing systems that aim to provide support for the management of product-related information. Sääksvuori & Immonen (2004) state that the use of information processing systems is not by means self-evident. Some simple actions can be taken to develop product life cycle management without any special and dedicated information processing system. For example, formerly product-related documents and drawings have been identified, classified and archived on paper (Crnkovic et al. 2003).

Related to the product information management during product's life cycle disciplines can be identified as follows:

- Requirements Management (RM): Requirements management manages elicited requirements, changes to agreed requirements, relationships between the requirements, and dependences between the requirements document and other documents produced during the systems and software engineering process.

- Software Configuration Management (SCM): The information management discipline to support software development process. SCM keeps the evolving software product under control.

- Product Data Management (PDM): Product data management (PDM) is the discipline governing the control of the product data and supports processes used during the product development.

- Enterprise Resource Planning (ERP): Enterprise Resource Planning (ERP) is rather a system than a management discipline. It controls activities related to company's supply-production-distribution operations. It includes elements such as contract management, production, and procurement.

- Document, or Content, Management: a coordinating process, usually supported by a common data repository (Content Management System, CMS), to manage, store, and disseminate enterprise's technical documentation in electronic format. Does not cover PDM or SCM behaviour (utilises and integrates to office or CSCW rather than technical design tools). Controls company's technical content, including various product-related and platform-related documents, and sometimes project's management and contract documents as well as. The content can be modular (structured for XML applications) or in common office formats.

Product-related data is produced in all phases during product development. This data is organised and stored into various product information management systems. These systems enable consistent information organisation, management, and distribution. As the needs are varying, also the information management systems have specialised to particular purposes, as can be see from the list above. As noticed by Svensson (2003), when new needs for information management have appeared, new information management systems have been developed.

One challenge with these tool domains is that often their functionality and managed information overlaps (Svensson 2003, Crnkovic et al. 2003). Same data is duplicated into various applications that complicate the traceability and maintenance of data. Keeping the data consistent would require integrations between existing systems. And the technical integration of these tools in itself is not sufficient but also adequate understanding of the development processes and their interrelations in the particular case is required. Therefore, the management of product related data requires a holistic viewpoint that contributes to better data and procedure consistency between product information management disciplines.

PLM can be seen as a unifying framework for the definition of consistent and accurate product information management. Often problems in the consistent management of product information arise from the complexity of development process and the product, as well as from globally distributed development environment. where several parties are involved in collaborative product development and manufacturing. In this kind of environment people, to begin with, likely have difficulties to understand each other. Inconsistent terminology is used, when the users of product information management system are located in several departments or organisation units. Literature introduces PLM as an important enabler to support collaborative product development (e.g. in Sääksvuori & Immonen 2004).

3.6 Virtual product design

We have described the complicated product creation process, which often geographically distributed product stakeholders participate. Efficient means of communication are clearly needed. Information technology has created opportunities for establishing communication platforms, which are based on graphical visualization technologies, powered by computer networks and communication tools. We could call this platform “a virtual design space" (Leppälä et al. 2003).

Virtual design may appear in various forms. There are actually two different viewpoints to the virtual design space, which can also be combined. The first, *virtual office* approach aims at providing a simulated working environment, where participants can share, review, and create product related documents, independently of their physical location. If business-level activities are included, we can also call this approach *virtual enterprise*.

The second approach is design-artefact centric, organising design activities around a *simulated product prototype*. In the most advanced form, this approach integrates realistic *virtual reality* representation with computer-aided design tools (CAD, CAE) and software development environments (CASE). An experimental virtual design environment is illustrated in Figure 6.

The virtual design space provides the designers means to create computational representations, which reflect the designers' idea of the product. In the early stages of design this computer-based platform is the playground where ideas are crystallized in a visual form, and consequently, can be tested and communicated to other parties. In the subsequent design phases, the same platform can introduce increasingly accurate product models, e.g. for testing software functions and validating user interfaces. In its advanced form the virtual design space acts as a platform for product simulations. Starting from the earliest phases of design, all stakeholders can take part and establish simulation sessions to achieve a realistic impression of the future product and its use.

Considering the increasing role of software in products virtual design is especially attractive. When designing software intensive products, the border between virtual and real product components becomes fuzzy. A virtual presentation of a product can also contain real product components. It is possible that a major part of the design object consists of real product components, or so realistically simulated product components that the virtual product presentation is usable in terms of the original product requirements.

Aerospace and car industry are recognized pioneers in virtual design. However, virtual design is an interesting approach for software intensive consumer products, like mobile telephones, fitness applications, portable multimedia and television terminals, personal navigators, automobile electronics and so on. With these products it is necessary to demonstrate both the product and the service which are used through the product. Commercial design environments offer already advances features: early, full digital prototypes, combination of physical mock-ups with simulated behaviour and real applications, and compiling behaviour simulations into actual runtime product software (see for example Cybelius Maestro 2005).

Virtual design, from a technical viewpoint, can be seen as a product design environment, but it is as important to see it as a business-development framework. It offers advanced product presentations, employing digital product models and simulations through the whole product life-cycle. Contributing participants, usually product designers, develop the presentation further: they provide new material and components for the presentations. Other parties, such as marketing managers, utilize the presentations in selected forms in their own tasks. If the user interface is presented completely, the virtual presentation originally created for design purposes can even be used for web-based customer support and training.

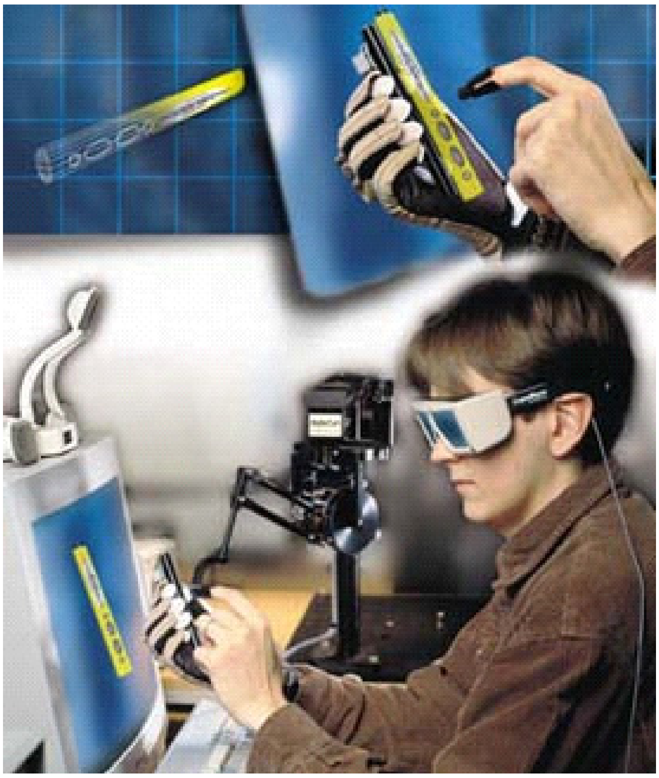


Figure 6. Experimental environment for virtual design (VTT Electronics).

4. Planning and deploying product creation processes

4.1 Nature of SE/PLM deployment

The planning and deployment of systems engineering and product life cycle management (PLM) is challenging. They both provide support for various engineering disciplines while retaining holistic viewpoint to product development and management. The systems engineering models were originally directed to support the creation of very large and complicated defence and other computer systems. Usually, however, the models used are simplified and idealised, whereas the development in real life is complicated and furthermore the detailed processes company specific. The PLM of a complex product appears as a collection of information management systems. The developers use these heterogeneous tools that manage data of several kinds. Deployment of tools for product life cycle requires understanding of the product development process as whole and defined practices in tool interactions. The amount of existing information management systems, desired new systems, and need for consistent product information management compose a complex that is beyond “a single system deployment”. At the worst case, there are several disciplines, tool categories and processes that need to be considered simultaneously. For example, Peltonen et al. (2002) state that for most companies the parallel deployment of several information management systems tends to be too complicated.

SE/PLM deployment contains characteristics from information system development, process improvement, and project management. Information system development includes at least tool requirements definition, tool selection, tool deployment, and verification. Additionally, process improvement is needed to manage the change and perhaps further develop and enhance the business processes.

Project management is needed for coordinating the whole development effort. Traditional project management is involved in carrying through a SE/PLM project. The role of project management is to coordinate the development work and to ensure that the development work is done in the frames of schedule, resources, and budget. In literature there are several guidelines for deployment projects. For example, Sääksvuori & Immonen (2004) describe stages that typical PLM projects pass. They emphasise that PLM improvement project is above all *a development project for business processes related to the formation and use of data*. The tools are used to bring systems and discipline to these processes.

4.2 Diversity of improvement models and standards

The improvement of systems engineering and product information management is above all a development project for business processes related to the formation and use of product data. The role of the engineering and product information management systems is to automate and to bring control to these company-specific processes. For example, Sääksvuori & Immonen (2004) state that how and at what level each company carries out its own PLM always depends upon the viewpoint from which problems are examined as well as from the company's objectives and strategies in this area. Therefore, the planning and deployment of SE/PLM happens always in the context of the company.

Various models and standards exist to help to assess, rationalize and develop business processes. For example, the ISO 9001:2000 standard emphasizes continuous improvement and ISO 15504 provides a framework for developing improvement method that complies with the standard. TQM (Total Quality Management) (Deming 1982) provides a systematic way to improve quality. It aims at comprehensive quality control that covers all functions in an enterprise. CMM (Capability Maturity Model) and CMMI (CMM-Integration) provide an assessment framework for assessing the maturity of processes. On the other hand, improvement is emphasised in Pr^2imer approach (Practical process improvement for embedded real-time software) (Karjalainen et al. 1996), which provides steps for analyzing, modelling, improving and measuring processes.

4.3 Understanding process improvement

From the organizational viewpoint, improving or implementing processes requires careful consideration. A straightforward process re-engineering approach has appeared to be risky, and is being replaced with more sensitive techniques. Every working organisation has developed and established ways to operate, communicate, and create results through a lengthy, iterative learning process. Even if processes would appear to be sparsely documented and ill-managed, they most likely are functional and fairly efficient in the company's context. Contemporary organisation-development research largely agrees upon that a system comprising of human activities can never be totally described, managed, or instructed. This is especially true with such sophisticated and creative activities like technical design and product development, where processes are largely guided by invisible, silent personal and organisation's cultural knowledge.

The lesson learned is that a process model, with all its detailed procedures, work instructions, and data resources, is not a template which the employees should imitate mechanically. Rather it should be understood as a framework, which provides guidance, instructions, and resources so that people can organise and plan their activities and direct their individual creativity in the most efficient way.

The general risk in a process improvement action is discontinuity. A new process always disturbs the social and personal networks and knowledge acquisition, which are essential for process execution and could degrade the performance of the whole organisation, even for a prolonged period. Additional side effects may be produced through suffering work motivation and organisational conditions. Process change may also launch political battles of power within the organisation.

We suggest reducing the risks of process change through a disciplined approach: attitude towards learning, honouring the principles of process modelling, and by a goal-oriented and well structured change process. The reasoning of this suggestion is as follows:

- Learning is an essential element in process improvement: it is a learning exercise for all participants. The process-improvement team should initialise the effort with a comprehensive learning process: how the organisation operates and why it operates the way it does. This phase essentially means collection of data and listening to the people. But it should also include learning some more common things: how to compare and measure the present operations; how these kinds of processes are typically conducted, and how he industrial processes are commonly evolving. Common quality standards and improvement frameworks are useful references, because they are usually results of comprehensive experience data and expert work. Data interpretation and analysis within the company requires such frameworks and theories, and the analysis phase is also a phase of learning. Finally, in the process change and deployment phase the personnel of the organisation should be invited to the leaning process, to create a shared understanding of the new process, and to provide feedback for further improvement of the new process.

- Process analysis and process management principles are used to create compact and informative process descriptions, to streamline the design of organizations, and to focus the planning and management efforts on the essential issues. Processes should be modelled along with the fundamental material and information flows, regardless of the formal decomposition structure of the organization. This does not necessarily mean that the organization structure had to be made identical with the process structure. The goal could be that positions in the processes are role based: people participate into the processes according to their roles, for example as performers of technical tasks, review tasks, inspection tasks, or approval tasks. Formal decomposition into basic process elements helps to define the essential focus of the processes: *input* is what is the necessary material or information to be processed, *output* describes accurate results, *resources* are needed to perform the process, *transformation* or *procedures* describe the actual tasks, and *control* includes managerial attention as appropriate. Finally, it is useful to check that each process has a clear *purpose* and *objective* regarding the core business performance.

- Process improvement and process deployment are planned and implemented as a goal-oriented and well-defined process, and often implemented in the project format. Objectives of the effort are clarified; roles of the change coordinators are defined; careful data collection and analysis precedes the definition of improvement actions; the action plan is refined according to the analysis; and each stakeholder's commitment to the plan is assured through reviews and discussions. The final and critical step is the actual implementation of the change, which means communicating the process descriptions and work instructions, training, phased deployment, and collection of feedback. The process maintenance or quality management functions should be early included into the process. The quality personnel should take the responsibility of processes maintenance from the very beginning, and it is most natural to start from the deployment phase.

5. Survival kit for product process deployment: the Product Experts' Knowledge Base

In the previous chapters product creation patterns and process change management were discussed. To conclude with practical actions to meet the challenges of smart product development, we propose SE/PLM enhancement as follows:

- The entire product life cycle must be covered: planning, design, manufacturing, distribution, and after sales, taking into consideration the product stakeholders and partners outside the company.

- Complexity of product related processes, which might lead to expensive and time consuming deployment projects, is tackled by learning from common systems engineering and discipline-specific development patterns.

- To implement the change, improvement frameworks and process quality standards are applied.

- Managing and coordinating the SE/PLM deployment as a goal-oriented activity, with process improvement involved early and in a sensitive and reactive way.

- Taking into account the mutual needs of, and interactions in between, the product process deployment and the information systems development.

As we have discussed, the modern product development requires well-designed processes, it has to integrate tools that create and manage the design artefacts and related data products, and it has to be executed in collaboration with internal and external product stakeholders and business partners. Setting up SE/PLM in this context requires combined skills of information system development, process improvement, and effective process and project management. Acknowledging the challenge to find techniques, models, methods, standards, and the best practices to SE/PLM improvement activities, usually under a challenging timescale, we propose a framework for *collecting, evaluating, maintaining and utilizing expert knowledge*. The information is collected from wide range of sources, from product and systems engineering to process improvement; from the research community and from practitioners. This knowledge will include common technical, discipline-specific, and even company-specific items; checklists, templates, concepts, tools, experience reports, and performance reports may be contained. We call this framework as the "*Product Experts' Knowledge Base*".

Existing efforts related to the subject are e.g. Eder (1998) and Virkkala (1994). Eder (1998) defined a list of techniques or methods that can be utilised in various design phases. Virkkala (1994) examined creative problem solving and presented several techniques for the subsequent problem-solving phases. An example from a knowledgebase, although from another domain, is Metodix (www.metodix.com), which is an Internet-based repository and e-learning environment for the scientific and applied research, its methodological background and practical implementation.

The knowledge base should not contain just static "one-type-of" method chains, but provide the pool of methods which can be searched according to the needs of all common improvement activities (see Figure 7).

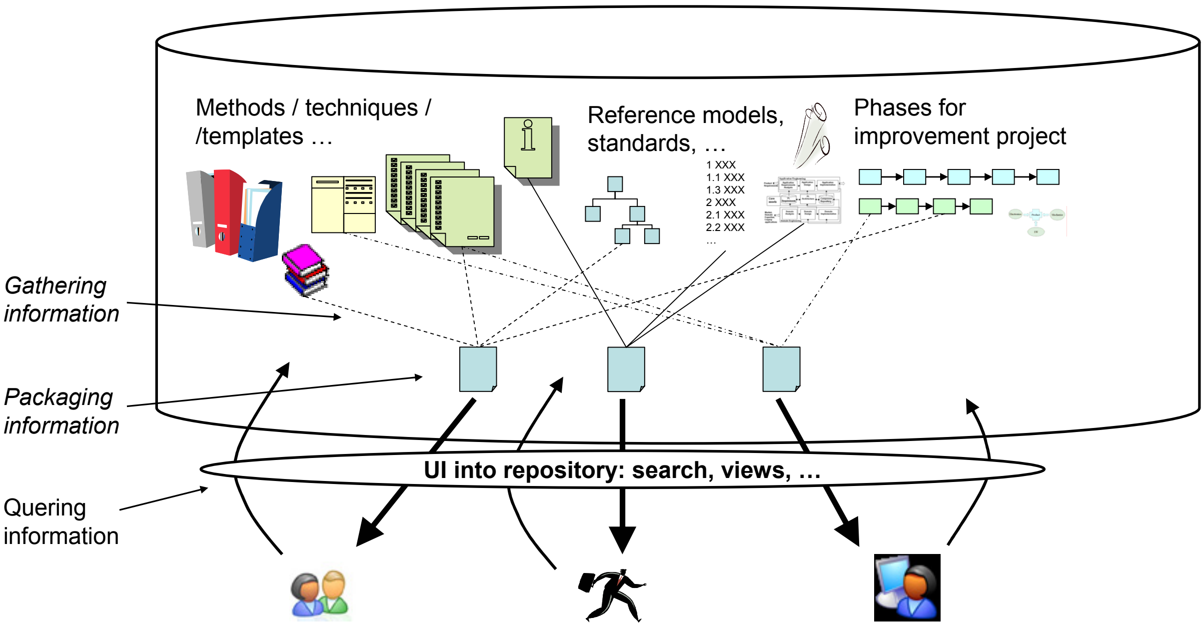


Figure 7. Data from the Product Experts' Knowledge Base is searched and utilised in practical development projects.

Implementation of the repository will provide easy-to-use means for searching, filtering, and selecting practical methods from the knowledgebase, packaged into an exploitable format. The implementation will run on standard office workstation, based on either open technology suitable for describing complex dependences (e.g. Resource Description Framework, RDF), or as an extension to an existing tool, e.g. "the General Expertise Management Tool Gem" (Gem 1.0, 2004).

To make the proposed "Product Experts Knowledge Base" a viable and useful resource, it is developed as coordinated activity, and the knowledge base will be controlled and operated through well defined and commonly agreed rules and operating principles. Fore example, public and restricted domains can be established, for example to encourage new parties to join the effort, and to allow confidential distribution of company-specific information in virtual organisations and among business partners.

The authors of this report are convinced that the industrial co-operation of product-developing companies is strategically important to strengthen product development and the supporting processes against global competition. Applying systematic approach and learning from the common and company-specific experience is needed to meet the challenges of the new industrial structure. We further believe that the target should be real life and field experience of deployment and utilisation of product processes, supported by methods, models, modern tools, and science based understanding. We are continuing the effort to develop the idea of the Product Experts' Knowledge Base, as a possible core concept and a shared business asset for this co-operation. We are also open to identify and promote any potential opportunities and ideas which might emerge from this work.

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