NordDesign 2004 – Product Design in Changing Environment
18-20 August 2004, Tampere, Finland

MANAGING DESIGN PROCESS OF INDUSTRIAL PRODUCTS

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Design management, process, industrial product

Abstract

This study focuses on the design process of industrial products, which are understood as technical systems that are used in business-to-business market. In industrial companies, a process-driven business model is increasingly gaining importance. To ensure sufficient market coverage, companies also strive for product variety. At the same time, the product is extended by intangible components, which consist of product-related services. An expert organization is usually responsible for designing the product and supporting a product family throughout its life phases. In this paper we advance a proposal that product, process and organization make one entirety with three aspects that may not be separated from each other. This proposal infers that we cannot influence on one aspect without interfering with the others. We strive to identify their key relationships in order to find elements that may be used for improving management of design projects.

1 Introduction

1.1 Motivation

Many industrial projects have proven how difficult it is to control the design process in such a manner that keeps all stakeholders satisfied. At least, managing time, quality and costs seems to be an inherent problem in large design projects. Why? There isn't any explicit answer. Industrial companies and the way they are doing business have drastically changed during the past 20 years. This change can easily be seen on the design processes, design tools and design organizations. Surprisingly, despite the change the problems seem to remain.

The author has had the opportunity to stand on the vantage point and make observations in a company that designs, manufactures and sells diesel powered solutions for marine and power plant applications. This paper is based on author's experience in developing of design tools and processes, and serving as a manager of a design organization. To give a consistent structure for them, the observations have been placed in the context of known models of technical systems and design processes. Driving force for this study has been the interest in understanding the key relationships between the three aspects where the problems have remained over the years. The objective has been to learn more about the topic and find ways how we can better manage large design projects for industrial products.

1.2 Background

Design organization is searching new forms and designer's role is expanding to new expertise areas. At the same time, there is a continuous strive for increasing design processes performance and design organization's productivity. New design tools and global networks have created new challenges both to the designers and especially to the design managers.

Despite the systematic approach of project management, every case is different and includes particular features that call for situational consideration. Even a careful planning does not guarantee stability in the design environment. On the contrary, it is likely that some essential changes occur in the premise: new technology calls for knowledge that is not available at a reasonable time or cost, the design scope creeps because of evolving market needs, there is uncertainty in financial conditions, and so forth.

We know from the practice that to keep the project schedule and/or budget, the external changes may be compensated by redefining the product being designed, restructuring the design organization, or adjusting the design process. Naturally, each case calls for a thorough analysis but knowing the fundamental relationships between product, process and organization helps us find quickly the right direction for the decisions.

2 Industrial product

Industrial products are designed, manufactured and sold for business-to-business market. [Hubka&Eder88] classify them into III and IV class of complexity. Typically, their functional features are decisive but also their life cycle costs and environmental impact are important decision criteria. Because industrial products make a part of customer's investment program, time component in the delivery process is crucial. Often the industrial product is made-to-order or engineered-to-order and the sale takes place between seller's and customer's organizations. The intangible part of the product – the services – is getting more and more attention in product planning and the companies are increasingly striving for growth in the life cycle support business. Usually a delivery includes at least product's installation, testing and on-site training.

2.1 Spatial and developmental variety

Company's products can be considered as elements in a space, which is defined in two dimensions: spatial variety and developmental variety. In industrial applications, every product individual involves adaptation to some degree, ranging from simple adjustments to extensive customer-specific engineering aiming at a tailored product derivative. These types of adaptation add to the *spatial variety*. It is related to the number of market segments and hence refers to the range of products that the company offers to the market; [Martin99]. The other dimension is time-related: In the course of time a company releases product updatings and new product generations, which later replace the old ones. The set of these successive product revisions at a certain point of time forms the *developmental variety*; [Suistoranta03].

2.2 Structures of an industrial product

The modern infrastructure facilitates communication between different institutions, industries and companies all over the world, allowing for profitable advances in combining knowledge from different fields. As a consequence of this technology fusion, [Phillips01], an industrial product is today an integrated package of various technologies. They take shape in different systems, like mechanics, electronics, and software, which form structures based on technical disciplines.

In order to ensure a wide coverage of market segments, companies strive for product variety, which is realised by means of configurable product families. Each configuration meets a specific combination of functions and properties and is built from a set of predefined solution elements. Typically the solution elements take shape in standard modules, which are more or less independent chunks.

The chunks can be decomposed into process, function, organ and component domains. We can also regard a proven technology, concept, application principle, subassembly, component, parts list, material item, and drawing as a predefined solution element. This infers that apart from different levels of abstraction, the industrial product can also be structured in different levels of specification. To extend this reasoning to non-standard products we notice that special requirements can always be met with customer-specific engineering, which typically combines standard and tailored solution elements.

3 Process

3.1 Business context

Processes and process management have gained increasing interest in business context under the recent years. The idea of modelling business as a net of processes is by no means new. Maybe one catalyst for this development has been the introduction of enterprise resource planning systems (ERP), which have forced the companies to describe formally their business processes.

There are many definitions for a process in the literature. However, in a business context some common features can be listed:

- A process is a set of linked activities and resources to obtain the desired result from a given input
- Processes cross the functional borders and are independent of the organizational structure
- Process thinking is interested in *how* to do, while the functional thinking emphasises *what* to do
- A process progresses in a systematic way, having a clearly defined start and finish
- A process has an explicit input (e.g. assignment, material, information) and the outcome (e.g. product, service, document)

Business process starts at the customer and ends at the customer, forming a continuum of activities. It can be split and arranged into sub-processes with distinct interfaces. These sub-processes are used to build a process map of company's business. It is a compound system of activities, data flows and operators. The process map defines the activity chains and their relations, including their order, hierarchy, types of operand, inputs and outputs, see Figure 1.

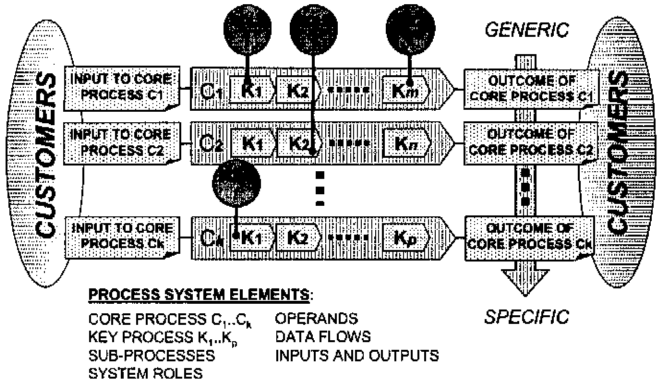

Figure 1. Business can be modelled with a process map, which is a system of hierarchically ordered activity chains (processes), system roles, operands, and data flows.

3.2 Product's origination and life cycle

The life span of a technical system can be thought of as a process of four major phases: Origination, distribution, operation and liquidation. Each of these contains partial processes, which can further be divided into operations; [Hubka&Eder88]. This is a generic description with no reference to any business or organization.

There are four points in the life cycle process with specific meaning. We call the first one *origination point*. It means the point, where we can consider the technical system to originate; i.e. its first idea in a human brain. This moment may be difficult to determine and would raise a vivid debate in the inventor's community. For pragmatic reasons we keep a *development decision* as technical system's origination point, even if it would be equally difficult to identify.

The second point of interest occurs after the technical system has been delivered to the customer's premises. This signifies that the technical system changes its essence from operand to operator. We call this a *handover point*. The third point signifies that the technical system changes its essence back from operator to operand. We call it a *decommissioning point*. The last point signifies the removal of the technical system (disassembly on explicit decision or destruction) and we call it a *liquidation point*.

If we map the technical system's life cycle process into business context we can make the following observations:

- The origination process encompasses different phases of product's designing and is embedded in company's business processes. In the case of an industrial product, the customer's order can be regarded as the origination point and then the actual design process may start accordingly. The product takes shape from the origination point to the handover point.
- From the handover point to the decommissioning point, the product operates in the customer's business. However, if the selling company provides after sales services, such as maintenance and operational services, the product can still be regarded as an operand in the seller's business. As discussed earlier, service makes an intangible part to the core product

and hence extends the selling company's direct involvement up to product's latest life phases.

- Each product lives through an individual life cycle process, which is linked both to the seller's and to the customer's business processes. In addition to these, also other companies or interested parties may be involved. These links are very strong because the product is the cornerstone of business. They also relate the customer's requirements and other feedback upstream to the company's process pipeline.

3.3 Design process

The design process in business context has different phases. The contents and outcome of phases vary from company to company but basically they have same elements, which are grouped under particular process names, see Figure 2.

Product planning has a strong link to company's strategy and sets targets for product's commercial performance. Market coverage requirements call for efficient product variation and thus a development decision for a product family is needed. Product development results in application principles and concepts, which serve as bases for the product and its solution elements, such as configuration structures, sub-systems, modules, and components.

Configuration design can be divided into two parts, which we denote here with CD I and CD II. CD I has a link to the sales process and its outcome is a structure with consistent building blocks that are combined to satisfy different needs of customers. CD II has a link to the manufacturing process. The purpose is to create from the sales configuration a product specification, which can be converted into a production order. This fact infers that CD II serves also as a basis for material supply and other logistical functions.

Customer solution engineering or customer-specific designing strives to find and realize installation-specific, efficient and environmentally friendly solutions according to customer's requirements, based on predefined solution elements. CD II yields standard specifications and product development yields standard modules and components, which are then used as input for customer solution engineering.

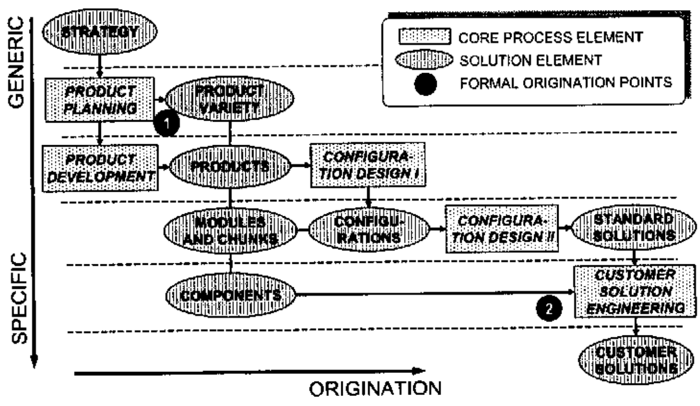

Figure 2. Product's origination takes place in company's design process, which is traditionally functionally organized.

3.3.1 Multidisciplinary design

Design process for an industrial product involves at least mechanical, electrical and software design. In principle, there are no differences in their theoretical basis. However, they are often treated in practice as different domains of designing with dedicated operators, who are correspondingly called mechanical designers, electrical designers and software designers. They need to work closely together in order to integrate their domains to form a complete product.

There are some barriers that hinder the efficient co-operation of multidisciplinary designers. First, every designer works in his own solution space that is specific to his discipline. This results in different states of existence for the solution elements, and hence causes misalignment in the project schedule. Second, each discipline has its particular features, which call for different types of knowledge and different contact networks (colleagues, suppliers, consultants, official bodies, etc.). Third, their professional education traditionally emphasises different areas of design theory. This has also resulted in specialized design tools, such as CAD software packages.

4 Organization

Time-based competition, technology-pull and a quest for cost reduction have forced the companies to find ways to shorten their product development cycles. Today they are searching for partnership, which basically means technological co-operation and collaboration between and at all levels of organization, both at the supplier and at the manufacturer. Also customer involvement is increasing, which means that the manufacturer builds its design and manufacturing processes accordingly. We can see that the company (manufacturer) is no more working isolated: Its design organization has virtual extensions at the supplier and at the customer.

Modern information technology has facilitated designers to collaborate and share information globally. While this development has increased the knowledge base and design organization's flexibility, it has also brought the people apart. This means that today the design organization is physically getting more and more fragmented.

4.1 Structures of design organization

To ensure sufficient resources, the companies can hire designers from external parties, such as engineering offices, institutions, and the like. They can also outsource their own resources either partly or totally but keep the management responsibility. In fact, companies have many options to organize their design resources. Without going deep into the organizational theories, we simply notice that design organization is built on various structures.

The *functional structure* is often analogical to the official organizational chart, where the functions correspond to the traditional phases of design process: Product planning, product development, configuration design, and customer-specific design. Naturally, the names and the borders for these functions are company-specific. A functional structure can also be based product-wise.

Within the functional structure, we can group the designers according to their expertise area, professional experience, and educational discipline. They form a *competence structure*, which in practice greatly determines how the design tasks are allocated.

Designers can sit in the same office or they can be decentralized in different locations, even around the world. This leads to a *geographical structure*. Despite the opportunities of information technology, communication between the designers diminishes rapidly as their distance grows.

4.2 Designer's roles

4.2.1 Traditional and current roles

Today designers have several responsibilities both in the formal organization and in different working teams. Often one designer participates in parallel design projects, which vary in contents: Some may involve simple redesign tasks for current cash cow products while the others are comprehensive projects aiming at a new product generation.

A designer's current role oversteps the traditional drafting and producing of documents. He is increasingly involved in technical reviews as an expert and gives technical support both to the manufacturing organization and to the sales people. He is consulted about new supplier candidates, especially when examining manufacturing technologies for a component. One extremely important role is to serve as a mentor for novice designers.

All in all, a designer works, at least in thinking, with several time schedules, on many abstraction levels and with varying ambitions. We can describe the designer's various tasks and responsibilities with a scheme of *natural roles*, which are time-dependent and have a certain preference order in designer's mind.

4.2.2 Roles in business context

As discussed earlier, the company's process map is a system of value-adding sub-processes, where also those activities that belong to designing are embedded. On one hand, the process map supports enterprise resource planning and control, on the other hand it disperses the operations that traditionally were grouped under various functions of product design.

In the ERP systems, operational tasks are assigned to impersonal 'system roles'. They determine what an operator can and may do in the system. Depending on one's job description, the operator can have several roles in one or many processes; see Figure 1.

Even though the process map is by no means an organizational chart, it has shaped the designers' territory. Their traditional tasks have been increasingly absorbed into the business context, where the designer is a role rather than a profession. System's process definition does not determine designer's habitus; he may be a senior or a junior, only a list of required and allowed transactions is given for the role.

5 Complex

5.1 System approach

So far we have discussed about an industrial product, business processes and organization as sets of structures. However, we can easily see that each of them can be regarded as a *system:* technical system, process system and societal system. While each of them can be treated individually with own elements and relationships, they can also be understood as one entirety – a complex; see Figure 3.

The system approach allows us to list some common features of the product, the process, and the organization. First, they have own life cycles. Second, all are subject to market situation and they are part of an active environment. Third, they can be developed, controlled, bought and sold. They can be characterized by performance, flexibility, capability and efficiency, and they can be measured in terms of time, cost and quality.

In a business context we can regard the product as a core, where the processes (or the way of working) and the organization (people) are its extensions.

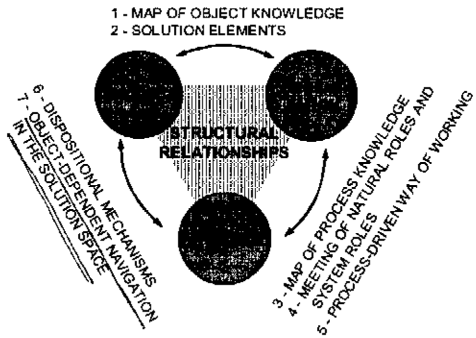

Figure 3. Product, process and organization make one system

5.2 Relationships

To facilitate design management we need to understand the complex as one system. In addition, we need to identify the relationships, which are based on the structural features of product, process and organization.

5.2.1 Knowledge maps

[Hubka&Eder96] present a model of technical knowledge. We can use this model to elucidate designer's knowledge areas, which form patches in the total area. In a similar way, we can build a map of a designer team's knowledge areas by projecting the patches of each individual and linking them together.

Knowledge map has two main aspects: Object knowledge and process knowledge. The former one is related to technical systems, i.e. the product and its extensions. The latter one is related to the processes, i.e. to the origination of the technical system.

5.2.2 Solution elements

As discussed earlier, the technical system can be understood as a configuration of solution elements, which has many structural views. Each of them can be linked to the map of designer's object knowledge. Changing the view requires a different knowledge emphasis and vice versa; changing the knowledge map (i.e., changing the designer) causes a different structural view to the configuration of solution elements.

5.2.3 Applying process knowledge in design situations

Design process is an infinite set of operations at different levels of abstraction, ranging from a generic problem solving to the specific command sequences on a workstation. The operations can be grouped to form systematic design tools with formally defined steps, which also are governed by various codes and rules. Nevertheless, they still leave much latitude to the designer. This may be called *situational consideration*; the designer applies his map of process knowledge to the design problem and this leads to a dissimilar result if design situation changes. This may be seen also vice versa: Changing the designer to one with a different map of process knowledge leads to a dissimilar result in the same design situation.

5.2.4 Dispositional mechanisms

[Olesen92] introduces the term *disposition* to signify "that part of a decision taken within one functional area, which affects the type, content, efficiency or progress of activities within other functional area." By substituting functional areas with the process model we arrive at similar mechanisms, where dispositions form a product-related linkage between different sub-processes. In the same way we can reason that decisions made for a specific process (say, manufacturing) may affect to the product.

5.2.5 Object-dependent navigation in the solution space

According to [Hubka&Eder88], a technical system's state of existence can be expressed in terms of maturity and completeness. It depends on the time elapsed from the beginning of the origination process. This process can be seen as navigation in the solution space, where every object that is designed follows a specific path. The 'form' of the path depends on how the design project has been set up, i.e. its time schedule, resource plan, and financing plan.

Figure 2 shows different levels of specification for a product. Each level can also be regarded as an object of a design task. Hence, to design an entire product, we must design various product-related objects: product structures, chunks, components, and the like. In a design process, every object originates and evolves following its individual path, Figure 4a.

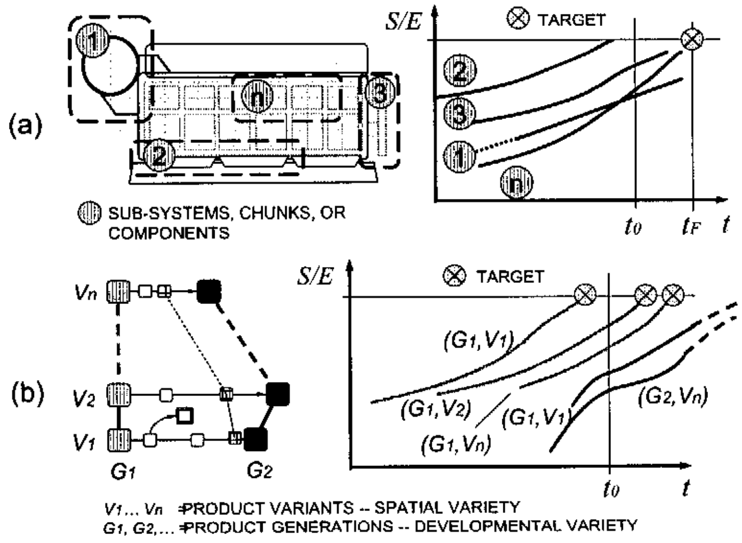

Figure 4. a) Technical system's state of existence follows different paths that are specific for the subsystems. b) Product variety has many states of existence at a particular point of time.

We call this relationship *object-dependent navigation in the solution space* and it couples the object with the product's design process. Even though the tasks are interrelated, the object-dependent navigation leads to varying states of existence at a particular point of time. This causes a coordination problem in a design project because usually tasks are scheduled and milestones set for complete blocks of product, where each one involves objects of different states of existence. A similar relationship can be found between design process and the product variety, where each variant progresses on one's own path, Figure 4b.

5.2.6 Meeting of natural roles and system roles

Designer's natural roles are attached to all tasks that a designer is responsible for. A designer performs the tasks under his scheme of natural roles, which embodies also the effect of human factors, such as motivation, ambition, preferences, and the like. System roles, in turn, include transactions that the designer is forced to perform in a specified order and make the designer work tightly coupled with the process system, leaving not much room for creativity. This causes incompatibility between the natural roles and system roles. Generally, it is question of adopting a process-driven way of thinking and working, which calls for organizational change management.

6 Conclusions

6.1 Results

In this paper we have studied the industrial product and its origination process in a company's traditional design environment. We have also elucidated how the organizations are restructured and designers' roles are redefined as companies introduce process-driven business models. Based on these discussions we have advanced a proposal that product, process and organization make one complex in the business context. It forms a system, whose elements are coupled to each other with complicated relationships. Identifying and understanding these relationships helps us make right decisions during large design projects.

6.2 Suggestion for future studies

The identified key relationships need further studies for expressing them in a more explicit format. This would require a refined model of the complex, taking also the changing business environment into account. The objective would be to develop systematic tools, which could facilitate in managing design projects for industrial products.

References

Hubka, V. and Eder, W.E., "Design Science. Introduction to the Needs, Scope, and Organization of Engineering Knowledge, Springer-Verlag Berlin-Heidelberg-New York, 1996.

Hubka, V. and Eder, W.E., "Theory of Technical Systems. A Total Concept Theory for Engineering Design", Springer-Verlag, Berlin-Heidelberg, 1988.

Martin, Mark V., "Design for Variety: A Methodology for Developing Product Platform Architectures." A dissertation for the Degree of Doctor of Philosophy, Stanford University, November 1999.

Olesen, J., "Concurrent Development in Manufacturing – Based on Dispositional Mechanisms", ISBN 87-89867-12-2, Institute for Engineering Design, The Technical University of Denmark, Lyngby, 1992.

Phillips, F., "Market-Oriented Technology Management. Innovating forProfit in Entrepreneurial Times", Springer-Verlag Berlin-Heidelberg, 2001.

Suistoranta, S., "Managing Industrial Products of Different Developmental Stages", Proceedings of the 14th International Conference on Engineering Design, Editors A Folkeson, K Gradén, M Norell and U Sellgren, The Design Society, Stockholm, 2003,File No. 1123.