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Product Configuration in Projecting Company: The Meeting of Configurable Product Families and Sales-Delivery Process

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"Always design a thing by considering it in its next larger context – a chair in a room, a room in a house, a house in an environment, an environment in a city plan."

-Eliel Saarinen

Abstract

The work presented in this dissertation is a qualitative research in the field of engineering design. The applied research method involves case studies and interviews in the industry. The data collection methods are briefly explained. A literature review is presented for the purpose of crafting the method of analysis for the collected data.
The context of the research is a projecting company which carries out sales-delivery processes with a project-based business paradigm. The concept of projecting is defined along with the engineering design and product development literature. The emphasis is on the project management situations as well as on the propagation of the engineering change. It is argued that the propagation of changes causes the project management situation to evolve from one stage to another. Moreover, with product configuration the evolution of management situation can be controlled.
An engineering design process is reviewed from the viewpoint of product structuring. The problems related to the development of standard, fixed products are reviewed and related to projecting. It is argued that the standardisation of product structures and architectures as a configurable product family can alleviate the problems related to the evolution of project management situation.
The different stages of product development are reviewed. Product configuration is defined and examined from both the design knowledge and the reuse point of view. Product configuration is presented as an option for product design in projecting. The sales-delivery processes are studied from the viewpoint of customization in process, product standardisation, as well as production. It is argued that the customization as well as standardisation of product design affects the sales delivery processes which constitute the state of a sales-delivery process. It is argued that the development of configurable product families is a means of transforming the state of the sales-delivery processes. Moreover, the scope of transformation, the functions and the organisations of sales-delivery project, are related to the means of transformation, the configurable product family. Applying the model of integrated product development is suggested.
The direct results of the interviews and the case studies are presented. In addition, an analysis of the collected material is presented. The analysis is conducted according to the synthesis of the literature review. It is pointed out that the changes of product design often have pervasive dispositional effects on the project activities. Thus, there is reason to believe that the first argument is valid. The application of configurable product families has had positive effects on the sales-delivery processes of projecting companies, such as sufficient engineering resources and shortened lead times. These are implications of the second argument, which can be regarded as valid. Both the interviews and the cases are related to the scope, means, and objectives of the development projects. The relations between the scope of the development project and its objectives are acknowledged. Also relations between the scope and the characteristics of the development project are examined. The cases and the interviews as a whole imply that the application of configurable product families in a projecting company is a means of transforming the focus from sales-delivery projects to systemic customization. This, however, requires the alingment of the means with the scope.

Acknowledgements

This report combines the pieces of knowledge derived from practical experiences. My experience is based on participation in a set of development projects in industrial companies as well as interviewing people who have expertise in the field. The set of projects started at the end of the previous millennium, with the Design for Configuration research project (DFC, 1997-1999), and four industrial companies with their own development projects. Verso-project (2000-2003) concentrated on the networking of companies participating in power plant delivery projects. Another research project, Conceptual Design for Manufacturing and Assembly (C_DFMA, 2005-2007), had a similar structure with eight industrial development projects. All three projects were funded by Tekes, the Finnish Funding Agency for Technology and Innovation. In between the two research projects, I have had an opportunity to participate in the instruction of seven M.Sc. candidates who wrote their theses for industrial companies. Three of the case studies derive from such a connection. The cases and interviews are shaded in Table 1. The contacts with people in the industry have been invaluable for my research. I am deeply grateful to the people in the companies for sharing a part of their time for the benefit of this research. The list of companies that have supported this research is presented in Table 1.

Table 1. The companies that have supported this research

DFC-project (1997-1999)	**Intermediate projects (2000-2006)**	**C_DFMA-project (2005-2007)**
Sandvik Tamrock (now Sandvik Mining and Construction)	**Verso-project (2000-2003)**	ABB
Kaso	Kvaerner Pulping (Metso Power)	Elcoteq
KCI Konecranes (Konecranes)	YIT Power (YIT Industria)	Konecranes
Tunturi (part of Accel Group)	Fortum Engineering (Metso Power)	Nokia Mobile Phones
Datex Ohmeda (part of General Electric Healthcare)	ABB	Nokia Siemens Networks
Neles-Jamesbury (part of Metso Automation)	Metso Automation	Metso Minerals
Ponsse	Wärtsilä	Perlos
Rocla	Fastems (2001)	Rolls Royce
Sisu Terminal Systems (Kalmar Industries, part of Cargotech Corporation)	Metso Paper (2003-2004)	Wärtsilä
Valtra (part of Acgo Corporate)	Profile Vehicles (2005-2006)	
Wärtsilä NSD (Wärtsilä)		

I am also obliged to Professor Asko Riitahuhta, who has not only shared his knowledge and contacts with his research group, but also supported and encouraged me in the progress of the research from DFC to C_DFMA.

A number of researchers have had an influence on the research reported here. In the Workshop of Product Structuring and Modularisation 2003, in Copenhagen, Professor Niels Henrik Mortensen advised me to "*just carry another little stone on the mountain*". In the International Conference on Engineering Design 2007, in Paris, Ulf Harlou and Petri Huhtala encouraged me to push through with my ideas with such sentences as "I see that there is a contribution..." These small words have had an effect that is more valuable than one might conceive at first glance. I also appreciate the efforts of Juha Tiihonen, Timo Lehtonen, Tero Juuti, Kati Sarinko, and Heli Laurikkala as well as Davor Pavlic and Mikko Vanhatalo in research projects where the situation has varied from complex to almost chaotic. Also, comments from the group of industrial Ph.D. students have been important. In particular, discussions with Seppo Suistoranta, Hannu Oja, and Niko Salonen have deepened my insight on the practical problems in engineering design. I am grateful to Rea-Maria Lehtonen for the proofreading of this dissertation.

However, work and studies would be just too hard to bear without friends and family, who, in the words of Mohammed Nadir, give the "*strength of life*". I appreciate his advice and company in charging the batteries. My band mates from The Generations and The Harkko have provided me with opportunities to step out of the continuum of everyday chores. Thanks, Markus et al.

"Tie them sticks in a bundle and try to break that." Course they couldn't. Then I'd say, "That bundle... that's family"; quoting Alvin Straight. My wife has been indispensable in innumerable ways. Thank you, Inka! Also, warm thanks to my parents and parents-in-law for their support. I dedicate this work to my son Eelis, who has shown me the best example in the resilient steps of research, which generate the pure joy of success.

Kangasala, November 2007 Antti Pulkkinen

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List of Abbreviations

BPR, Business Process Re-engineering

CCSP, Conditional Constraint Satisfaction Problem

CAD, Computer Aided Design

CPF, Configurable Product Family

CPM, Critical Path Method

DFC, Design for Configuration

DFMA™, Design for Manufacture and Assembly

DFX, Design for X

DSM, Design Structure Matrix

ERP, Enterprise Resource Planning (system)

FMS, Flexible Manufacturing Systems

IPD, Integrated Product Development

JIT, Just in Time

KBES, Knowledge-Based Engineering System

MRP, Materials Resource Planning (systems)

OOA, Object-Oriented Analysis

OOD, Object-Oriented Design

OEM, Original Equipment's Manufacturer

PDM, Product Data Management (system)

PERT, Program Evaluation and Review Technique

PFMP, Product Family Masterplan

PLM, Product Life-cycle Management

PMBOK, Project Management Body of Knowledge

ROI, Return on Investment

SCM, Software Configuration Management

TBSP, Time Between Successive Products

TTM, Time to Market

UML, Universal Modelling Language

Introduction

In this research, the topic of product configuration is examined in the context of project business. Moreover, it is about the transformation of the sales delivery process from engineered to order to configured to order. The focus is in the product definition as it is the point where the knowledge of configurable product family (CPF) meets the sales-delivery process.

Apart form the scientific purposes, the dissertation presents a summary of the practical experiences on the approach to the topic in the given context. The experience is collected by both participation in a set of development projects which have been conducted over a long period of time, and interviews in companies. The theme of this thesis is the approach from product design in projecting to product configuration.

Background

In the late 1990s, the author started his career by participating in research and development projects. The objectives of these projects varied from enhancing the activities of design and supply in networked sales-delivery projects to improving the efficiency of product development in the manufacturing industry. One of the projects, "DFC - Design for Configuration" [Pulkkinen et al. 1999a & 1999b, Pulkkinen et al. 2000], aimed at developing a methodology for the family of methods called Design for X. Probably the most well known methods among the family are Design for Assembly [Andreasen et al. 1988] and Design for Manufacture and Assembly™ [Boothroyd et al. 1994].

THE IDEA OF DESIGN FOR CONFIGURATION. Ideally, the products of a company should be deliberately re-engineered as a configurable product family. This, instead of merely applying state-of the art tools for capturing the knowledge of the set of pre-existing or -planned products [Pulkkinen et al. 2000]. Also, the aim in the project was to analyse the ease of configuration, i.e. configurability, as a property related to products as well as to develop a computerized tool for the modelling and analysis of configurability. The idea adopted the concept of the DFMA™ tool released by Boothroyd Dewhurst Inc. in the 1980s. [Boothroyd et al. 1994]

However, during the project it became apparent that applying configurable product families is a many-faceted issue in companies. Moreover, it soon became uninteresting to decompose the problem of the application into a set of practical, generic sub-problems which is the case of Concurrent Engineering research [Tomiyama 1997]. Actually, the application of configuration appeared as an integral, entangled web of sub-issues and *per se* non-decomposable, in the sense of [Simon 1980]. Moreover, it is related to the transformation of a company [Rouse 2006].

Development at large

Developing business is an essential aspect of product development [Roozenburg et al. 1995]. Thus, a brief look at business development is given here, even though this research is about the development of configurable product families in the context of project business.

Characterisation of business by means

Business transformation can be characterised by scope, means and objectives [Rouse 2005]. The product and production types characterise the means of business. Moreover, these two are related to the scope and the objectives of a company. Traditionally, the four types of a product with different kinds of varying attributes in the product structure are presented as follows [Schomburg 1980]:

- Standard products,
- Standard products with variants defined by the company,
- Standard products with variants defined by the customer,
- One-of-a-kind product.

RELATED TO THE APPROACH AND MODE OF BUSINESS. Three generic business approaches are related to the above categorization of products and to the production volume which are the ingredients of the business scope. These are the serial (mass) production of standard products to stock, customisation by making and/or assembling variants to order, and delivering engineered to order products [Verho et al. 1993]. Naturally, the categorization is artificial and it is difficult to find companies that represent the approach purely. Instead, a company often has different kinds of products with different kinds of approaches.

MASS PRODUCTION VS. PROJECT ORIENTED BUSINESS. The mass production approach utilizes optimized production lines that make a volume of products according to sales estimates. Instead, engineer-to-order products are typically the results of large delivery projects that can be characterised as time and resource consuming as well as risk-intensive. In the former paradigm, the product and the production system are fixed (do not vary for each product delivery), while the market (the set of foreseen customers) is estimated. When the product is engineered to order for a known, i.e. fixed for a delivery, customer, the product and the production process is defined *ad hoc*. In both ways, product design is based on ill-defined knowledge, either about the customer or the delivery.

PRODUCT CONFIGURATION. In configuration-oriented processes both the production system, the product and the customer are fixed to a certain degree. However, the product is adapted to the specific customer's requirements according to a pre-planned scheme and produced by a system that can be planned in advance, i.e. fixed. So, the *ad hoc* estimation is either totally cut out or limited from the definition and delivery of an individual product. Also, the customer is fixed for a delivery. Therefore, a delivery is supposed to be based on well-defined facts, and the contingencies of a delivery are supposed to be minimized.

Different contexts

The generic business approaches have their counterparts in the activities of different functions as well as the structures of related knowledge and products [Sanchez et al. 1996, Victor et al. 1998, Miller 2000]. Here, the combination of processes and activities, product and organisation structures as well as data, information, and knowledge create the context of product structuring. The business approach is either a strategic choice or the result of a legacy that is reflected to the case of product structuring.

THE CONTEXT OF PRODUCT STRUCTURING. The scope and the objective of a company's business are related to the means of product structuring. For example, the market coverage is directly affected by the product portfolio, i.e. offering, of the company. The portfolio is composed of product families where products have structural commonality, or separate products. There, the variety offered to the market is related to the means of a company via product (family) architecture [Riitahuhta et al. 1998].

THE CONTEXT OF KNOWLEDGE SYSTEMIZATION. Similarly to product structuring, the knowledge capturing and systemization can be regarded as a means that indirectly meets with both the scope, the objectives, and other means of a company. The needs and the requirements of product and the articulation of its knowledge, optimization, and re-use vary a lot according to the business approach.

THE CONTEXT OF BUSINESS PROCESS RE-ENGINEERING. The business approach is reflected on a number of other contexts and points of view. For example, marketing and manufacturing functions operate in a different mode when the products are engineered to order than when a large number of standard products are sold to a set of customers, i.e. market. As presented on the previous page, the effect of business approach to the product structuring is probably most evident in the product design and sales delivery processes. The constitutions of processes are remarkably different when the approaches are being changed which is the topic of this research.

Archetypes of transformation

Globalization leads companies to seek higher competitiveness through higher profit. Higher profitability can be achived by the increase of added value with unaltered or reduced effort. To achieve this, the enhanced utilization of means is required. A business transformation aims at higher value as well as the improvement of means to make it. The objective of transformation can be the expansion to new markets and striving for higher profits for shareholders that are also globally scattered. The archetypes of transformation are [Rouse 2006]:

1. Transformed value propositions are the transformations of business models and market offerings.
2. Transformation via acquisitions and mergers which involves the transformation of the acquired company.
3. Transformation via new value proposition means the development of completely new business model and practices.

The real transformations, i.e. transformations in companies, seldom occur as evident cases of a certain archetype which represent the characteristics of transformations. Takeovers and mergers are an option addressed for expansion; they represent the second archetype. However, transformations within a company or the network of companies are the options of increasing the overall productivity and, consequently, shareholder value. The transformations within represent the combinations of first and the third archetypes of transformations and take place when a company changes its business models.

TRANSFORMATIONS BETWEEN PARADIGMS. Transformation is often considered a change from mass production to business process re-engineering [Hammer et al. 1993] and lean manufacturing [Womack et al. 1990] or to mass customization [Pine 1993, Olsen 1998]. However, other kinds of transformation are also recognised by [Anderson 1997, Victor et al. 1998]. According to them, businesses typically evolve through a fixed sequence of transformations from one paradigm to another. According to Anderson [1997], Victor and Boynton [1998], a company can transform from craft to mass production and further from mass production to process enhancement and furthermore to mass customization, but not directly form craft to mass customization.

DIMENSIONS OF TRANSFORMATION. In the transformation, the scope of business, the means to run it, and the objectives of the business are changed [Rouse 2005]. The transformation of business involves changes in the levels of scope, such as activities, functions, organisations and enterprises. Similarly, the re-engineering of means takes place in transforming the skills, processes, applied technologies, and strategies. The ends of the business transformation are related to costs, perceptions, offerings, and markets.

Situation in industry

As this research is related to the application of configuration in an industrial practice, it is valuable to strive for an insight on the situation of the industry. As mentioned, part of the insight has been gained by personal participation in a number of interviews and cases as well as by attending discussions with the industrialists themselves. However, it is worth taking a look at the bigger picture on the incidents that taken place in industry during the past decade.

Opening economy creates challenges on productivity

Until the 1990s Finnish economy was protected by national rules and regulations. The economy was then gradually opened to the global financing as well as competition. Some of the milestones in this progress include Finland joining the European Union in 1995 and the introduction of the euro in 1999.

Positive issues have emerged, as the past decade has been a period of continuous growth for the Finnish economy. As a small economy, Finland has been susceptible to economic fluctuations throughout its history. In fact, the euro was commonly considered as a stabilizing element in the national economy. However, along with the growth as a trend, short-term alternations and changes have taken place, i.e. minor up- and downswings. Not only the trends but also the short-term changes have an effect on all of the development projects and processes that companies initialize.

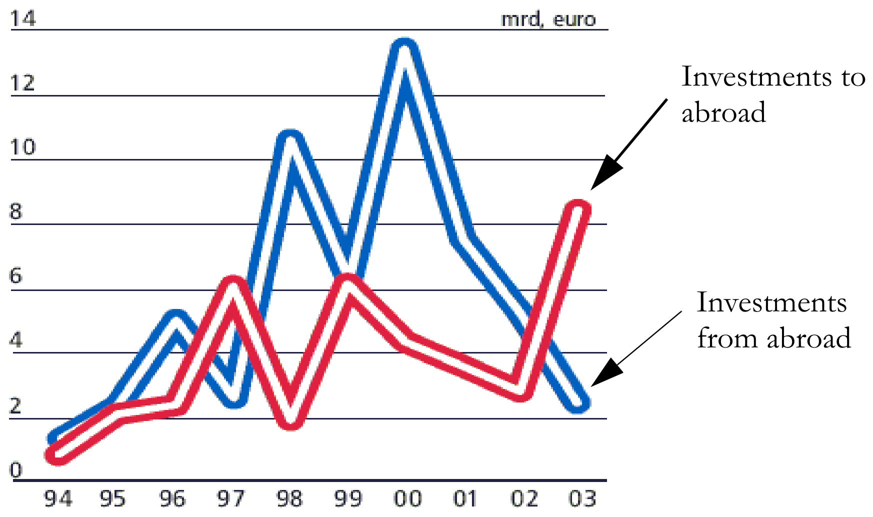

Figure 1. Investments to and from Finland [Puustinen 2004, p.26]

TRANSFORMATIONS VIA ACQUISITIONS. A recent trend in the Finnish economy is the large amount of mergers and acquisitions which is the second archetype of enterprise transformation [Rouse 2006]. Figure 1 indicates that in recent years, high-value Finnish companies have been bought by foreign investors. The value of purchases of Finnish investors has declined from the year 2000. Even though the foreign acquisitions have caused concern among the personnel in Finnish companies, a buy out by a larger international company can offer a larger position in the international market. However, an acquisition or a merger or the set of consecutive mergers sets a considerable challenge to a company. Foreign investors typically require not only changes in organisations and how they operate, but investors also have high expectations for the return on investment as well as for the productivity of the company. [Puustinen 2004]

Fluctuations in growing production

Figure 2 presents six characteristics describing the development of the Finnish industry during 1995-2004. The source for the data is Statistics Finland [Savolainen 2006]. The figures from statistics have to be proportional with each other, for enabling comparison. Consequently each characteristic value is compared to the value of the characteristic from the previous year. Thus, we acquire the columns in the Figure 2. The figure represents change, i.e. the percentage of increase or decrease in respect to the previous year. The columns represent the changes in the working hours of the employees and labour as well as their sum, added value of production, and the number of product deliveries and their ratio. The ratio is referred to as relative added value later on and it depicts the average value of products produced. In the rightmost column the overall change from 1995 to 2004 is illustrated.

LONG TERM – CONTINUOUS GROWTH. For example, the added value of production increased dramatically (by 11%) from 1996 to 1997, while it had decreased from 1995 to 1996 with 1%. The tendency continued during 1998 and 1999 with a smaller increase of approximately 8% and 4%, respectively. Also, the year 2000 was even more productive with an increase of nearly 16% in comparison to the previous year.

There has been an increase in almost all the characteristics of economy during our period of observation: on top of the number of deliveries, added value as well as the working hours of employees also increased steadily. The working hours of labour and the relative added value of product deliveries decreased. Apparently, the companies were producing deliveries with a smaller scope which indicates an increase of specialisation with more fine work breakdown structures (WBS) as well as an increase in competition.

SHORT TERM ALTERNATIONS. Figure 2 shows that during the past decade some major fluctuations have occurred in the Finnish economy. The relative added value in particular has gone up and down periodically. The periods of trends have lasted from two to three years. Second, as the number of employees increased, the number of workers dropped and the output of industry did

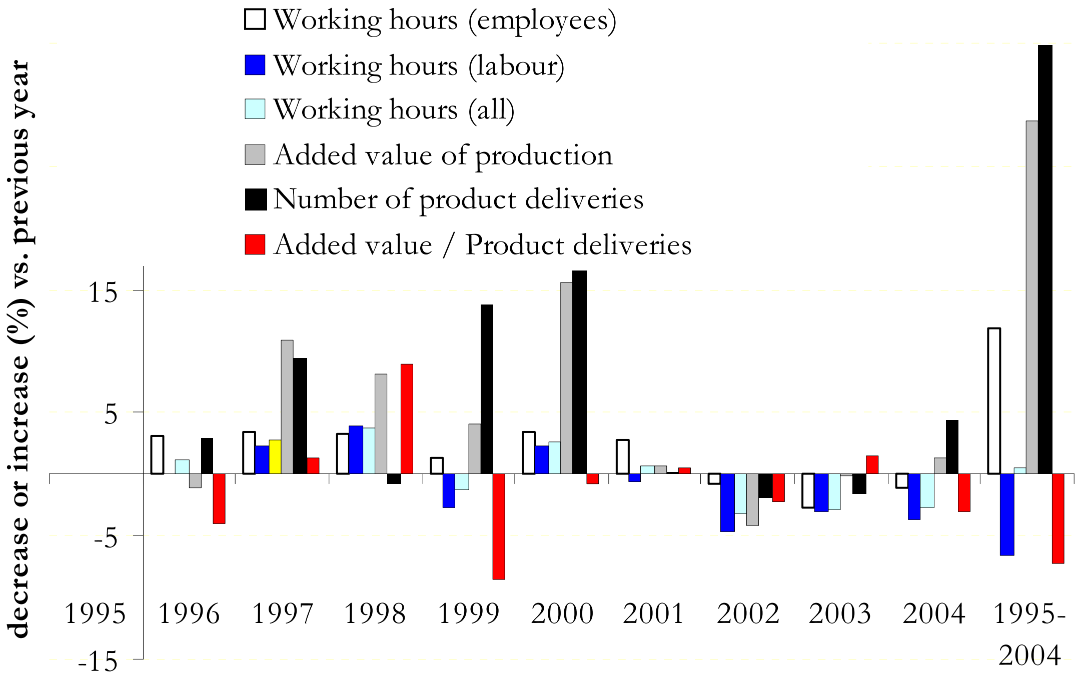

Figure 2. The industrial development in Finland (1995-2004) Source: Statistics Finland (www.stat.fi — accessed at 18/08/06)

boost. Thus, in the Finnish industry the efficiency of shop-floor level activities has increased, but the efficiency of office activities has not significantly increased.

As the industry is experiencing fluctuations, strategic development projects are susceptible to changes and uncertainties. This, in turn, may prevent the companies from taking a long-term perspective with visionary goals. The idea of continuous development with an indefinite number of consecutive steps aiming at a set of low-level efficiency increases may be dominant in the transient situation.

Trends in the operation of the manufacturing industry

By studying the more selective sample of industry, the manufacturing of machines and equipment [Savolainen 2006], it is evident that the situation has been similar from an overall viewpoint. For example, from 1995 to 2004:

- the added value of manufacturing machines and equipments increased by 40%
- the number of deliveries increased by 60%
- the working hours of employees increased by 24%
- the working hours of labour did not change (an increase of 4%)

THE INCREASED COSTS OF SALARIES AND WAGES. A comparison of some factors from the statistics reveals more about the trends. The number of employees rose by 22.3% and their working hours by 23.7%. At the same time the same characteristics of labour rose by 7.5% and 4.1%. The cost of increased personnel was notable, as the cost of salaries and wages was 54.4%, higher in 2004 than 1995. The overall costs rose by 79% from 1995 to 2004, while the purchased raw materials was the biggest single item of expenditure in the year 2004.

LESS WIP — INVESTING IN RAW MATERIALS. Despite the increased value added of production and volume of products, the cost of floating assets decreased during the late 1990s and the early 2000s, but rose back to the level of 1995 in 2004. What is remarkable is that the costs related to work in progress (WIP) remained almost the same, but, for example, the costs related to the inventories of raw materials were increased continuously to the double of the value of 1995. Also, the cost of undefined inventories had risen ten times. [Savolainen 2006]

The numbers above suggest that production processes are efficient in details, but lack an overview and total optimization. Plausible approaches to overcome this are Lean manufacturing principles [Womack & Jones 1996] which emphasize the recognition and cultivation of the value flow as well as the eradication of stagnated waste. Problems may occur due to the sales delivery processes which are suffering from the poorly managed customization. There seems to be an interest to enhance the sub-sections of the processes, but not the process as a whole. The overall confusion remains as it is, even when some details are clarified during the past decade.

Financing costs instead of investing development

Companies seem to be living from hand to mouth. Most of the income is spent on running the business as usual and ensuring the financing. Hence, there is little room to invest in production facilities or in product development. Therefore, business process re-engineering and reorganization efforts focus on streamlining internal processes and cutting costs from internal organizations. This has lead to an increase of specialization as well as outsourcing, i.e. subcontracting and networking.

CHANGES IN INVESTMENTS. Generally investment costs have decreased while the cost of investments in information and communication technology have increased. There was an almost monotonous decrease of investments, being nearly 45% less in 2004 than in 1995. On the contrary, the costs related to computers and software increased continuously. Actually, they were the 7th highest cost item in 2004. Almost four times the value of 1995, they superceded the R&D costs of 2002. In 1995, costs related with the information technology were approximately 17% in comparison with the costs of investment in machines. In 2004, this ratio was 83% and 74% when compared to all investments.

Hence, manufacturing companies are investing on systems that support controlling and communication activities rather than to research and development or the production facilities in Finland. This gives reason to believe that companies are not interested in developing products or the actual manufacturing process, but rather typically invest on management of those processes. Another interpretation is that companies are suffering from problems related to the management of existing or missing data on products and processes, since quite often the ICT is considered solely as a solution for problems rather than the means of the solution.

INCREASED COSTS OF SUBCONTRACTING. An interesting issue is the rise of subcontracting which in 2004 was the third biggest item of expenditure. It superceded the following item, merchandised goods, in the year 2001, and in 2004 subcontracting costs represented approximately 45% of personnel costs. In 2004, subcontracting costs were more than thousand times the figure of 1996 as well as over 12 times the costs of research and development which was tenth in the list of items of expenditure.

Manufacturing companies are specialising, downsizing, and outsourcing as well as offshoring in Finland. When reflected to the above interpretations of the situation, we may consider that the management rather seeks an increased efficiency from outsourcing than a transformation within the company, internally (see "Transformations via acquisitions" on page 6). However, outsourcing does not solve the problems related to unmanaged sales delivery processes. Rather, it amplifies the problems related to change propagation, as we will see on the following pages.

Personal interest and experience

Statistics reveal some pervasive trends in the industry, but the actual phenomena in practice remains concealed. For the understanding of the problems and situations in practice, taking a closer look is necessary. To a certain extent, the point of view is always subjective. However, describing the subjective point of view makes the insight if not substantiated, at least justifiable.

The manufacturing industry in Finland is quite largely dependent on customized products that are delivered by repetitive, but substantially differing projects. Of course, few exceptions do exist, mainly in electronics and communication technology. However, many of my industrial contacts have been to companies that deliver products with annual volumes far less than a thousand. Thus, my experience is in the field where practically all products are manufactured in customer oriented delivery projects and to some extent they are different from each other.

Another common theme in the research and development projects in which the author has taken part is the enhancing of engineering productivity. This is also a tradition within the research group the author has been a part [Riitahuhta 1988]. In the earlier cases of the group, the common method for attaining productivity seemed to be the novel utilization of applied artificial intelligence [Riitahuhta 1988, Aaltonen 1996]. However, for the past decade the focus has shifted towards the structuring of products [Riitahuhta et al. 1998, Pulkkinen 2000, Riitahuhta et al. 2001, Aarnio 2003, Lehtonen et al. 2005, Juuti et al. 2006, Pavlic et al. 2006, Suistoranta 2007] and changing processes [Pulkkinen 1998, Pulkkinen et al. 1999a & b, Pulkkinen 2001, Martikainen et al. 2006].

Observed problems

Changes, incompleteness, and errors in product definitions. The motivation for the research project came from literature as well as the author's own observations on practical problems [Tiihonen 1999, Pulkkinen et al. 2000]. Among these were design changes and their effects in project deliveries, such as the increase of costs and the snowball effect in engineering: the majority of the design work was assigned on changes and corrections due to the changes. Also, most sales specifications were often incomplete and many of them were invalid. This, of course, led to the problem of long lead times in finalising the definition of the product, i.e. the design, as well as in selling and delivering the product.

Problems vs. project organisations and delivery processes. The problems related to the uncertainties as well as to the changes of information are cumulated to another degree in a networked project organisation, where transactions take place in different kinds of circumstances. The locations and times for certain inputs and outputs may not meet. For example, it is not unusual in the sales delivery process of a power plant that a large number of revisions and changes are made at relatively late stage of project. Typically, these kinds of changes lead to a number of problems in the procurement, supply, logistics, manufacturing, assembly, and erection at the site. Most difficult are the cases where the information on the change is not propagated due to an obstacle, such as the different locations of organisations, temporal limitations or conceptual mismatches. The obstacles can be characterised as a lack of common place, time, or language. [Pulkkinen 1998, Pulkkinen 2001]

Synthesizing the overall situation and subjective insight

The substantiation of decisions in vacillating contexts. An investment is supposed to enhance the productivity, quality, and/or capability of processes. These intrinsic properties of a company must meet the extrinsic requirements, such as markets and economics. Therefore, it is important to have a vision of the future requirements. Management may choose to invest on the basis of strategic vision of growth. However, in practice, they will have to bear with short-term changes and fluctuations. With a short-term focus, an investment may appear to be unsuccessful ans is rejected which can be assumed from the statistics. Propably some cases of adopting configurable product families are failures due to reasons which are extrinsic to a company. However, with poor intrinsic capabilities, a company will hardly reach a successful situation. Therefore, the timelines of decisions are as crucial as the intrinsic capabilities.

Redundancy and legacy of products, solutions and parts. There is a reason to presume the manufacturing paradigms, such as JIT, have been adopted fairly well in production. However, the companies seem to have struggled with the proliferation of different kinds of products, composed of overlapping assemblies and parts. This is probably due to the legacy of mergers and customer-specific solutions which require from production systems and supply networks a high capability of delivering large number of varying sub-solutions. Keeping the rare solutions, parts and components, in stock is not feasible, but the capability to make from the varying stock of raw materials. I substantiate this deduction to the decreased cost of WIP and the increased cost of raw materials.

Demand of productivity. As previously mentioned (the section "Long term – continuous growth" in page 6), there is a demand of higher productivity, especially among the operations of the employees as the efficiency of labour has risen. Productivity is normally considered to be the relationship between effort and result. Automating the repetitive tasks reduces the effort and standardizes the result. The rise of ICT investments suggests that the office automation is an ongoing activity.

However, in engineering design the repetition of tasks is seldom evident, since design *per se* is not repetitive. Duffy defines design productivity as a composition of efficiency and effectivity, where "*The efficiency of production of a design solution, within a business context, that is effective to the overall requirements*" [Duffy 1998]. Obviously, this means that enhancing the productivity demands actions that minimise the effort but also improve the meeting of the result and the requirements. These actions, their implementation, and support are the means for business transformation within, i.e. the archetypes 1 and 3 (see page 4).

The context, purpose and point-of-view

The author is not alone in this field. For example, one the themes of research in Cost Management Center at Tampere University of Technology is the cost of customization [Sievänen 2004]. The benefits, the problems and the methods of configuration have been studied by the Product Data Management Group of Helsinki University of Technology [Tiihonen 1999, Soininen 2000, Männistö 2000]. In Denmark, the Center for Product Modeling at Danmarks Tekniske Universitet [Mortensen 2000, Harlou 2006, Hvam et. al 2008] and in Switzerland, in Autonomous System Laboratory at

ETH, Zürich [Bongulielmi 2003, Puls et al. 2003, Sekolec 2005] have been active in the modelling of configurable product families.

Thus, the context of this research is overlapping the topic of a number of research groups. However, the purpose and the viewpoint of this research are different from the mentioned studies.

This research relates to both the engineering design science and in the industrial practice of product development. More specifically, the subject is the development of configurable product families (CPF) within manufacturing companies which have previously developed customer-oriented products in an *ad hoc* manner.

Thus, the focus of this research is in the transformative processes of development, documentation and utilization of configurable product structures. The research provides a descriptive model and, therefore, a contribution to theory of product family developmement.

In contemplating the context of this dissertation, a number of questions have emerged. These included

- What could be the argument for the scientific approach?
- How to strive for scientific contribution?

Practical context

These questions were partucularly relevant for the practical context of the research. With the first question, the dilemma was the topic. Is it of such a kind which can be scientifically studied? As the "*impulse behind science ... is the itch to know things, to find out how and why the world is as it is*" [Checkland 1991, pp. 24], it gives reason to believe that it is so. That is, it is possible to know more about the engineering of product families for configuration within a projecting company.

The second question can be reformulated as: how the experience and knowledge which has been gathered from practice by, for example, participating in practical cases, could be related with the current state of research? Moreover, how to formulate, validate, and verify the knowledge? The practical problem appeared to be such a diversiform and complex subject that coming into scientifically valid and verified conclusions about it seemed very difficult.

I had contributed, although to a varying extent, to the cases as well as to the formulation of the questions and themes for the interviews. Therefore, the attempt to draw justified and objective conclusions about the collected knowledge seemed impossible. However, the modern theories of science have, to some extent, given up scientific objectivity. Therefore, the purpose and point of view, *Weltanschauung*, according to [Checkland 1991] has to be stated plainly.

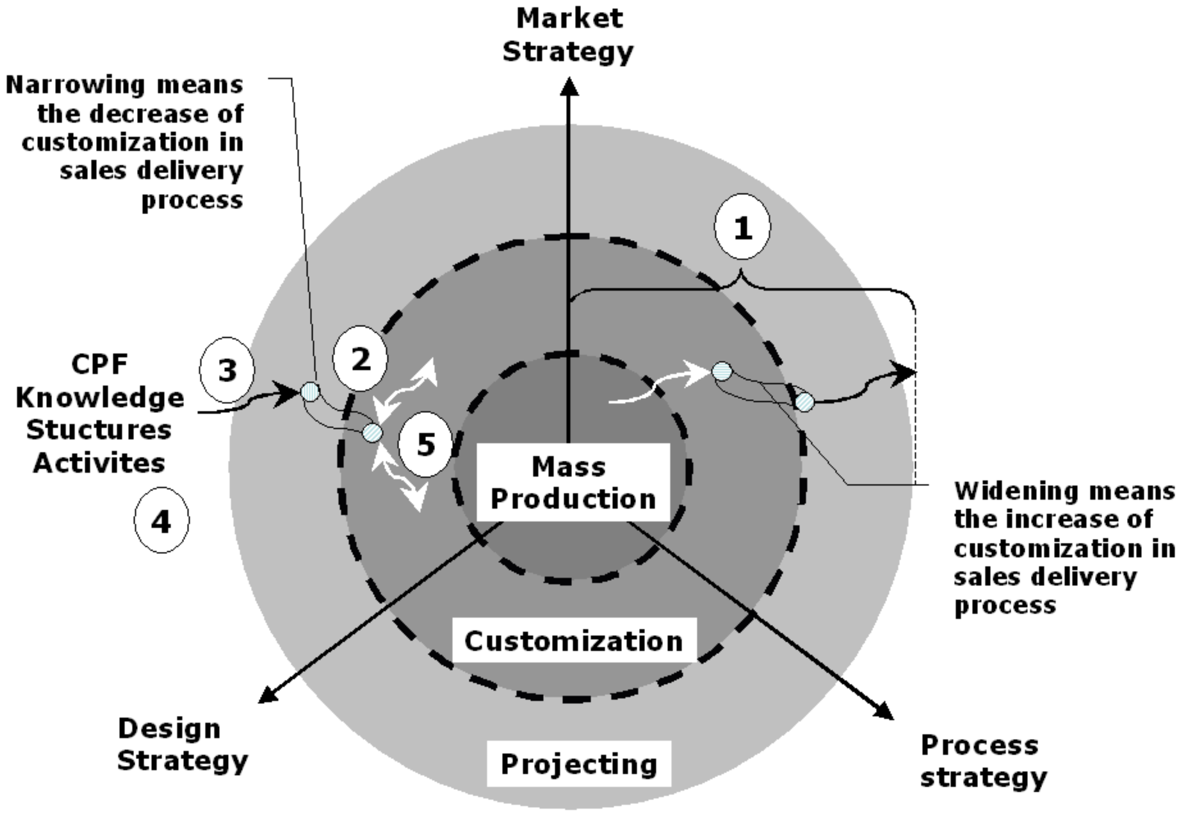

Figure 3. The *Weltanschauung* of the research

Purpose as a model

In this research the *Weltanschauung* is as follows:

1. In different production paradigms, such as mass production, mass customization, systemic customization, and projecting, the value creating processes, such as sales-delivery process, are substantially different.
2. There are transformations between these paradigms which have an affect on the processes of a company. Particularly the sales-delivery and product development processes are affected.
3. Product development process is a means for transformation, as it provides new knowledge for other processes. Particularly, developing configurable product families is a means for transforming company from projecting paradigm to systemic customization.
4. The development of configurable product families is comprised of the standardisation of product family structures and the documentation of configuration knowledge which are the means of configuration activities.
5. It is possible to collect information about the means and the effects of transforming a company from projecting to systemic customization by studying product development and sales-delivery processes.

6. It is possible to make scientific statements about a transformation by structuring, analysing and drawing conclusions of the collected information.

Figure 3 presents the arquments of the *Weltanschauung* as a circle, where the activities of functions form the scope of transformation in a company. In the figure the statements of *Weltanschauung* are presented with numbers. The purpose of this research is to collect knowledge on phenomena, presented with the figure above.

The viewpoints

THE CHANGE OF PROCESSES. I originally comprehended the topic of product configuration as a way to define product individuals in paradigm of mass customization [Pine 1993]. However, it became clear that configuration is also a viable and powerful way to enhance product design and other activities in a company where the "mass" is missing from the phrase mass customization [Pulkkinen et al. 1999a, Pulkkinen et al. 1999b]. In these cases, the volume of sold product individuals is low even though the sum of transactions, such as the price as well as the cost related to a single product delivery, may be massive. These are actually the characteristics of the focus of this research which is the sales-delivery process of projecting.

ENGINEERING DESIGN. As the phrase "engineered to order" refers, in projecting paradigm the individual product is defined by the engineers. In defining the common grounds for the product individuals, often referred as a product platform as well as a product family, the engineering design may not be omitted. Thus, this research is a contribution to the science of engineering design [Hubka et al. 1996, Pahl et al. 1996]. Moreover, the contribution is related to the processes of engineering design in projecting with and without configurable products.

KNOWLEDGE AND INFORMATION MODELLING. Instead of considering configuration as a business or an engineering issue, configuring is also a practical activity that can be and often is supported with a specific branch of information technology and software engineering. Thus, a third interpretation on the context can be taken from the point-of-view of information technology and computer science.

Research questions

With the above studies a number of questions are risen:

1. What is the difference between an engineered-to-order product and a configured-to-order product, in respect to the project management situation in a sales-delivery project?
2. Why is it important to relate the activities of a sales-delivery process to the development of configurable product families and to the articulation of a configuration knowledge model?

3. How are the product development, product structures, and configuration knowledge related to the scope of transformation?

The structure of dissertation

In the second chapter of this dissertation, the methods and the material of this research are being reviewed. The research method applied involves case studies and interviews in the industry. Hence, the structure of the interviews as well as these composition of the case studies are briefly explained in the chapter.

The third chapter is a literature review on the related fields. First, the context of transformation and the sales delivery process in relation to different business paradigms are reviewed. Second, the concept of projecting is defined along with the engineering design and product development literature. Product configuration as an option for product design in projecting is then presented.

The third chapter of the dissertation presents the results from the interviews and the case studies. These are formulated and unified according to literature review. Finally an analysis on the collected material is presented.

The thesis ends up with a conclusion, followed by a list of references.

Methods and material

In this chapter the generic aspects of science are being contemplated and related to the engineering design science. The characteristics of engineering design science and the models of research in it are examined. The research methods include conducting aliterature study, a series of interviews and case studies in companies. The course of the research is briefly explained with the collection of data from practice.

The material and the product of science is knowledge that is being collected, refined and structured. Christopher Alexander [1966] contemplated about the differences between different kinds of knowledge that control and guide the designers' work. He argued that design knowledge varies from myths and beliefs, which are beyond doubt, to scientifically proven realities.

However, the value of the attained knowledge – the contribution –- must be examined through the approach of handling knowledge: the research method. Moreover, as there is no single definition of a scientific method, it is neccessary to state the comprehension of the science itself. Any scientific contribution must be evaluated by a scientific community. Therefore, it is neccessary to acknowledge the field of the contribution.

The research reported here belongs to the science of engineering design. Moreover, it is a study of a particular sub-topic design of product families that has in the recent years been the focus of both the industrial practitioners and academic research. Thus, the characteristics of science and research of engineering design are briefly examined.

Another theme in the research is a change, a transformation, within an industrial company. Even when the contribution is not targeted to management sciences or operations research, an industrial context gives the research a strong as well as a practical flavour. Thus, some studies on changing the business paradigm are reviewed.

Scientific approach

In order to be accepted as a contribution, the result of research has to be a (public) subject for a trial by a scientific community. The result is essentially new, tested knowledge about the phenomenom. Although there are a number of scientific approaches, most of them are based on the idea of cumulative growth of knowledge [Chalmers 1999]. The novelty of a knowledge is the critical matter of a scientific contribution, it usually contains a review of the existing knowledge. Without the review a new contribution could not be separated from, nor related with the already existing knowledge.

TRUTH IS A MATTER OF COMMUNITY. Proven knowledge is a concept that includes the presupposition of true and justified belief on the topic of research. Moreover, according to Popper a scientific contribution is such that it can be refuted, i.e. falsified [Checkland 1991, Chalmers 1999]. In a scientific contribution the results have to be attained and confirmed to be true with the research paradigm approved by a scientific community.

Different kinds of sciences

In the tradition of natural sciences, the paradigm that fulfills the terms of falsification and testability has been the reduction of the subject into such kind of (publicly available) experiment that can be isolated from the variations and disturbances as well as repeated [Checkland 1991]. In physics, which apparently is the most archetypical example of restricted sciences, this is an indubitable issue.

However, reductionism, refutability and repeatability are not the characteristics of non-restricted sciences, where the studied phenomena cannot be reduced into laboratory conditioned, repeatable tests. Typical examples of such a science include sociology and geology.

THREE PHASES OF SCIENCE. By following the generic typology of sciences by Auguste Comte [according to Checkland 1991, pp. 61], the development of scientific knowledge can be classified in to three phases:

- In the **theleological phase** some fetishist beliefs and totemic religions explain the phenomena.
- In the **metaphysical phase** supernatural causes are replaced by ‘forces’, ‘qualities’ and ‘properties’, which construct an explanation on the phenomena.
- In the **positive phase** the concern is to discover universal laws concerning the phenomena.

As mentioned above, in science it must be possible to test the explanation anytime. This is not the situation in the theleological phase as an opposition to the latter two phases. In the metaphysical phase, the repeatability of experimentations (if they exist at all) as well as the refutability of knowledge is often at least questionable. Thus, the positive phase of science may be regarded as a zenith of science. Comte, the founder of sociology, wished to create a naturalistic science of society. Thus, he had the approach of a reductionist when he wished to create such a law of man that would be comparable to the laws of physics.

The role of knowledge in science

When the body of knowledge is attained in practice, irrespective of the scientific paradigm, it has *ad hoc* characteristics. As such, the compilation of knowledge can be regarded as theleological or, at most, metaphysical knowledge. One such compilation is the Project Management Body of Knowledge [Duncan 1996]. There, many practical aspects as well as the set of methods and tools on the topic of project management have been compiled, but no theoretical treatment of the subject is presented. Within engineering, there are a number of viable facts and beliefs that form the body of engineering knowledge. The body of knowledge applied in everyday engineering design tasks may be regarded as non-scientific, since some of the facts are taken as given – not as a subject of question. Actually, the engineering design methods presented by academia have not been widely adopted in practice [Tomiyama 1997].

As a discipline, mechanical engineering is a subject of education and learning about the facts related to mechanical artefacts, for example, laws that hold the knowledge about the kinetics of solid structures. In the discipline, the knowledge is about the mechanical devices, such as Hooke's law on the relation of the force and deformation of a material body under certain conditions. These pieces of knowledge are utilized daily in engineering work, in contrast to the scarce utilization of the engineering design methodology.

DYNAMIC INCREASE OF KNOWLEDGE. However, Comte's contemplations are not the end of the story. According to Kuhn, new and more precise laws of the phenomena can (and will) be formulated [Chalmers 1999, Checkland 1991]. This, in fact, is an essential characteristic of science. Instead of being a set of facts, science is a collection of interrelated pieces of knowledge under revision.

Knowledge is characteristically related to a context, a viewpoint and a purpose. It is about something, it is perceived by and relevant for someone, and there is an intention or use for the piece of knowledge. In science, all these are related to the scientific community, whose aim is to know more about the topics in the discipline. Thus, the context is interwoven to the discipline and the point of view is usually inherently determined. From the pure scientific point of view, the purpose of scientific knowledge lies within itself, as there is no other reason than knowledge *per se*.

Scientific method

NO METHODICAL SUPERIORITY DUE TO EVOLUTION . The problem related to methodology is such that no universal or superior scientific method can be formulated. This is due to new, emerging sciences as well as the development of new means for collecting and analysing data as well as setting up knowledge. Thus, the disciplines are dynamic and the modern approach is not to provide the ultimate, definitive truth, but knowledge on a topic with an icreasing precision with reality. Scientific methods are either qualitative or quantitative.

INTERLACED IN DESIGN AND CONTINUOUSLY CHANGING. However, in applied sciences as well as in the practice of engineering, the role of knowledge characteristics is different. The activity of engineering design is not an activity that merely utilizes the technology, i.e. knowledge on technology, provided by applied sciences. Other sources, such as experience and experiments, market studies, sales specifications, production processes, etc. are viable sources of knowledge that frame the topic at hand, the task of product design and development. Moreover, in engineering new knowledge on the topic is being generated as a by-product. The context, viewpoint, and purpose of a particular engineering design task are evolving issues. This, inevitably, has an effect on the engineering body of knowledge. Thus, some parts of it are replaced as they are less relevant than others. For example, if it has been decided to give up die casting in a company the knowledge of die casting becomes obsolete as well as a subject of deterioration for the design engineers of that company.

Engineering Design Science

Modern, interdisciplinary and application oriented

The roots of engineering design research are in both the natural, technical and human sciences as well as in the practice. For example, Pahl and Beitz [1999] consider engineering design as a rendezvous where restricted natural sciences, such as physics and materials science, meet unrestricted human sciences, such as sociology, psychology and cognitive science.

As Hubka et al. [1996] point out, the practice of engineering design has existed as part of the creation of artefacts for centuries. However, product design and development as a distinct activity from production is the offspring of the industrial revolution and the division of work [see e.g. Smith 1904, Taylor 1911]. Thus, engineering design is a relatively new branch of science, because both the (industrial) practice *per se* and some of the related sciences have not existed for centuries. In the practice of designing an artefact, the activities of design take place in the intersections of various of contexts, such as natural, techno-physical and socio-cultural environments [Rosenman et al. 1998]. Thus, engineering design is an modern as well as interdisciplinary science.

Approaches to design. According to the contemplations by Alexander [1966] the reasoning as well as the manner of design, i.e. how an engineer comes up with a design, can be divided into three categories:

- **The reactive manner**, where a solution to a problem is based on a reaction according to some beliefs, often in the form of tacit knowledge.
- **The analytical manner** is such where the above-mentioned beliefs are replaced by a framework or conceptualisation which construct an explanation of the phenomena and, consequently, an approach to solve the problem.
- **The positive phase**, in which the concern is to discover universal laws concerning the phenomena.

The classes above are similar to the development phases of science (see page 18). As we will see in the literature review on product structuring (see page 51) and configuration (see page 69), most of the current methods and tools are based on either reactive or analytical beliefs. Some, including [Suh 1990], have tried to approach to the positive beliefs, i.e. axioms, on the engineering design, but they have not been accepted such as the axioms of physics.

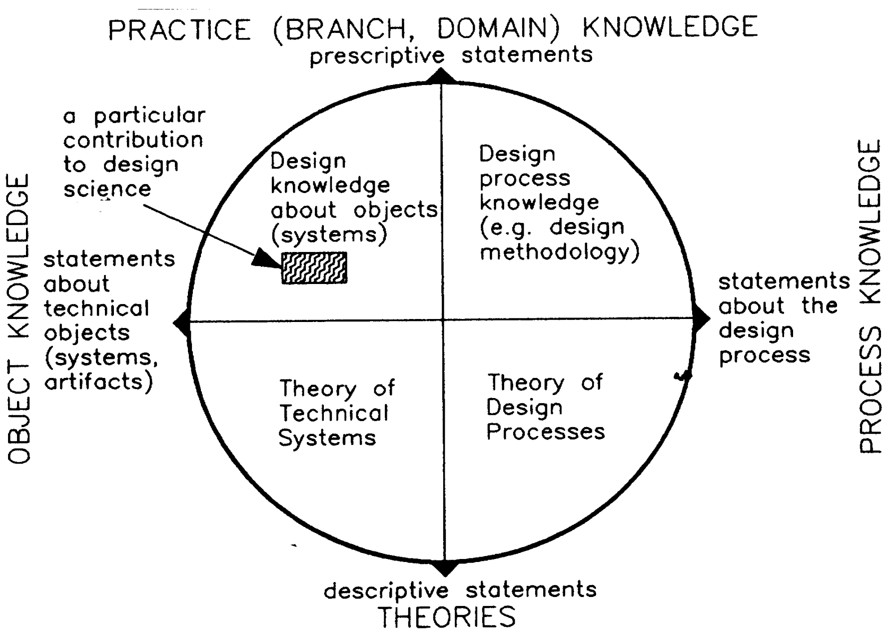

Figure 4. Main Categories of Design Science [Hubka et al. 1996, p.82]

In engineering design science the context of research is either a technical system or a design activity (see Figure 4). The research context of a technical system may be one of the domains of a technical system or the life-cycles the system traverses. Also, relational topics such as degrees of complexity may form the context of study. The context of design activity research may vary from management to actual design work as well as to the activity of design support. A researcher may choose a descriptive or a prescriptive viewpoint, which largely affects the purpose of the research. Often, the purpose of design research is to aid or support the design activity by providing design methods. Usually, a piece of engineering knowledge, formulated as a theory, has a potential of use. This, however, requires the development of a method based on the theory. Moreover, the application of the method contribute to its utility [Olesen 1993]. Thus, the different segments of the Figure 4 ought to be related.

GROWING SUBJECT BUT SCATTERED STATUS. Engineering design is a branch of science that is constantly being constructed. For example, there is no standard set up of scientific methods [Blessing 2003]. Instead, an journal of design is often a "motley collection of papers", as Roozenburg pointed out about Issue 2, Volume 19 of Design Studies [Roozenburg 1998]. In the mentioned issue, the papers covered topics varying from graphical to textile design, product design to structural engineering design, from psychology to knowledge management. Within the articles of one issue, the applied research methods varied not only from case studies to a philosophical approach, but also from the development of computer support (tooling) to controlled experiments.

Blessing [2003] acknowledges the scattered status of design research by admitting that "*many strands of research have emerged, that are neither clearly established nor clearly defined*"[Blessing 2003, p.8]. She continues that it is impossible to obtain an overview of the results and criticizes the community for referencing islands. Also, a lack of ontology[1] does exist because common terminology is missing and some of the most fundamental terms are ambiguous. An example of this is presented later (see page 49).

FROM GENERIC METHODS TO SPECIFIC TOOLS. Previously, the engineering design community was criticised for the rarity of practical applications based on the research results obtained [Tomiyama 1997, Eder 1998, Frost 1999]. One reason for this state of affairs may be that the engineering design research community has been academically oriented, while the concurrent engineering research community has had a practical orientation [Tomiyama 1997]. This means that in Figure 4 the contributions of engineering design research used to be located on the lower sections of the circle.

The concurrent engineering research, which is not related to either of the suggested theories, focuses on the concrete methodologies, i.e. the top sections in Figure 4. While until the late 1990s, engineering design research

1. *Ontology* is (in philosophy) the branch of metaphysics that deals with the nature of being and (in logic) the set of entities presupposed by a theory. Ref.: Collins English Dictionary" 5th Edition first published in 2000 (c) HarperCollins Publishers 1979, 1986, 1991, 1994, 1998, 2000.)

had been focusing on generic and abstract research problems and results, the concurrent engineering research focused on generic but concrete problems and solutions [Tomiyama 1997].

The community has shifted from the original abstract towards a more practical orientation. The largest number of recent research reports have been devoted to providing new tools for the practitioners [Cantamessa 2003]. However, the methods are seldom directly related to any existing theories, such as systems theory [Klir et al. 1967], domain theory [Andreasen 1980], or theory of technical systems [Hubka et al. 1988].

The two approaches have inherent dilemmas. The generic approach hardly meets the practice, even if it were applicable, and the number of practical, yet case based, approaches may be too large for creating an overview of design problems and suitable as well as persistent tools and methods. Thus, a practitioner has a problem of finding an up to date method or a tool for his or her problem. However, my own experience is that most practitioners are searching for tools rather than theories, even if the phenomenom is ill defined.

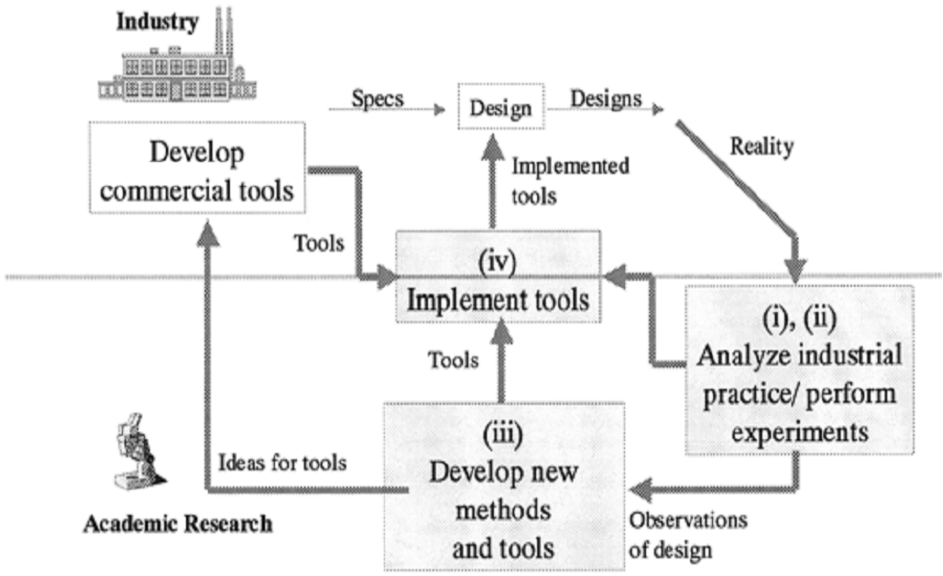

Figure 5. A model of complementary research objectives in engineering design [Cantamessa 2003]

A new model for the research approach was formulated by Cantamessa [2003]. It is the model of complementary research objectives in engineering design (see Figure 5). The mindset behind this research approach may be that the validity of research results can be derived from the acceptance of the practitioners and the scientific community [Olesen 1993]. However, one might criticize the model by Cantamessa it resembles the topic itself, which is product development.

In many cases of research, the contribution is a tool for the activity of engineering design. Research is driven by practical needs and results with applications for the practice. As this enables a potential success with industrial applications, it often does not take into account the existing theory or the existing design methodologies. At least in Figure 5, there is no explicit link to the theoretical basis of engineering design. Moreover, in the practice of synthesizing a solution, the ends may justify the means as long as there is something that justifies the end. Thus, one might consider that in engineering design research "*scientists should follow their own subjective wishes and anything goes*" [Chalmers 1999, pp. 162], which actually is a modern "anarchistic" account of science by Paul Feyerabend.

PRODUCT STRUCTURING RESEARCH. The interest in the topic of this particular research, i.e. product structuring, was divided into two interpretations of structuring [Tichem et al. 1996]:

1. Design interpretation of the product structure.
2. Design data management interpretation of the product structure.

Since the interest of the community shifted to modular engineering in practice, product data management and methods integrated to product development processes in the early 2000s [Riitahuhta et al. 2001]. However, in the Product Structuring and Modularisation workshop at ICED07, the importance of understanding the basic phenomena via cases was acknowledged. This can be characterized as a shift from defining and tooling (iii), to application (iv) and finally to the understanding of the phenomena (i) – see Figure 5.

The interest of the product structuring research community has been focused on many directions, as can be seen from the contributions. For example, the development of tools and methods has been the topic of a number of dissertations in the field of product structuring and modularisation, see e.g. [Martin 2000, Stake 2000, Blackenfeldt 2001, Aarnio 2003]. However, at the same time, some contributions to theory were being delivered [Jensen 1999, Mortensen 2000, Harlou 2006]. In these contributions, there was also suggestions to methodological support. Also, some dissertations with the aim of relating modularisation with the activities and organisations were delivered [Miller 2000, Oosterman 2001].

Other fields of research

As the topic of this research indicates, this research is related to other fields besides engineering design. These are project business as well as product configuration and the change, transformation of a company. The development with the research of project management [Loch et al. 2000] and project business [Artto et al. 2005] appears to be similar to that of product structuring research. Also, business process re-engineering and change management literature appears to evolve from the prescriptive models, based on the cases analysed [Hammer et al. 1993], to theories [Rouse 2006].

In the 1980s research on product configuration was related to pioneering cases, such as [Baker et al. 1989, Sviokla 1990, Riitahuhta 1988, Karras 1988, Schwarze 1996] and basic research in expert systems [Dym et al. 1991, Bobrov et al. 1988]. However, during 1990's the understanding of the phenomenon of configuring [Mittal et al. 1989, Tiihonen et al. 1996, Brown 1998, Tiihonen 1999] as well as the generic aspects of supporting and modelling configuration knowledge [Mittal et al. 1989, Sabin & Weigel 1998,Soininen 1998, Männistö 2000] have dominated. Nowadays, the research is turning back to tooling, as signs of practical applications have re-emerged [Bongulielmi 2003, Nummela 2006]. Moreover, the methodologies that integrate the object oriented modelling and the theoretical background from design science have emerged [Mortensen 2000 , Harlou 2006]

To sum up the findings, the research approaches have contributed to many aspects in Figure 5 In the fields of this research, the approaches have evolved from reactive to analytical phases (see page 21).

Context, purpose and point of view

Here, the context of research lies in the practice of projecting industry. The purpose is a contribution to the emerging theory of product families. The point of view is in the development and utilization processes of configurable product families.

> **The research presented here is about the development of configurable product families and documenting the related configuration knowledge in a configuration model for the use of sales-delivery process.**

Knowledge in relation to the topic

The concept of knowledge is related to the topic, the context which it is all about. For example, we may speak about the knowledge of dimensioning rigid bodies under stress or the knowledge of managing design process. Another issue, which is apparent in these kind of examples, is the purpose of and the point of view in collecting, formulating, validating and verifying the knowledge. In engineering sciences, increasing knowledge is typically not considered a virtue *per se*. Instead, the application is decisive, because questions "*how can I use this theory*", "*can I apply this method for solving my problem*" often arise.

Method

Several approaches were neccessary for carrying out the research. According to [Yin 1994] the case study research should start by creating a framework for the phenomenon of study. This is done here with the synthesis from the literature (from page 37 onwards).

However, the theoretical framework has to be validated and verified with

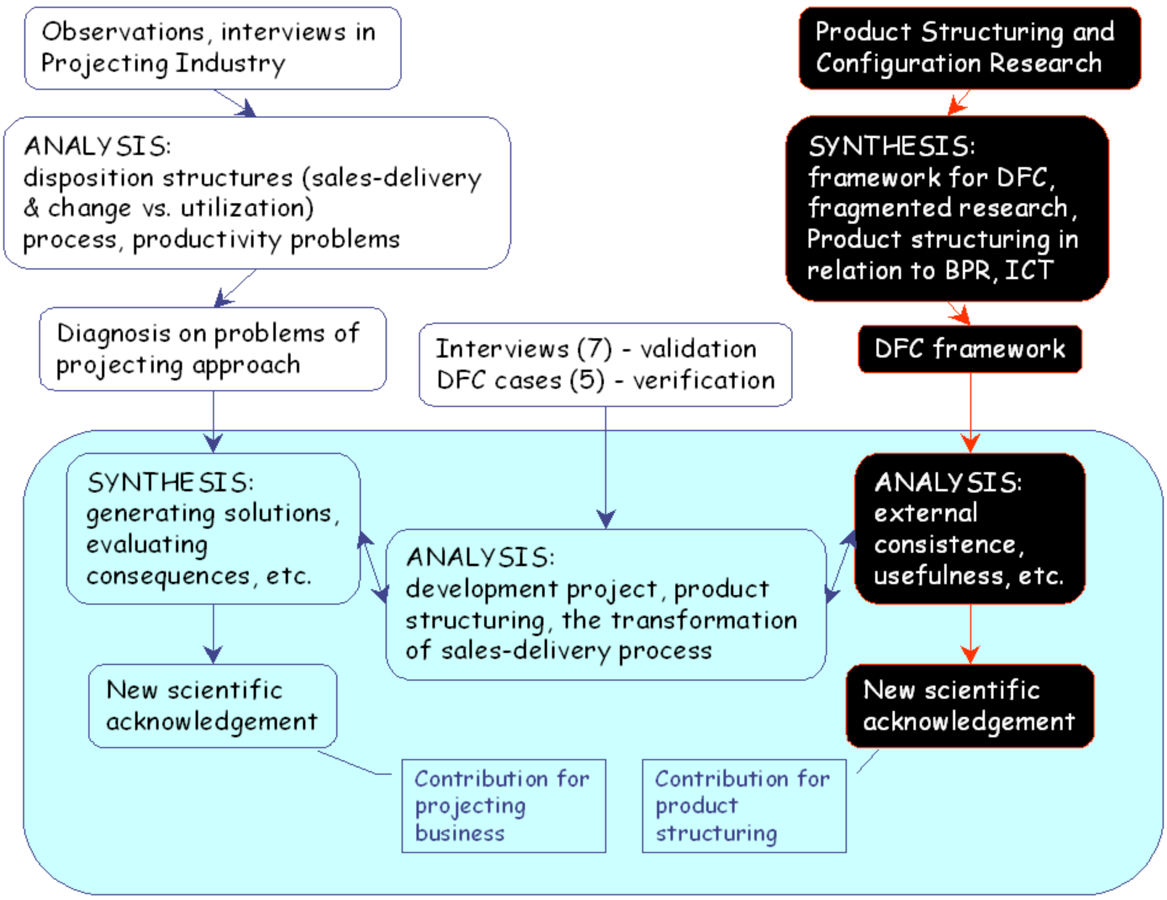

Figure 6. The research method adopted from Jørgensen [1992]

some evidence. Another part of this research is conducting the interviews as well as the case studies. The manner in which these were carried out is briefly reported in the next few pages.

The third part of this thesis is the presentation and analysis of the resulted material. The purpose is to reflect the practice by framework as well as to verify and validate the hypotheses. As the utmost purport of this research is to contribute to the theory of configurable product families, the final part of this research is presented in conclusions and discussion, where both the practical and the theoretical findings are summed up.

Interviews: purpose and structure

The objective of the interviews was to collect experiences from the practitioners of companies that had approached configuration. Our aim was to study the committed efforts and the attained effects of approaching configuration as well as the relation of the efforts and the effects. The main difference between the interviews and the preceeding research [Tiihonen et al. 1996, Tiihonen 1999] in the field was to study the approach to configuration (i.e. the transition from *ex ante* to *status quo*) instead of studying the importance, the processes and tasks as well as the long term management of configuration.

Prepared questionnaire

For interviews our research group developed a 19-page questionnaire that was edited after the first interview (see Figure 7). The themes of questions varied from the issues of business processes to the matters of product structuring as well as required support. Also, our interest was to find out how the practitioners define and comprehend the concepts of configuration, because the change could not have been studied without characterising the objective of the change.

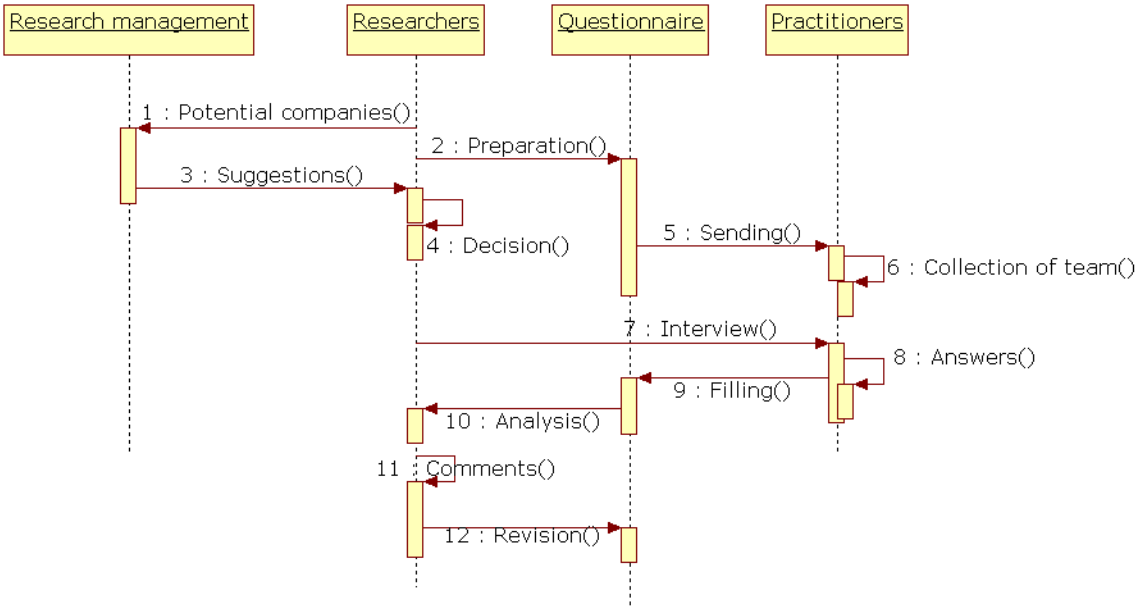

Figure 7. The sequence of interviews in DFC project

Course of interviews

Figure 7 presents the course of interviews. First, the group of researchers prepared a comprehensive list on the advanced companies in Finland and presented it to research management. The companies were selected with discussions with senior colleagues and experts in the two research institutes. We approached companies with the request of a one-day interview and the questionnaire, i.e. it was sent to the companies pre-hand (see Figure 7). As the research institutes were known by companies, all of the requests were accepted. Also, the other research institute participating in the interviews had conducted a similar research earlier [Tiihonen et al. 1996, Tiihonen 1999]. Thus, we considered that the interviewed companies well represented the state of pratise in Finland, at the time of the interviews.

The interviewed companies and their products

Seven companies took part in the one-day interviews. Soon after the interviews the interviewers documented the interview of each company, as illustrated in Figure 8. The companies were producing

- medical care equipment (A),
- mobile machinery, such as terminal trucks (B), tractors (C), trucks and equipment for storage logistics (E) as well as forest machines (F)
- diesel power plants and engines (D)
- industrial valves (G)

The letters in parentheses refer to the approaches of companies in Figure 8. below. There, the paradigm which company was utilizing is represented with an area, and the transformation is represented with an arrow. Company D had founded the business unit we were interviewing on the basis of partial configuration. Thus, there is no arrow in Figure 8. Also, Company G had several different product lines and no clear transformation from one paradigm to another.

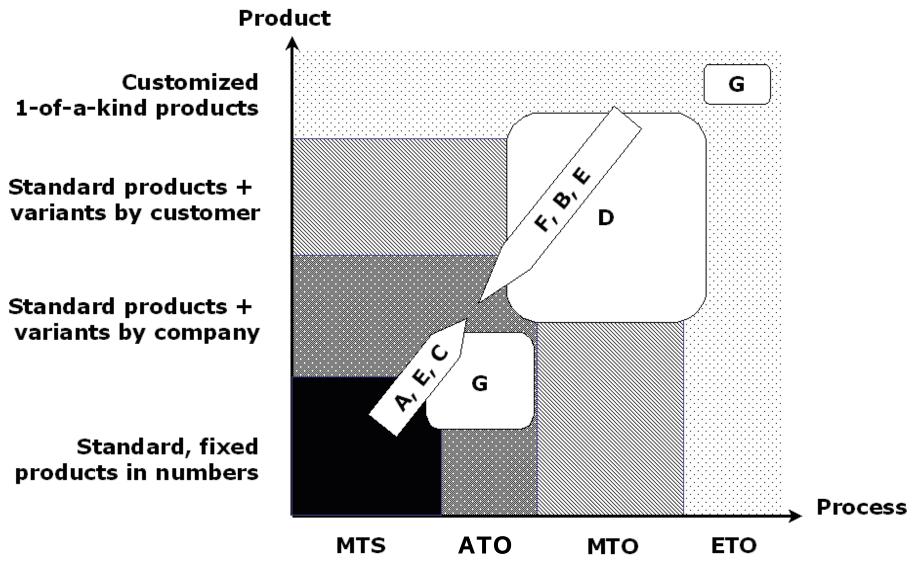

Figure 8. The paradigm of process and product customization

Interviews on the clear widening transformation

INTERVIEW A. In 21 December, 1998, we interviewed one person at Datex Ohmeda, now part of General Electric. The company (A in the figure above) had a product line with modular architecture that could be confirmed from several viewpoints. The product line was considered modular also from different points of view and it benefited in a set of different life-cycles [von Bonsdorff 1998]. Previously, each product had been a result of an individual research and development project and serial production, as the company had applied a made-to-stock paradigm. The product concept was based on a standard frame with variants defined by the company. The concept had direct relations between the function and part domain, i.e. the modules were organs.

However, the relations did not indicate a straight one-to-one mapping, but many modules could fulfill the specific function.

The company had exprieced configurable products as a key element in taking a share of markets where big international competitors already existed. In the transformation to the utilization of CPF the company had advanced to the co-configuration [Victor et al. 1998], because the products could be easily re-configured even in the use phase.

INTERVIEW C. On 30 September 1998 we interviewed [Huuskonen 1998] at Valtra Valmet, now a subsidiary of Agco, a world leader in manufacturing, marketing, and distributing agricultural equipment. The company had long traditions in modularisation, started already in the 1980s. At that time, standard products were made to stock, which had grown hardly without control. The company reported a number of advantages of having CPFs.

For example, modularity appeared beneficial in product development as it was organised according to the architecture of a tractor. Also, the modular options, sold with a form, related mostly to separate assemblies. Therefore the products could be assembled in a production line, despite of the individual structures of product instances.

Interviews on clear narrowing transformation

INTERVIEW B. An intervierw in Sisu Terminal Systems (now a subsidiary of Cargotec under the brand name of Kalmar Industries) was conducted on 25 May 1998. According to the interviewed person [Henrikson 1998] the company had modularized terminal tractors with a plus-modular approach. The product development produced a basic structure for a tractor and set of optional devices. Thus, the product paradigm was similar to Company A.

The configuration process relied on the structured sales forms and each individual of the CPF was made to order in the sales-delivery process. Previously, sales had been based on the approach of clean sheet and projecting, i.e. the engineer-to-order paradigm. The company reported a number of advantages of applying CPF based on the paradigm of standard products with company-defined variants.

INTERVIEW F. Two persons [Pekkarinen et al. 1999] from Ponsse (company F in Figure 8) were interviewed on 14 December 1999. The company had a straightforward transformation and no problems related to legacy products. With a strong product policy the company had transformed from projecting to an approach based on a manual configuration process, i.e. from engineer to assemble-to-order deliveries. A strong product policy meant that the company strictly adhered to a paradigm of standard products with variants defined by the company.

INTERVIEW D. Four people [Storholm et al. 1998] from Wärtsilä NSD (now Wärtsilä) were being interviewed in 13 October 1998. The company had increased its market share substantially with an approach originally based on partial configuration. Typically, parts of delivery were engineered to order. However, a major section of the product comprised of standard parts with variants defined by the company and its suppliers, but only seldom by customers. The compnay's competitors relied on the engineering of a delivery, as a whole. The products of Company D were made to order.

Interviews on hybrid transformation

INTERVIEW E. In 16 December 1998 four representatives [Jokisalo et al. 1998] from Rocla were interviewed. In Company E, configuration was regarded as a key enabler for maintaining viable production in Finland. Previously, the company had also been producing standard products to stock, but at the time of the interview, the company was assembling and making products to order. Thus, the transformation was a widening even beyond of configuration. The products comprised of standard structures and variants defined both pre-hand and *ad hoc* by the company. The products of a different paradigm associated with the classes of process paradigms.

INTERVIEW G. The last interview was carried out on 15 December 1999 at Neles Controls (now part of Metso Automation), and it included two interviewees from the company and three interviewers [Mäkinen et al. 1999]. At the time of the interviews, the company was not applying configuration – according to strict definition (see page 74). Instead, the company, which at the time was the largest and the most international of the interviewed companies, was making both standard and engineered to order products. Some of the delivered items were truly one-of-a-kind products specifically designed and made for a specific customer. For example, the steel alloy used and the dimensions of a product could have been defined separately in each sales delivery project.

Characteristics of interviewees

The interviewees were business and engineering managers, designers, sales and marketing representatives and people from IT and production management. As our intent was to address the questions to the representatives of business management, engineering, IT and production, the titles of the interviewees suited well. However, in most of the companies, it was not possible to interview a representative of each of the functions. In three companies, one person was interviewed; in two companies two interviewees took part; and in two interviews there were four interviewees. Two interviewers took part in two companies [Henrikson 1998, von Bonsdorff 1998] and in the rest of the companies there were three interviewers.

An overview on the content of the interviews

How was configuration defined in practice?

It had been noted in previous research [Tiihonen 1999] that the practitioner's meaning of concepts such as configurable product varied substantially. Thus, questions on the definitions of products were supposed to clarify the category of products the interviewed company was producing. The idea was also to disclose the contents of different kinds of product categories in each company. To these questions, companies were able to give a variety of answers.

Questions related to the change

THE EFFECTS OF CONFIGURATION. With questions related to the importance of configuration to a company, the aim was to explore the advantages and disadvantages of having configurable products. Even though this had been studied before [Tiihonen 1999], the aim was to find out the effects of configuring. However, these questions were often unanswered, propably because exact data was not available. Often the answers were relative to

- preceding (*status quo ex ante*) situations
- plausible situations if configurable products had not ben applied
- benefits and weakness experienced by certain departments in a company.

These point illustrate the characteristics of research topic as well as the suitable approach of analysis. The constraints of strict positivism (see page 18) cannot be applied, as the laboratory like conditions are missing.

Thus, the questions forced the interviewees to speculate. Also, people responsible for business management gave very generic answers based on personal intuitions. In some cases the advantages and disadvantages were regarded as selfevident facts, but hardly any evidence was provided. Apparently, the relation between benefits and disadvantages is not clear and depends considerably on the characteristics of transformation.

The third theme was a set of questions on the history of the company's products and the development project of a configurable product family. The idea was to find out whether the company had been dealing with the mass production of fixed products or projecting of engineer-to-order, one-of-a-kind products.

THE CHARACTERISTICS OF CHANGE. With these questions we wanted to know how and from where the company had proceeded. Also, the questions dealt with

- the reason for configuration
- the source or the initiator of the change
- the way of work in the development of configurable product families

In general, interviewees were able to give answers to these questions, e.g. the reason was often regarded as inevitable afterwards. However, some companies found it difficult to answer questions related to a development project. Most often, in these cases the interviewees had not participated in the entire project, which had not been precisely documented.

On the development of CPF

PLANNING AND MANAGING CPF. The fourth theme covered product planning and management as well as engineering policies and procedures. Arranging these functions appeared to be a very important matter with configurable products. A strict product policy appeared to be quite an important issue to a company that had been previously projecting engineer-to-order, one-of-a-kind products. Thus, a number of clear statements were being given. Also, some procedures on how to actually manage products were given:

- the way of action in the continuous product family (module) development and some results indicated by the interviewees
- the way of action both in the sales and production processes

THE ARRANGEMENT OF OPERATIONS. Within the questionnaire, the fifth theme covered operations such as sales and production as well as product development. Originally, it was addressed to the way of action in sales delivery processes. Questions regarding operations were commonly comprehended and the answers were clear. However, the questions instructed the interviewees to concentrate on information flow and the way of action especially in a sales situation. Internal processes as well as the supply chain issues were not dealt as widely as the ”front-end” matters.

THE IT SUPPORT OF OPERATIONS. The sixth theme in the questionnaire was related to the support of information technology the companies were using. As this was often quite a clear issue, answers were adequate. An eminent fact, at that time, was the low number of actual, commercial configurators in the companies that applied configuration. Instead the support of Product Data Management system was either utilized or the implementation of such a system was planned. In many cases, the companies relied on the structured sales forms and competent, qualified personnel.

STRUCTURING AND MODULARISATION. As the seventh theme of the questionnaire, product structuring and modularisation were addressed. There, a set of generic beliefs and detailed examples of modularisation were given. However, the answers were wide issues from product structuring to standardisation and the parametrisation of components. Only a few companies were able to give both detailed and generic answers about the philosphy of their product structuring and modularisation approach. Most of the interviewees could only give an overview of the product structuring philosophy or detailed examples. Thus, the analysis of product structuring is not uniform and relies partially on the perception of the interviewers.

THE SUPPORT FOR THE DEVELOPMENT OF CPF. The final theme was related to supporting the development of configurable product families by methodologies and tools. Special attention was paid to the requirements of product development, IT support and data transfer between different programs. However, these questions were usually unanswered or only briefly considered. This was probably due to two factors. First, both the interviewees and interviewers were getting tired in the long one-day interviews. Second, the issue is of the most abstract kind and therefore required common grounds (concepts and semantics). This was not always the case, because of the varying background of the interviewed people. Also, the number of interviewees from IT support was quite low.

Case studies: purpose and characteristics

Even though the transformation and the results of having CPFs became clear, the interviews only briefly revealed the situation of the companies. The characteristics of the development processes mostly remained scattered, because not much information on the course of development project was collected in the interviewed companies. This was the situation particularly when:

- the process had been an evolution process instead of a clear development project, as in interviews with [Huuskonen 1998],
- the interviewed person had not participated into the project [von Bonsdorff 1998],
- a long time had passed since the development project (most of the intervies).

Also many of the latter questions, such as "How operations are arranged and supported by IT?" and "How to structure CPF?" as well as "How to support the development of CPF?" remained undisclosed. This was due to lack of time and some of the questions, especially the latter ones, were just too difficult to answer.

Thus, a more focused study on the following aspects was required:

- What is the role of structuring and re-engineering product families for configuration in a projecting company?
- What kinds of aspects are required in the development project, when a (projecting) company is approaching the application of configuration?
- What kind of documentation of the configuration knowledge is adequate and suitable in practice?

Experiences from practice

Another set of research material with a practical problem oriented approach was available in the form of industrial cases, in which the author has participated. The cases have been carried out during a period of time from 1998 to 2006. The duration of the cases has varied from 10 weeks to nearly two years. In this report six case studies were selected. Even though being involved in the cases, the author's responsibility has been very limited in all the cases. Therefore, the author claims to have certain objectivity in relation to the cases.

First, a study on experienced uncertainties in the projects of power plants is presented in order to define the characteristics of problems related to the sales delivery process in projecting. Then the set of cases is presented in order to represent the characteristics of transformation from engineer-to-order projecting to configuration-based systemic customization. In three of the cases, the author participated as an instructor to the M.Sc. thesis projects, and in two of the earlier cases, his participation was more intensive. However, the instructing of the theses was quite intensive.

The characteristics of cases

MUTUAL CHARACTERISTICS OF THE CASES. All of the case companies loperated on business-to-business markets, i.e. produced investment goods. The products were relatively expensive and the volumes of sales were limited. Moreover, the cases shared the mutual narrowing transformation from projecting to systemic customisation. In line with the transformation was the objective to change sales-delivery processes from engineering to order to partial configuration. Also, the common goal was to convert product design so that it would result in a number of optional as well as structured solutions, instead of separate one-of-a-kind products with a vast number of separate solutions of the similar kind.

DIFFERENTIATING CHARACTERISTICS OF THE CASES. However, the companies had considered quite different kinds of means for implmenting the transformation: the change of sales-delivery processes as well as the product development process. Also, the scope in the development projects varied substantially, as one of the companies focused on part standardisation and analysing functional relations in part domain, while another was changing the way of work in both product development and sales delivery. Relating the cases to each in this respect other may provide a useful frame of reference, as presented in Figure 9 below.

Two of the earliest cases focused mostly on structures and parts. The third case concentrated on defining a product family as well as the structures that enable the family. The forth and the fifth cases were about structures in one product family. Thus, none of the cases was pre-eminently focused on the business level issues.

Also in the two earlier cases, the process and the organisational point of view was not given much thought. In the third case the structures were related to sales-delivery process. The fourth case was a balanced study on both sides of

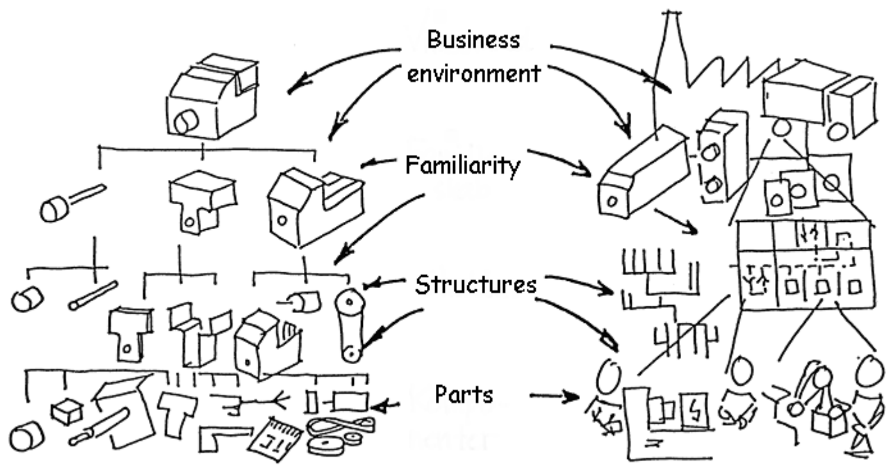

Figure 9. Product and process structuring levels [Mortensen 2000]

the Figure 9. In the fifth case the development started from production lines, i.e. the level of structures in the right side of the Figure 9.

Also, the case companies differentiated from each in matters such as company size and history as well as the sales volume, product and production technology. Three case companies had global market presence and therefore quite heavy organisation for sales-delivery processes. In two cases, products had been sold mostly to the domestic markets and the organisations were remarkably smaller. However, both of the companies were expanding to the European market. The products of the case companies varied from mobile rock drilling to milling machinery and from electrical engineering in cranes to a section of a paper making machine and, finally, to special vehicles.

In three of the cases, there was a long history of selling products with quite limited annual sales volumes, between 50 to 200 products per year. From a longer perspective, the products of these companies were remarkably similar to each other and shared the basic functionality. The introduction of new technology appeared mostly by automations and computerisations of the controlling functions or by applying new technology on top of the old. Arguably, some of the products could have been developed gradually so that new features would have been implemented as modules.

Two case companies sold and delivered their products with a traditional projecting business approach. There, very small volumes, actually less than 20 in each year, of one-of-a kind products were engineered to order. However, these two companies were very different in their size, regarding factors such as the personnel, the turnover and the market presence.

The interviews and the cases present a point of view that covers many aspects of Finnish industry. These cases also provide the qualitative verification for case study research.

Literature review

This chapter defines the topic of this research from the viewpoint of the related literature. Literature is treated as the material for the objective of the chapter, which is to formulate a model that relates the characteristics of projecting and product design as well as the development of product family and the configuration knowledge to sales-delivery processes.

First, the topic is studied in the context of business literature including the production paradigms and transformations (from one to another). Then the paradigm of projecting is defined from the perspective of product engineering in a sales-delivery process. Engineering design is reviewed from the design process and product structuring viewpoint. Product development processes well as the product development paradigms are described. Configuration as a means for deriving the description of product family instances is reviewed. The relation of product types, sales-delivery and production process is described. The result provides a model that describes the concepts of meeting and disposition in the development of configurable product family.

Transformation of business

There are stable and changing issues in companies. For example, the management of changes in products, components, and documents is one of the main functionalities of PDM systems [Crnkovic et al. 2003]. The persistent ways in which a company deals with everyday operations such asthe management of production are stable. However, more pervasive, stategic changes that alter the operations are an issue that during the 1990s was the topic of Business Process Re-engineering [Hammer et al. 1993]. The change from projecting to systemic customization is one of the latter kind of changes. Product configuration is a means for systemic customization and it is the essence of this research. Therefore change from engineering in projecting to configuration is a part of strategic change.

According to Pine [1993] and Anderson [1997], there are four major production paradigms: innovation, mass production, continuous improvement and mass customization. Major changes from one paradigm to another can be regarded as paradigm shifts that are related to the rate of product and process changes (see Figure 10).

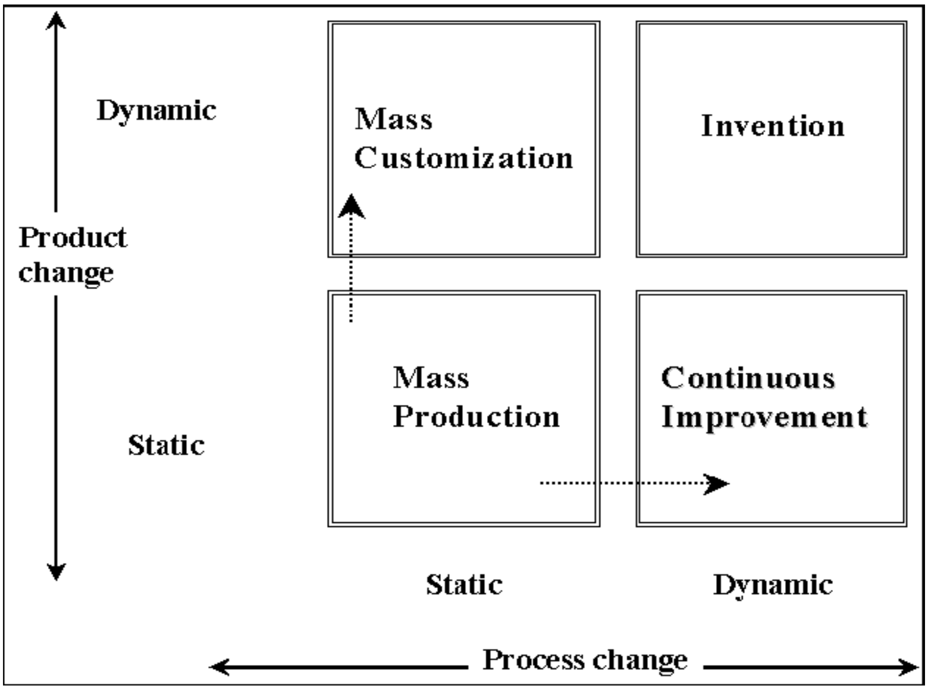

Figure 10. Production paradigms according to process and product changes [Boynton et al. 1993]

Shifting from paradigm to another

MASS PRODUCTION BY STRUCTURED DEVELOPMENT. During the era of mass production, the situation was quite stable, i.e. contingencies, disturbances, and major market fluctuations were rare [Womack et al. 1990, Pine 1993]. The system of mass production reached its peak in the American automotive industry few decades ago. It was highly structured and persistent, which worked well from the managament viewpoint, but suffered from lack of horizontal communication [Womack et al. 1990, Norman 1999]. The attitude of handing product documentation “over the wall” from design to production is often related with such car manufacturing corporates as Ford and GM [Boothroyd et al. 1994]. Consequently, product development became slow, involved large organisations, and produced poor results in quality [Womack et al. 1990].

LEAN PRODUCTION BY CONTINUOUS IMPROVEMENT. In the late 1980s, the paradigm of advanced companies was streamlining production processes and systems as well as making organisations lean [Womack et al. 1990]. In order to alleviate the product development problems of mass production, new methodologies and tools were introduced. Concurrent engineering [Winner et al. 1998, Dwivedi et al. 1991, Cleetus 1992, Olesen 1993] and integrated product development [Andreasen et al. 1987] are examples of such methodologies. Benefits were gained from diminishing lead times and improvements in product quality. The goal was to gain competitive benefit from keeping the production fast and costs low. Customer satisfaction was expected to be gained through efficiency, even, and aligned quality. These issues reflect the change from mass production to continuous improvement, which is the second paradigm shift in Figure 10.

MASS CUSTOMIZATION BY STRUCTURING PRODUCTS. By the early 1990s customers' demands were not anymore aligned, but the market became turbulent [Pine 1993]. Hence, the goal of a number of companies shifted away from developing products that fit the needs of one or an average customer. Rather, the aim was to develop generic product models that could be customized to specific requirements of individual customers. This also affected the corresponding production processes and systems. Production had to be flexible enough to be able to manufacture the variants. The paradigm started favouring modular engineering [Anderson 1997, Miller 2000] as well as the tools related to it, such as design structure matrix [Eppinger et al. 1996].

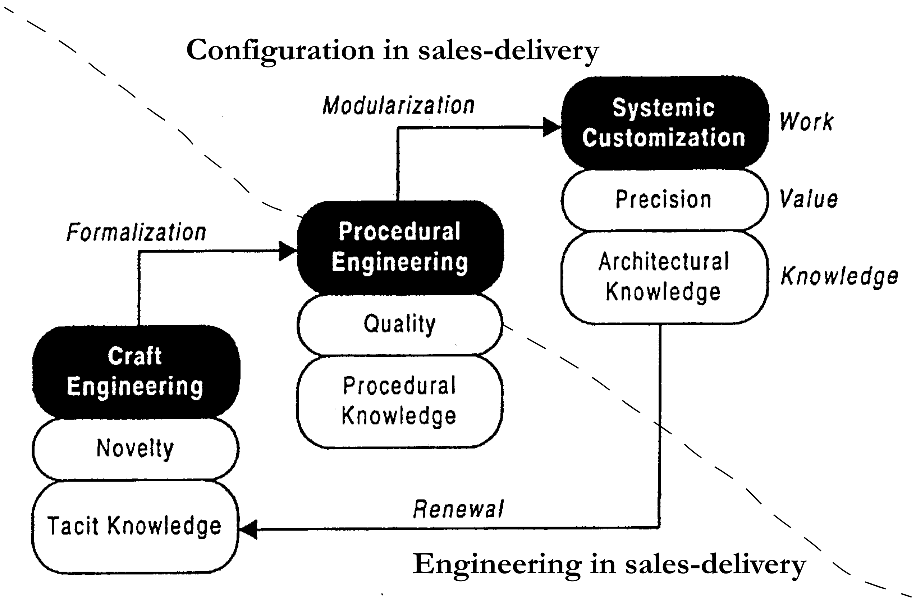

Figure 11. The step wise development of engineering from craftsmanship to systemic customization [Victor et al. 1998]

PROJECTING BY FLEXIBILITY. As shown in Figure 10 many of the models to approach mass customization and continuous improvement originate in mass production. However, in all of these paradigms and paradigm shifts the sales, engineering, production, and the delivery of products with small annual volumes has existed. The advantage of this approach is the flexible customer oriented-project organisation [Pinto et al. 2001]. As these products are engineered-to-order, the design process and often the product development activities take place in a sales-delivery project. Moreover, the processes are evolving from one project to another. Thus, the situation appears quite similar to innovation. However, the design tools and methods applied in this case are similar to those in the separate product development projects of mass production.

The evolution pattern in Figure 11, clearly demonstrates why Anderson [1997] argues that the paradigm shifts occur with a regular pattern. The inventive organisation defines the new product innovations that utilize the novel product and production technologies. As technology advances, the product offering is targeted to larger markets, where cutting the cost as well as retaining uniform quality are the desired properties. These are further elaborated with continuous improvement. At the same time, the usability of products becomes an issue to win the market [Norman 1999]. As the market evolves to turbulent stage, the mass customization paradigm becomes dominant [Pine 1993]. Similarly, [Victor et al. 1998] have defined that engineering evolves in three steps. The idea in Figure 11 is that the characteristics of engineering knowledge, the value of it, and the work process that utilizes it are in line (between each other).

Transformation

The theory of enterprise transformation [Rouse 2005, Rouse 2006] suggests that a business change can be characterised by issues divided into three categories, which are: **scope, means, and ends**. Within the scope of transformation Rouse includes the organisational levels; activities, functions, organisations, and enterprises. The means of transformation are the individual skills, processes, technologies, and, more generally, strategies. The ends can be evaluated with costs, perceptions, and, more generally, offerings and markets.

In the context of configuration in a projecting company, the scope of transformation is the set of activities, functions, and organisations related to sales-delivery projects. Actually, these projects are transformed into processes – the definition of project is later (see page 42). The means for the transformation is product and process related knowledge. The knowledge is to be developed and articulated for the transformed processes. The objectives of the transformation are related to the performance of (sales-delivery) processes – not the constitutive properties of product families.

The context of the transformation requires the clarification of the state at the beginning and the end of the transformation:

1. What do we understand by projecting and how is the performance of the sales delivery project affected by product design?
2. What do we understand by product configuration and how is the performance of sales-delivery process affected by configuration?

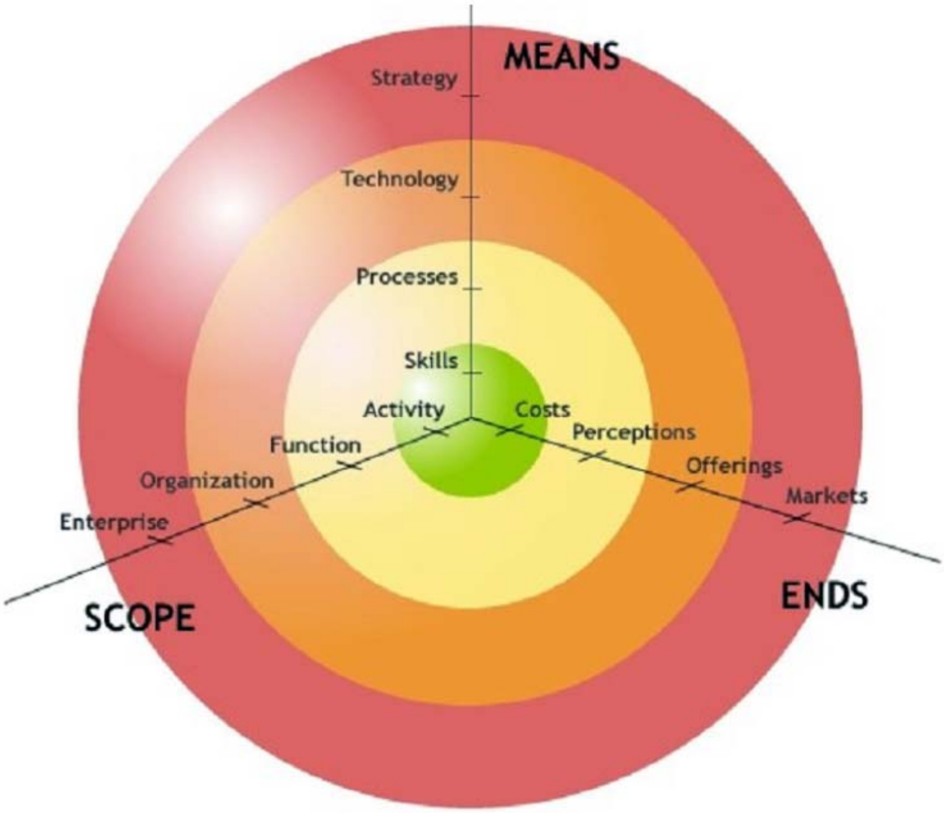

Figure 12. Transformation framework by [Rouse 2005 pp. 287]

These two require further elaboration, even when it is obvious that there is a remarkable difference in the selling and producing products in projects and configurations. However, it is neccesary to relate these two in the context of sales-delivery, because project nor configuration in itself is not the objective in itself.

Characteristics of projecting

The concept of projecting can be characterised as follows:

> **Projecting is the mode of operation that a company in project business carries out. A projecting company is an organisation that operates by participating in planning and executing consecutive projects.**

This definition is invalid if we do not further define the concept of project business and the concept of project. Let us start with projects.

The definition of project. According to project managment body of knowledge (PMBOK) "**a project is a temporary endeavor undertaken to create a unique product or service**" [Duncan 1996, pp. 4]. It is executed and controlled by people, with limited resources according to plans. Because of unique and temporary characteristics, the planning is done *ad hoc* for each singular project and the timetable, especially the two dates that define the beginning and end, dominates the plan. Projects are carried out by project organisations, which are typically networks of companies.

In PMBOK the meeting or exceeding stakeholder needs and expectations is emphasized. Therefore balancing competing demands arise among:

- Scope, time, cost, and quality.
- Stockholders with differing needs and expectations.
- Identified requirements (needs) and unidentified requirements (expectations).

Project management is different a discipline than operations management. The root cause of the difference lies in the temporary and unique characteristics of the activities and deliverables of projects. In operations management; the activities are repetitive and the deliverables standard.

Project business

There are many objectives and contexts where projects are carried out and the related literature is remarkable. However, the behaviour of the organisations that carry out the consecutive projects is seldom considered holistically. In a bibliometric study [Artto et al. 2005] define project business as follows:

> **"Project business is the part of business that relates directly or indirectly to projects, with a purpose to achieve objectives of a firm or several firms." -**Artto et al. 2005, pp. 351

Characteristics of project business. However, in this consideration only product development and sales delivery projects, with the objectives of customized product and profits, are of interest. This limitation excludes, for example, the maintenance projects as well as the projects of other kinds of services. On top of the above definition, projects are characterised by seven issues [Artto et al. 2005]:

1. The dominant role of R&D
2. No operations management content
3. Scarce representation of strategy research
4. Environment-dependent approaches
5. Need for several theoretical foundations
6. The firm from organisation theory viewpoint
7. Inter-organisational collaboration

Artto and Wikström [2005] further elaborate the seven characteristic issues from both the scientific and the managerial viewpoints. Without going into details, it is noticeable that the projects are based on rigid methods and tools that lack scientific theory base, such as strategy and operations management theories. Thus, the projects are often related to the hand-to-mouth business approach, where the case at hand, i.e. the environment (issue 4), dictates the means.

Typically, projects involve product design engineering, but here we must emphasize that the engineering processes of sales delivery projects differ from the product development processes, where the aim is rather generic need, instead of a singular specification which is the case in projecting.

A projecting company considers each production case as being unique and therefore the commonalities of product design are not acknowledged or systematically utilized in the life-cycle of projecting products. This does not exclude the situation in which product design is unique and there is no commonality of designs, which is rare. When a projecting company begins to utilise the variant or standard designs as a part of the product design, it enables the utilization of the standardisation in production. The company makes a transition from pure customization towards standardisation.

Uncertainty with projects: the state of project

The performance of a projecting organisation is unpredictable since projects, by definition, are unique and therefore uncertain. Project uncertainty, ambiquity and complexity has been treated by [Loch et al. 2000, De Meyer et al. 2002a]. They model projects as systems that evolve from one state to another. Knowledge about the relations between the system input and output is the main characteristic of the state of the project. The characteristics of different project management situations are:

- Complexity – a large number of interacting activities typically modelled and managed with Gantt graph, Project Evaluation and Review Technique (PERT) and Critical Path Method (CPM).
- Variation – the progress of a large number of activities is influenced by a multitude of small uncertainties and managed with buffers, reservations, and provisions, which are typically assigned at the end of each task, as well as by calculating the distribution of possibilities to meet the planned schedule, simulation, and critical chain techniques.
- Risk – a distinct and identifiable project influence, i.e. one that is plausible to anticipate, that may have a major impact on the project can be, but seldom is, represented and managed with a decision tree, where branches represent different outcomes of tasks and encourage the planning of alternative action paths.

- Ambiguity – an unforeseen factor that may have a major impact on the project similarly to risk, but cannot be anticipated (and therefore transformed into risk) without continuous scanning and tracking as well as re-planning by project management by the evolving decision tree.
- Chaos – when interdependent ambiguities and the emerging influences on the project success are both unknown and interrelated leading to situation where it is impossible to construct a decision tree, but to iterate.

Different project management methods can be applied in different situations. Typically projects are regarded as complex systems where the changes in some element, such as resource allocation, can be handled with traditional project management methods such as the Gantt and the PERT charts (Project Evaluation and Review Technique) as well as the critical path method (CPM). The variation within a subsection or one element cannot be totally anticipated, but statistical methods give a valuable estimate in the next state. With the unforeseen uncertainty, risk, a decision tree is a useful tool, but incomplete when at the initial state some of the parameters affecting the result are unknown. In that state, ambiguity, an evolving decision tree is suggested by [Loch et al. 2000]. Finally, in the chaotic situation, the parameters of the system, i.e. the project, are interdependent so that the proceeding of a project becomes totally unforeseen. In that state the project management becomes a task of trial and error.

According to [Pich et al. 2002] the classical approaches to plan and manage projects as well as the related risk presuppose that all the required information on the project is available. They label this approach **instructionism**. The concept of the adequacy of available information is therefore almost an axiom with the CPM and PERT techniques. Instructionism often fails in projects, because the presupposition of information adequacy is not valid. According to Pich et al. [2002], more suitable approaches for this situation are:

- **learning**, which provides project management with flexibility and overall vision
- **selectionism**, where the top management with selection from multiple optional projects.

These approaches are adjusted to the situation instead of trying to adjust the situation to a fixed approach. However, learning and selectionism are not as usual in practice as instructionism is. Also, they do not seem as efficient as instructionism, as the learning approach involves a more holistic view (and plausibly more time) and selectionism a number of (probably concurrent and) competing solutions, which requires more resources.

Engineering design

In everyday conversation, concepts such as product, artefact, and design are used to signify varying, but sometimes quite similar meanings. For example, a product is the result of production, in common language. Further, production is a directed set of activities transforming the object from raw-material to products. With these objects and relations our, thinking seemingly ends up with applying circular references as well as zero value in expression. However, the essence is in relationships rather than in objects. The prerequisite for an object to be a product is that there **has been** a connection to production. Thus, the relation of activities and their inputs as well as the outcomes define the objects.

Design objects in relation to design activities

Engineering design process is a directed transformation of information from specifications to the description of a technical system [Hubka et al. 1996]. It is controlled by engineering design knowledge that can be separated into two parts, knowledge on technical systems as well as knowledge on design processes (see Figure 4 on page 21). Even though it is directed, the design process is hardly deterministic. Rather, its characteristics include contingency and polymorphism of the iterative steps taken in the transformation [Ullman 1992]. As a result, a number of dissimilar systems may fulfil the given set of requirements and constraints.

INTERLACED TRANSFORMATION PROCESS. According to Hubka and Eder [1996], an engineering design process consists of the management, work, and supporting processes. An interlaced process contain sub-processes such as the support for systematic information processing. From the systems point of view, a design organisation carries out a transformation, in which the operand of transformation is information. The transformation itself is from the (often vague and ill-defined) design specification to the definition of the technical system. In the model of transformation, the operand in the intial state is characterized as needs, requirements, and constraints placed on the technical system. In the final state, the operand is characterized as a description of the technical system [Hubka et al. 1996].

The formal documentation of the result of the process is the topic of curriculum in all the technical universities and supported well by the information technology, such as CAD (Computer Aided Design systems) and PDM systems. However, the design specifications vary and they are an evolving topic of research. The formal categories of product design specification have been defined by [Hansen et al. 2004].

The execution system of the design process is both the human and the technical system that is the engineering design organisation and the design means, respectively. Other factors influencing the process are information, management, and environment, including time.

In product design, the solution space is considered open, meaning that the result of the design activity is unforeseen. Also, the problem space is usually somewhat obscure in the beginning, even when all the requirements and constraints are specified. This is due to the nature of the process, which contains both the synthesis and the analysis of the technical system. The analysis is well-defined and regressive from result to requirements and constraints. The synthesis is ill-defined and progressive to the opposite direction.

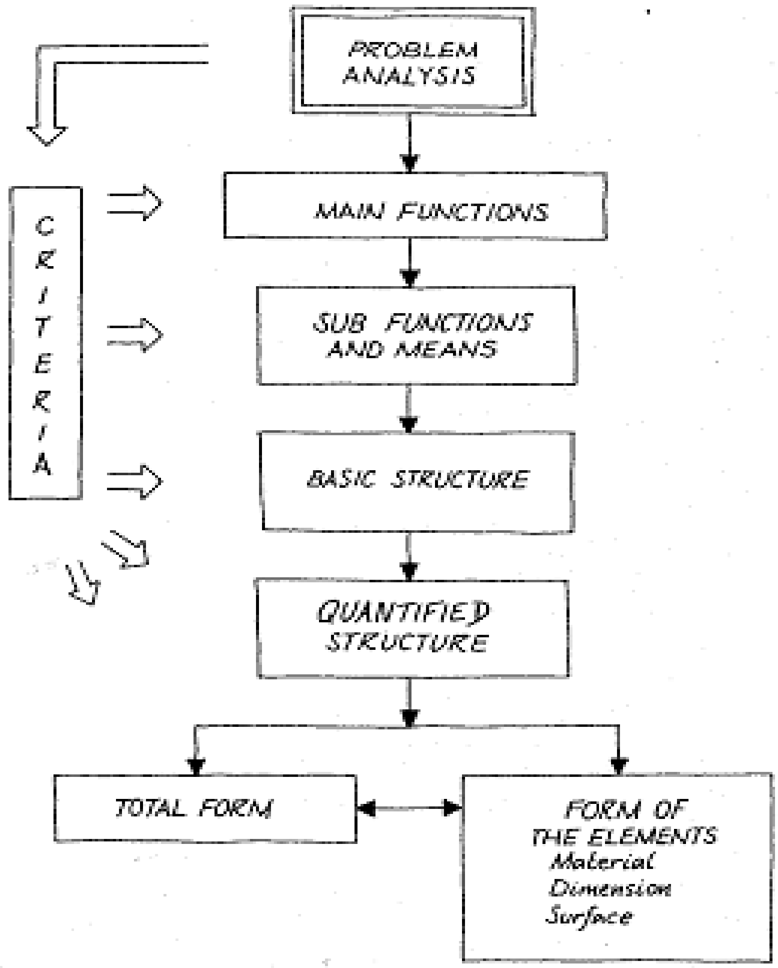

Figure 13. Design according to Tjalve [1979]

Several models on the engineering design processes with different points of view have been presented. Fundamentally, the models are based on systems theory [Klir et al. 1967]. The morphological box for systems engineering is composed of three dimensions: **professions**, **phases**, and **steps** [Hall 1969]. For example, the steps include problem definition, system synthesis and analysis, optimization, and decision making. The phases of product development include program and project planning, as well as system development, etc. The process is carried out by different professions.

The most commonly known prescriptive model on engineering design is the linear, though recursive, model by Pahl and Beitz [1996]. Linear means that the designer takes steps in sequential manner, forming consecutive phases of product development. The process model starts with the clarification of task and continues with the search of solution principles, function structures, and so on. There the characteristical phases of design are conceptual, embodiment and detail design [Pahl et al. 1996]. In the process, the information about the result, i.e. product design, is specified and concretized. Similar models can be found from [Hubka et al. 1996, Ullman 1992].

PROBLEMS RELATED TO CHARACTERISATION. The deliverables of sub-processes are related with the names. For example, the conceptual design produces the concept of a product. The concept contains characteristics for both the internal and the external stakeholders. This is characterized by the *idea in* and the *idea with* natures of product concept [Hansen et al. 2003]. Thus, the word *concept* refers not only to the stage of the process but also to the documentation in a certain state with the certain amount of information content, and also to the purpose and the point of view of the documentation.

There are two kinds of problems related with naming the processes with words related to the deliverables of sub-processes. First, the names become easily ambiguous and redundant, as presented with word *concept* earlier. Second, in practice the processes are split into different levels of decomposition. Thus, the concept in Company A refers to a different state as in Company B. For example, the conceptual stage of a power plant design (as a whole) differs considerably from the conceptual stage of a fuel delivery system, which is a part of a plant.

Structuring a solution in a context

An essential part of engineering is the initial problem statement or as [Pahl et al. 1996] define: the clarification of the task. Another important issue in product synthesis is the definition of structures for the product. An essential part of the prescriptive model by [Pahl et al. 1996] is the definition of the function structure. Figure 13 presents the process model by [Tjalve 1979]. There the basic and quantified structures are significant steps in the design of the total form. The properties of structure are decided with the numbers and types of elements and their relations. The form of elements, their materials, dimensions, and surface characteristics are decided in the detail design.

Andreasen considers design an interplay between different domains and related structures [Andreasen 1980, Andreasen et al. 1997]. There, structures are essentially similar to the Theory of Technical Systems by [Hubka et al. 1996]. As a structure is a combination of elements and relations [Andreasen et al. 1997], the emphasis of design may be laid on the total form or the form of elements [Tjalve 1979]. A hierarchical structure of functions and sub-functions is created according to a function/means law, where each (overall) decision limits the following (subsequent) decisions about the function [Andreasen 1980, Hubka et al. 1996, Tjalve 1979].

STRUCTURING FOR CONTEXTUAL CONSISTENCY. Alexander [1966] has considered the process of designing as a process of giving (a solution) form to a context. There, design is a process of solving and avoiding the inconsistencies with the context, since a designer observes more easily inconsistencies than compatibilities [Alexander 1966]. As the context changes, the existing solutions become inconsistent with the context – design activities are needed. Also, some solutions and their structures become either obsolete or plausible when the context of product life-cycle evolves. For example, a number of solutions related to typewriters have become obsolete along with the popularity of personal computers.

The consecutive sub-processes of the design process produce a set of structures, as shown in Figure 13 on page 46. Thus, another way of describing the state of the design process is to relate the deliverable of a sub-process to the structure it produces. For example, we might specify that a design process is in state where the *plant lay-out is finished*, i.e. in the terms by Tjalve: the quantified structure of a plant has been selected. In this way, the state of the design process can be related to the structure of a product (under design). As the structure is under development, the process is also evolving. Consequently, defining the exact state of the process would be impossible and converging to a suitable result uncertain. Simon considers a design process as a "*…highly selective search thorugh a large combinatoric space of possible components to the desired object*" [Simon 1980, p.27]. Due to selectivity, the convergence occurs.

INVOLVEMENT OF HEURISTIC LEAP. Also "*there does not exist a theory or method that leads a designer from function to solution directly*" [Mortensen 2000, p. 10-11]. According to [Hubka et al. 1996] and [Ullman 1992] design is always (to some extent) an idiosyncratic activity, where a design engineer takes a heuristic leap. In practice, this means that both the design process and the result of the process cannot be totally predicted or automated, even if there would exist a perfect specification for the designer to start with. The design process is then a complex system that cannot be completely torn down to sub-sections.

Nevertheless, the structures are used to refine and to solve the problem in a more confined solution space. The role of the function structure can be regarded as an aid for structuring the problem and searching optional solutions. However, the concept of function may refer to different things in different contexts.

MAPPING FROM ONE CONTEXT TO ANOTHER. According to Suh [1990], the context is a set of functional requirements, which are mapped against the set of design parameters (of a solution concept). The inconsistencies appear both as parameters, which do not satisfy the functional requirements, and also with the decoupling of relations between the functional requirements and design parameters [Suh 1990]. Consequently, the solution is either not satisfactory or attaining one is a difficult task. Thus, search for other kinds of design parameters or design structures should be continued. In Suh's principles, however, there is a presumption there exists a "loosely coupled" decomposition of the structure of system, which is under design. These kinds of contemplations presuppose that there already exists a solution to be selected, improved or changed by the designer.

However, the process of engineering design is not generally a straightforward mapping from requirements to functions and further to determination of parameters. According to Herbert Simon:

> "... in most design processes, criteria of generation and evaluation are applied that go well beyond function, and may have little or no relation to it." [Simon 1980, p.27]

Multiple interpretations on structural concepts: function

Also, there is no common understanding of the structures neither or their elements. As stated previously (see page 22), this conceptual or even ontological mismatch has been acknowledged by [Blessing 2003]. According to her, there is no common understanding of the essential terms such as function.

For example, when [Suh 1990] writes about functional requirements, the concept of function has a somewhat different meaning than in the systematic approach by [Pahl et al. 1996]. In the axiomatic approach by [Suh 1990] a functional requirement can actually be a life-cycle requirement, such as20 % lower material costs. Instead, Hubka et al. [1996] consider the function as the capability of a technical system to perform or to permit the internal transformations. A function can also participate to the inhibiting of an unwanted transformation. Transformations are directly related to the purpose of a technical system, the technical processes. The functions contribute to the system's internal processes, which as a whole provide both primary and secondary effects as outputs.

According to the definition of Rosenman and Gero [1998] a function can be restricted as (a part of) the description of what the product does. Moreover, a function is related to the purpose as well as the behaviour without being a part of either one. A structure exhibits a behaviour that has effects, which can be functions for the use of the system (see the Figure 14).

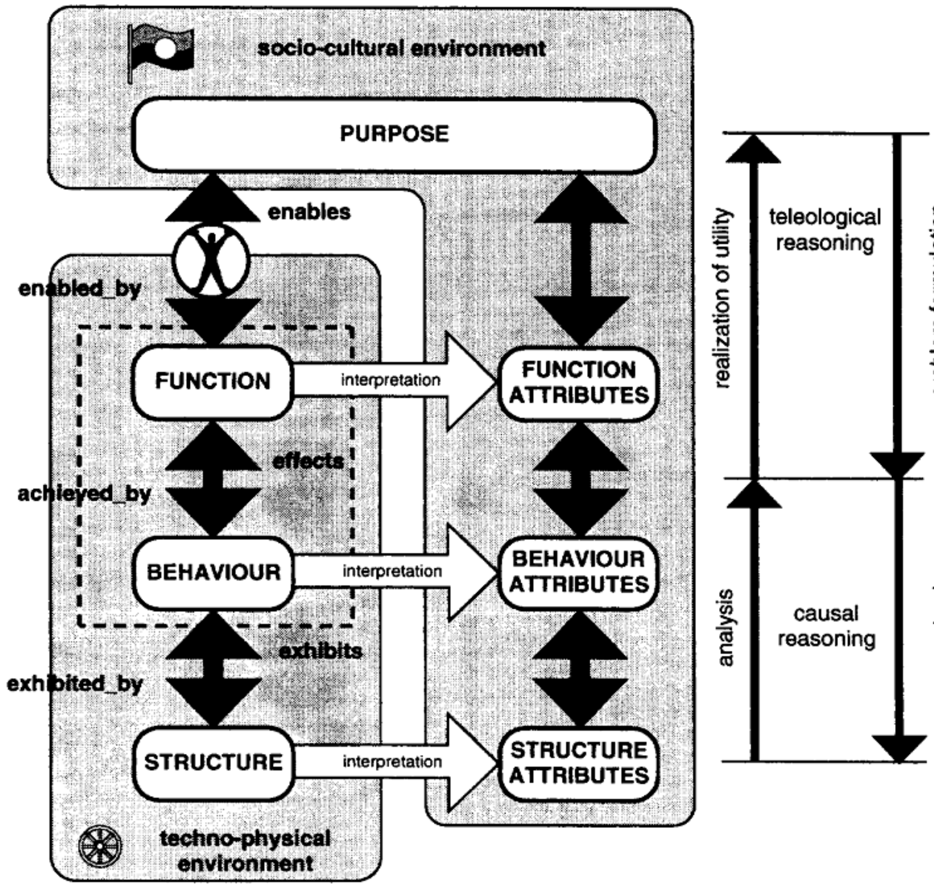

Figure 14. Concepts, environments and process [Rosenman et al. 1998]

Thus, in the model of [Rosenman et al. 1998], a function appears to be what [Hubka et al. 1996] consider a transformation. It appears to be so that the definition of function by Suh is more or less the same as behaviour of the product. The behaviour of the product is related to the life-phase system, such as production, distribution, use, etc.

In summary, the different models of a design process are hardly comparable and usually not compatible so that a certain submodel from one theory could substitute a part of another theory. However, there are contributions that complete the existing theory and make it more precise. In engineering design research, a theory or a part of is seldom disputed.

An affinity which appears to be common to the above statements of theories, is the acknowledgment of different contexts or domains, represented by objects and relations that form a structure. For example, the behaviour of a system appears in the process and the function domains and is related to the process and the function structures. Eventually, a designer may not be optimizing the functionality or an attribute of a system, such as weight, but searching for structures that ensure the consistency of properties in and relations between the different domains.

Product Structuring

Product structuring in relation life-phase system

Two main interpretations of product structuring consider the design of and the design data management of product structures [Tichem et al. 1997]. The product structure is a conventional topic of analysis and re-engineering for enhancing life-cycle activities. For example, in Design for Assembly [Andreasen et al. 1988] and Manufacturing [Boothroyd et al. 1994] some modularisation and integration patterns exemplify the ease of assembly. Typically, a production activity is the reflection of a certain kind of a structure. Generally, this reflection is referred to as the mechanism of disposition by [Olesen 1993].

In industrial applications, such as Product Data Management Systems, the structuring is often related to the management of product information and engineering workflow [Stark 1992, Peltonen et al. 2002, Crnkovic et al. 2003, Stark 2004]. Undoubtedly, many companies have recognised the issue not in product development processes but in the implementation of PDM and the quest for Product Life-cycle Management (PLM).

As presented, the roots of product structuring lie in design research, where the different kinds of structures are used for representing and describing the product and its synthesis [Tjalve 1979, Andreasen 1980, Pahl et al. 1996, Hubka et al. 1996]. Tichem et al. have summed up the field of product structuring as follows [1997, p.45]:

> "Product structuring plays an important role in creating products, which have good functional and life-cycle related properties, in design process management, and in several other company functions like production control".

For example, a typical aim in design for assembly is to consolidate a set of components to one larger component for the ease of assembly [Boothroyd et al. 1994, Whitney 2004]. In fact, in some cases this has led to the eradication of all assembly activities. The relative properties of a product, such as shortened assembly time and diminshed costs, are reflected to the company's external properties, such as competitive edge.

Propagation of change

Eckert et al. [2001] have studied change and its propagation in engineering design. According to them, engineering changes can either be initiated, i.e. based on deliberate decisions, or emergent changes that arise from problems with the design, such as unexpected behaviour due to the unintended interaction of parts and/or unforeseen side-effects. The latter are often the result of mistakes. However, with complex products, both categories of change result with the propagation of changes.

CHANGE AND PRODUCT STRUCTURES. The propagation of change in a product design engineering project can be transmitted by the operand, which is a piece of product data. Moreover, the data is related to a part of the product structure. For example, the data can be the selected material of a beam that is part of a crane. Within the structure of the crane, a beam can be categorized as the absorber, carrier or multiplier of change, when the categories are from [Eckert et al. 2001]. Absorbers typically inhibit the propagation of change while the carriers transmit it. The multipliers are nodes that spread the change to the multiple branches of the product structure.

The propagation of change is problematic with the integral product architectures that do not contain absorbers of change [Jarrat et al. 2002]. The result can be categorized as the ending and unending chains of change. In the ending category there are "*ripples of change, which are a small and quickly decreasing volume of changes, and blossoms, which are a high number of changes that are brought to a conclusion within the expected time frame*" [Jarrat et al. 2002, p.75]. On the contrary, unending changes form an avalanche of change which does not settle down within the given time frame or converge to a satisfactory solution.

CHANGE IN ENGINEERING NETWORKS. Studies on the engineering and the delivery of power plants also show that there are problems related to communication and co-ordination in a networked organisation [Pulkkinen 1998, Pulkkinen 2001]. In the studied context of projecting companies most problems were related to delayed changes and change propagation. The changes covered both the scope, i.e. the product design and realisation, and the activities, e.g. the activity of designing and supplying prefabricated parts. It was also typical that the changes were interrelated and led to changes in both categories.

For example, a change in the part, typically material, the dimensions and/or the geometry, of a piping system was often propagated in the design of other parts of the system as well as other systems such as the design of steel structures. Consequently, the downstream activities of supply, manufacturing, assembly, and erection at site were usually affected. In this kind of a change the project planning had to be revised and in the worst cases, the contracts re-negotiated. Thus, changes in product structure usually affect on the activity structure of a project.

Product architecture

Product architecture is a specific kind of a structure, as it relates the functions and the clusters of part domain [Ulrich et. al 1991, 2000]. It is a scheme of how clusters of parts contribute to a function. Consequently, an architecture may be the result of conceptual design in a separate product development project or, as the scheme may be reused, conceptual definition of many products that follow the common scheme. This scheme, appears in the qualitative and quantitative structures by [Tjalve 1979]. Thus, a product architecture represents the inter-domain relation between functions and parts as well as the intra-domain relation of parts. In the latter meaning the common architecture may be the dominant design of an era [Baldwin et al. 2000, Whitney 2004].

Product families

A product family is the set of products that share something or have something in common. The commonality may be seen from a number of different viewpoints, such as marketing and sales as well as production and suppy, but here the viewpoint is design engineering. According to Whitney, the product families are composed of common platforms and variants [Whitney 2004]. In the most simple case of this definition, a platform equals to a base unit, to which modular, varying units are attached, according to specific requirements.

PRODUCT FAMILIES AS MARKET STRATEGY. Lehnerd and Meyer define the platform as consisting of not only system elements but also common structures and interfaces. The development of platforms is then co-ordinated so that it corresponds to market segments and tiers, such as user groups and the level of quality. [Lehnerd et al. 1997]

PRODUCT FAMILIES IN PRODUCTION. However, engineers comprehend products and product families through structures, as it is represented in another section of this chapter (see “Structuring a solution in a context” on page 47). Generic constitutional structures (in the part domain) are often being developed for product families. These can be seen as the sets of parts or their characteristics, such as in group technology [Hyde 1982], or common structures in assembly and logistics [Lapinleimu 2001].

A design engineer is not only responsible for the characteristics of parts and the feasible assembly of a product, but also for the behaviour and the life-cycle properties of a product. Hence, structuring in design engineering is more diversiform. As engineering may be aim at the primary development of the total form or the characteristics of elements [Tjalve 1979], the product families may be parametric, i.e. based on size ranges and similarity laws, or configurable, i.e. modular [Pahl et al. 1996, Simpson et al. 2007]. Also, the domains of thought in engineering [Andreasen 1980, Hubka et al. 1988] suggest that product families may be either based on processes, functions, organs or parts. All these options must be taken into account when developing product families and choosing the correct strategy of product structuring.

CONFIGURABLE PRODUCT FAMILIES. Usually, configurations are supposed to be different from each other. As the elements and the ways to relate them are pre-defined, only structural variation between configurations emerge. A configuration is the definition of a product individual, i.e. an instance of all possible variants. Tichem et al. define that "*the distinctive aspects between individual product (family) variants is the difference in the individual structure*"[Tichem et al. 1999]. Therefore, a configuration is a description of product individual, which is a member of product family.

REUSE AND STANDARDISATION. Following the engineering design research, Harlou considers design as a definition of design units in four domains. The essential aspect in design is the interaction between them. Typically only the part domain is well documented, while the process, function and organ domains remain tacit. A design unit is a standard design if three requirements are fulfilled [Harlou 2006]:

1. **reuse**, so that a standard design is or will be used in consecutive product versions,
2. **documentation**, so that the standard design is documented with a pre-planned manner,
3. **responsibility**, so that there is an organisational body that is responsible for a particular standard designs or a class of them.

Thus, design reuse is built in with the concept of a standard design. Based on the definition of standard design, Harlou has further developed the concept of architecture to define either the elements and the relations of a product, a product assortment, or a product family. In this way the architectures are also product assortment archtectures and product family architectures. Essential with the architectures is not only the reuse of design units but also the reuse of interfaces. In the case of a specific product, the product architecture is derived from the design units and the interfaces of the product. The product assortment architecture covers the product asortment in a certain moment of time as well as the specification of the recent and apparent changes in the product assortment. The product family architecture defines the reuse interfaces and units in time. [Harlou 2006]

PRODUCT ARCHITECTURE AND BUSINESS. Architecture is often related to the generic characteristics of business. The cost of variation drives architectures towards modularity and the cost of performance drives architectures towards integrality [Erens et al. 1997]. For example, [Reinertsen 1997] suggests a set of architectures that each support different kinds of development objectives:

- Low-Expense Architectures
- Low-Cost Architectures
- High-Performance Architectures
- Fast-Development Architectures

Whitney considers integral architectures better than modular ones from the product performance point of view and modular architecture better from the business performance point of view [Whitney 2004].

MODULARITY IN RELATION TO LIFE-CYCLE. However, the aspects of architecture and their relations to business are not as straightforward as the above references claim. Many of the properties of architectures, such as modularity, are relational: the architecture is perceived from a certain point of view [Riitahuhta et al. 1998, Andreasen et al. 2001]. Acording to them, the properties of architecture, such as complexity, commonality and variability, are related to and experienced within the life-cycle of the product. Thus, it could be useful to consider the concept of modularity in similar way as the concept of design in DFX methodologies: modularity for assembly, modularity for configuration, modularity for transportation, etc.

Varying dimensions in Configurable Product Families

The generic structure of a product family itemizes the varying standard designs from the static, fixed standard designs of a product family. Both the varying and the fixed designs of product structure can take place in the types of elements in different domains, the attributes and numbers of elements, as well as their mutual relations. Variety between configurations may be created with a number of dimensions, by varying:

1. the number of similar elements
2. the type of an element (a module in part domain)
3. the (horizontal) relations of elements
4. the attribute of an element (module characteristics)

Varying the type of an element may be regarded as a special case of varying their attributes if the type is based on varying a specific attribute. In the former case, an attribute typically gets discrete values, while in the latter case the values are continuous. In practice, a number of of the varying cases may occur simultaneously in the product architecture.

PRODUCT MODULARITY. Varying the product can be promoted with modularity, which is a characteristic of product family architecture. Modularity is a relational, diversiform issue that has a number of implications. Basically, it enables component swapping in a configuration and component sharing between configurations. Other categories of modularity are fabricate-to-fit, bus, and sectional modularity [Ulrich & Tung 1991] as well mixed [Pine 1993] and stack modularity, which is a property of product assembly structure [Andreasen et al. 1988]. A wobble pump is an example of stack modularity, because the tabular structure of the pump enables varying the functional properties along with the number of stacked bellows.

The dimensions in a product family are varied or fixed according to the type of modularity. For example, the element type is varied in component swapping, but fixed in component sharing. In stack modularity, the only varying dimension is the number of similar elements. In sectional modularity, all of the dimensions may be used, but the dominant varying dimension is the relations of the elements, which in bus modularity is the only fixed dimension. The fabricate to fit modules are parametric components and the dimension of variety is the attribute or the set of attributes of an element.

The degree of intended variety is highest with sectional and mixed modularity, where all the varying systematics may be used, which means that the numbers of element and their types, attributes, and relations can be different between configurations. With mixed modularity, even the relations of the elements often have no meaning and they are arbitrary. Sometimes, the mixing order has an effect on the end configuration, as in the case of mixing emulsions or water and acid.

VARYING DIMENSIONS AND PRODUCTION. Product differentiation in production processes is one of the issues that has gained considerable interest. Ideally, the variety should be produced as late as possible in the process – see Figure 26 on page 84. Different dimensions of variety have an effect on this. Generally, the standardised set of variant elements (in part domain) enables customized standardisation, i.e. the differentiation of products in assembly. However, the parametric components, i.e. varying the attribute of an element, locates the point of differentiation to part manufacturing. In part manufacturing the varying of the number of elements is favourable, as the number of different parts can be one. Categorically, it is a case of customized standardization. Also the sectional modularity, i.e. varying the relations of elements, makes assembly somewhat arbitrary and therefore not as systematic as it may be in the cases of varying the type or the number of elements. The list of dimensions presented in previous page is the favourable order of variation from the production point of view.

Engineering Design in Different Contexts

There is a large amount of literature on product development. Reviewing all of them it is not the idea here. The prescriptive model on engineering design, the VDI 2221 by [Pahl et al. 1996], appears to be a reference to a number of these models. VDI 2221 separates the process into three consecutive phases with clear milestones and reviews. For example [Ulrich et. al 2000 and Dym et al. 2000], present product development models with more or less the similar step-wise approach.

IPD acknowledges the business context

However, the model of integrated product development [Andreasen et al. 1987] takes a more holistic point of view on the phenomena of product development. Integrated product development (IPD) is a model of three overlapping processes in five phases. The processes are functional, i.e. different functions are responsible for carrying out the subtasks of the processes. As marketing is responsible for customer requirements, market studies, and so on, the product design department is ultimately responsible for the product design.

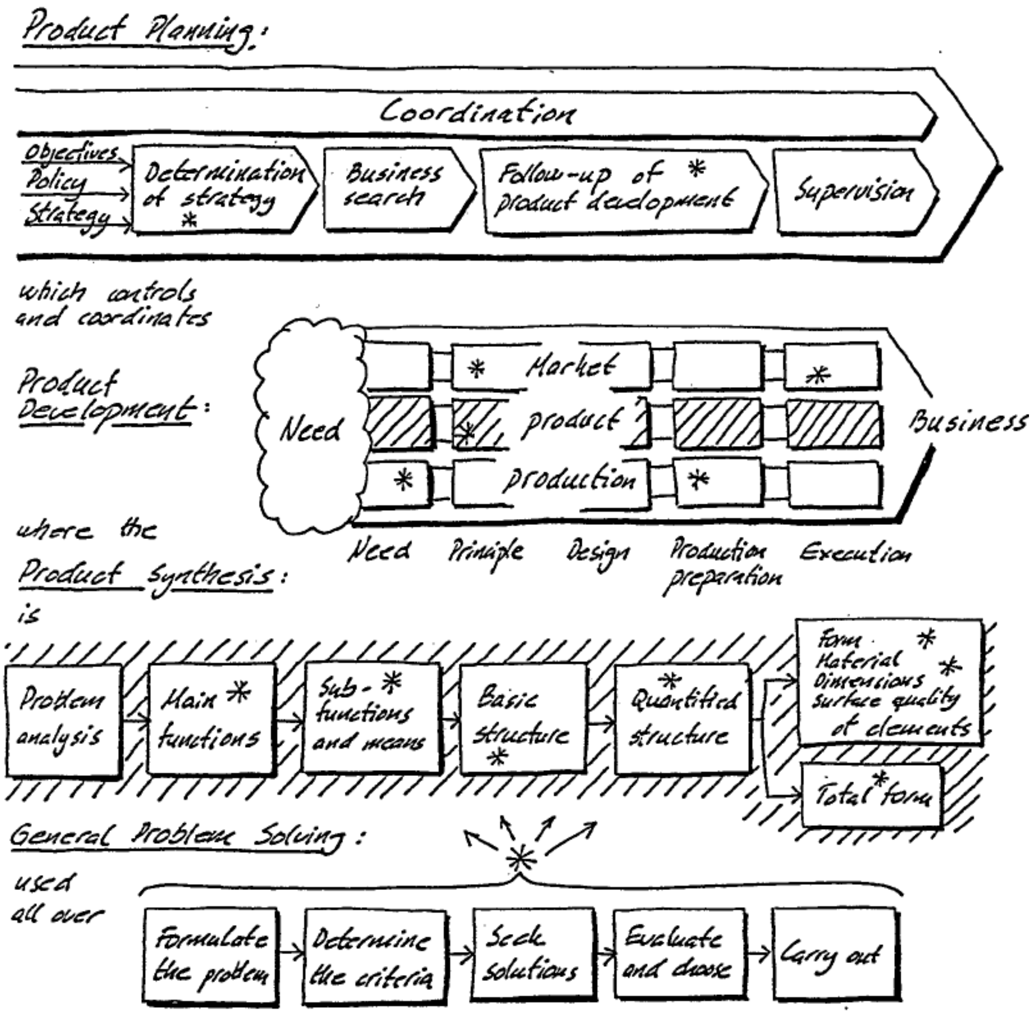

Figure 15. Integrated Product Development in business context [Olesen 1993, p.30]

Similarly the responsibilities of production department are related to the definition of production processes as well as methods and, eventually, production systems. Product planning is an ongoing process that controls the IPD project. A part of IPD is product synthesis that recursively utilizes the engineering design methods and tools, such as problem solving techniques.

IPD considers not only the phases of the project and the repetition of the elementary steps in the phases, but also the dimension of professions is involved. Thus it is in line with the morphological box of systems engineering by [Hall 1969]. Moreover, the model of integrated product development takes into account the "*refinement from business-related decisisions to detailed solutions to problems in product-related tasks*" as Olesen [1993, p. 30] presents. Figure 15 shows how the product development is a project in a business context.

Organizations and business paradigms

SPECIALIZED HIERARCHICAL ORGANISATIONS. The activities and the decisions of the design engineers always take place in an unisolated, instead of a laboratory-like, cirmcumstances. Engineering design activities and departments, even though specialized in industrial organisations, have interdependencies with other the activities of a company. According to [March et al. 1993, p.180]:

> "the greater the specialization by subprograms (process specialization), the greater the interdependencies among organizational subunits".

However, the tolerance for interdependence is high in a repetitive and predictable situation [March et al. 1993]. Therefore, the highly specialized organisations of mass production were able to resist the interdependencies during the era of mass production. Also, Sloan developed a hierarchical management system that could handle the interdependencies as well as the outsourcing of supply [Womack et al. 1990].

IN RELATION TO INDUSTRIAL DEVELOPMENT. Both the organisational structures of traditional mass production and typical project oriented production have presupposed the existence of a strong superior principal. In projecting, the principal organisation is usually referred to the main contractor. In mass production, such as in the automotive industry, the set of original equipment manufacturers (OEMs), supply the assembly facilities of a customer company, such as General Motors or Toyota, or its OEM assembling partner, such as Magna Steyr or Metso Automotive.

Varying ways for arranging the characteristics of customer-supplier relationships – their terms, responsibilities, the ways and means of co-operation as well as lengths – do exist. In automotive industry, the effect of the characteristics of customer-supplier relationships on the business as a whole has been analysed by Womack et al. [1990].

The traditional hierarchical organisation structures appear to be evaporating, as the activities – including engineering – are being more and more outsourced. Simultaneously the OEM companies are growing and in some sectors they supercede the main contractors in the number of personnel. For example, in Finnish shipbuilding industry the shipyard provides a channel to market and a facility to final erection of a vessel, but most of the segments of value chain, including engineering, material supply, prefabrication, and assembly activities are outsourced [Martikainen et al. 2006]. Thus, the model of integrated product development is probably even more actual than it was in the time it was presented, in the mid 1980s.

Product development problems

The development of engineering design methodologies and the related tools during the past century [Cantamessa 1998] has reflected on the specialization of tasks. Also, the project management methods developed in the late 1950s

[Moder et al. 1983] and the emergence of concurrent engineering research in the 1980s contribute to the management of either large, complex product development organisations or interdisciplinary dependencies. Thus, the problems addressed are typically related to the lack of overview that is the result of extensive specialization

Both the hierarchical and the outsourced organisation models show weaknesses in the communication and co-operation, as the progress of a product development process is horizontal rather than vertical [Norman 1999]. This is especially problematic with the large data sets of the consecutive stages of product development [Reinertsen 1997]. We will review this problem later in the section "Corrective interventions mode of operation" on page 66.

Moreover, in a turbulent market situation, the organizations are continuosly changing [Pine 1993] and the repetitive and predictable situations become rare. Also, the recent trends in industry, as presented section "Increased costs of subcontracting" on page 9, favour not only specialization within companies but also outsourcing (see Figure 1 on page 5). The combination of these issues, with the trend of offshoring functions and affiliate organisations set high requirements for the communication, co-ordination and overall performance of product development.

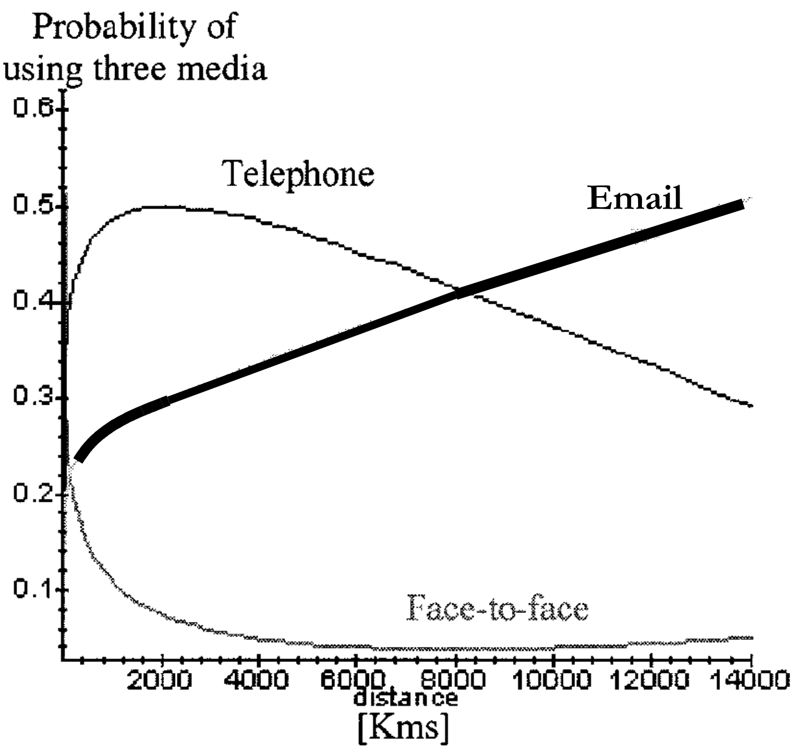

Figure 16. Relation between separation distance and the probability of communication [Sosa et al. 2002, pp. 53]

As illustrated in Figure 16, more formal methods are applied when the physical distance of transmission and retrieval increases. If there is a lack of common time, communication takes place almost exclusively via documentation. Thus, the communication is inevitably dependent on the media and the update of content. Email is a form that is seldom systematically updated, alone.The problems related to (sometimes even deliberated) information hiding as well as neglected changes cause re-work and scrap, waiting, delays and other kinds of disturbing effects on the projects as stated in the section “Uncertainty with projects: the state of project” on page 43. These, as a sum, cause losses which have a negative impact on the overall productivity of an iterative process.

The addressed problems of IPD

Andreasen et al. [1987] used a set of problems related to key roles within product development organisations as a motivation for Integrated Product Development (see Table 2). The problems of an executive management may be regarded close to the viewpoint of a customer or investor, because business management is responsible to customers and shareholders. As a system the categories of problems can be seen as the inputs and outputs of a black box, the development process. A common denominator for the problems of executive management in product development organisations is the productivity, i.e. the relation of input and output – investment and Return on Investment (ROI).

Table 2. The categories of product development problems in relation with organisation [Andreasen et al. 1987]

Problems	1 – of a executive,	2 – a project manager,	3 – and a team member,	4 – addressed to no-one
A – related to time,	project duration	keeping up with the plans	lack of time	early stages
B – cost,	cost			costs
C – commune-cation,		not enough information	lack of information	communication
D – result,	competitive-ness, quality			
E – performance,	productivity, competitiveness	input / output uncertainty		
F – and leadership		poor commitment of executives	lack of motivation, creativity and appreciation	controlling and motivation

According to the formalism of design performance measurement and management by [O’Donnel et al. 2005], the problem of an executive management is related to the overall performance of design activity in a work process, but the management of project management, the performance of design management activity is not of his interest.

In the roles of project organisation, both as manager or as team members, the viewpoint is that of an insider. Typically, project management acts in the interface of the black box as his attention is in the reporting of overall costs, keeping up with the project plan, and the communication within the project and outwards, i.e. to executives and shareholders. These problems are related to the performance of design activity as well as the activity of design management.

However, the actual carrier of a work process in a product development project, i.e. the team member, typically suffers from the lack of time, information, motivation, creativity as well as appreciation. These problems can be related to design co-ordination and, in general, design activity management. Therefore it seems that the management is experiencing the poor performance of design activities as a problem and the team members suffer from the poor performance of design management activities. Apparently, the relation between design management and design activities is strong, but the utilization and management of this relation is poor.

Concurrent engineering

The model of integrated product development [Andreasen et al. 1987] is quite close to concurrent engineering [Winner et al. 1998, Cleetus 1992]. The idea of concurrent engineering is to

- carry out simultaneous, synchronized development processes in different disciplines and business functions, such as marketing, product design such as production,
- have frequent communication between these processes as small packages of information,
- take into account all life phases of the product from cradle to grave, and
- the product is not only developed but also developed for certain purposes, such as sales and production. Required changes in respect to this are made during the project – not as consecutive re-engineering projects.

DISPOSTITIONAL MECHANISM. The aim of IPD is to ensure that all the important points of view are taken into account already in the product development and the important dispositions [Olesen 1993] have not been omitted. The dispositions emerge in the values of relative properties when product design meets its life-cycle, such as the time required for assembly.

The dispositional mechanism how design decisions influence on other life-cycle stages is is illustrated in the figure 17. [Olesen 1993].

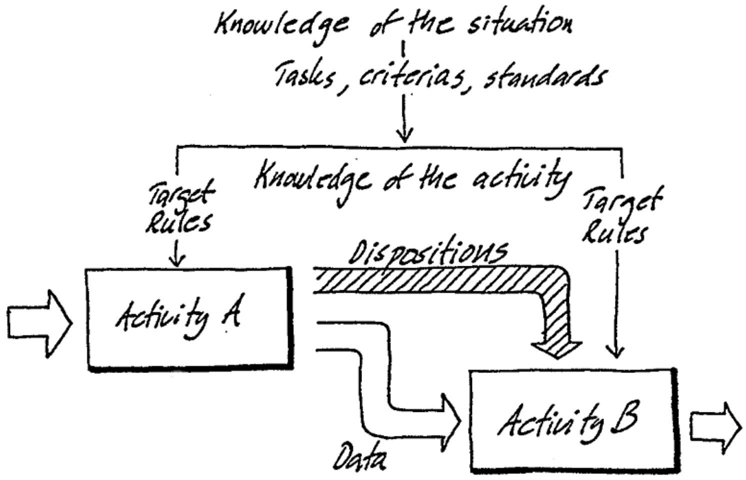

Figure 17. The dispositional mechanism [Olesen 1993, p.52]

The concept of disposition is formally defined as [Olesen 1993, p.53]:

> By a disposition we understand that part of a decision taken within one functional area which affects the type, content, efficiency, or progress of activities within other functional area.

In IPD, the meeting of a product and its life-phase is therefore pre-planned, based on the knowledge collected. In this way e.g. production would not encounter surprising characteristics and properties later on, since these should not be included in the product design. For example, such surprises include the late changes that hamper supply and production both in project-oriented production as well as in mass production: see "Changes, incompleteness, and errors in product definitions" on page 10 and in [Womack et al. 1990].

With the concepts of disposition and meeting, it is possible to explain and develop the products for their life-cycles. This is the idea behind Design for X methodologies. These concepts are presented here not only for the generic information, but they will be used later in the formulating the results.

Product development projects in relation to each other

Jandourek [Jandurek 1996] separates product development practices into three separate paradigms:

1. Serial Development Projects,
2. Multiple Parallel Projects, and
3. Platform Development.

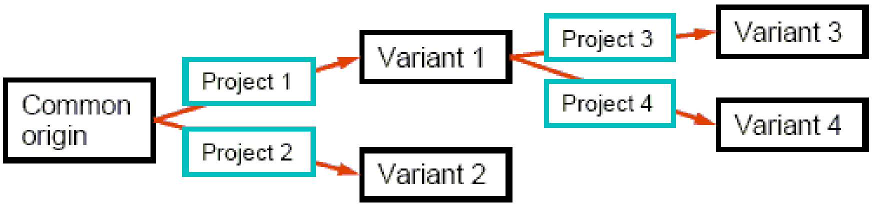

Figure 18. The serial project paradigm [Martio 2007]

Serial development projects

In the first paradigm, small development teams carry out development projects independently, one after another. Their mind set is to "just build it" and, therefore, product structures are implicit and often partially documented. If a series of consecutive products is going to be developed, the experience of people and teams enable the reuse of knowledge and particular designs. Thus, the products can be regarded as revisions or variants of each other, when no defined product family exists. Figure 18 illustrates a typical situation of product development and/or sales-delivery projects that end up with variants of a common origin: the engineering knowledge. Typically, the reuse of engineering is based on copying old projects, i.e. a product versions, as a template.

Organizational learning and leverage from preceding products can reduce the time to market (TTM). Jandurek points out the ideal situation in which *"the bulk of the effort invested in a latter project is directed at those value-added, differentiating features that are visible to customers"*[Jandurek 1996]. Moreover, he relates the reduction of TTM to the amount of similar product functions. Thus, the potential of reuse is related to the similarities of product requirements, and the time between successive products (TBSP) is not less than the TTM of an individual product development project.

Multiple parallel projects

According to Jandurek, the emergence of the second pardigm is dependent on the development curve of product technology and market acceptance. For a number of product variants, there has to exist a number of different customers with varying needs. As the product variants exist simultaneously on the market, there is a need to shrink TBSP below TTM of individual products. As a result, a number of teams work in parallel to build closely related products.

A pressure to reduce both TTM and TBSP may jeopardize the consistency between the products, since a product development organization is composed of separate teams. The leverage from earlier projects is from the first paradigm and, therefore, the knowhow grows old. Eventually, the "*benefit of leverage is subject to an inherent limitation and in the worst case may be negative*"[Jandurek 1996]. As a result, the organization tends to forget the past knowhow and concentrates on pursuing new implementations.

In this situation, pre-planned reuse is a key to balance the time pressure of and the consistency between product variants. As leverage refers to looking in the past for existing solutions and practices, "*reuse fundamentally looks to the future and orients development around what follow-on products will require*". This is comprehended as preuse by [Andreasen et al. 2001].

In software engineering, reusable components "*can be plugged into new products without any modifications, ... because the component user's primary concern is with the external behavior and interfaces and not with the internal details of the components*"[Jandurek 1996]. Instead, leveraging is often based on the modification of components or structures.

The practices of reuse and leverage can take place at the same time, if they are pre-planned and co-ordinated. These practices can take place in multiple levels of projects from sharing the generic structures of initial specifications to having in common detailed documents, such as blueprints.

According to Jandurek, "*the larger the granularity of work shared, the greater the impact on reducing project TTM*" [Jandurek 1996]. Sometimes it is very difficult for software companies to define the reusable components. In these cases a potential approach would be the identification of repeating and re-usable patterns [Gamma et al. 1995]. Patterns are typically more abstract and require engineering, but initiate the engineering faster by defining a structured definition of the task at hand. This is related to the development of standard design in a number of levels and domains of a product family structure "Reuse and standardisation" on page 54.

Platform based projects

Software companies which operate at the level of the second paradigm, often have independent and autonomous teams, project managers and architects for each product. Therefore, it is difficult to coordinate the sharing of work between teams. However, a company operating with the second paradigm has capabilities, such as established presence in the market, customers beyond the early adopters, and a deep customer and product understanding. The capabilities enable them to move to the third paradigm, Platform Development, which is an extension to second paradigm.

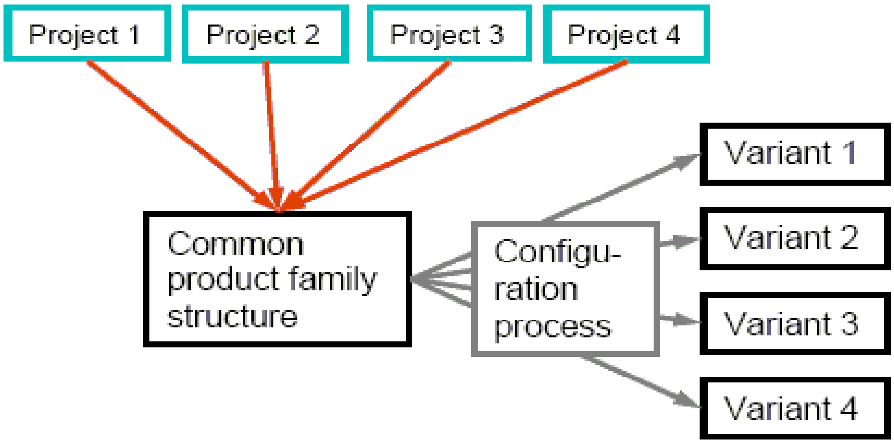

Figure 19. Product family structure as a platform [Martio 2007]

In platform development "*the common elements within a product family are factored out and developed once*". An essential factor for a successful platform is extracting the stable and well-understood product elements, features, and subsystems, which provide a basis for value-added, differentiating features. According to Jandurek the platform is different from a reuse library, because it has a "*cohesive, underlying architecture*". A platform does not provide a contribution to an individual product, because the implementations of platforms vary. In fact, the elements of products may be migrated to the platforms as they are verified and validated.

According to Jandurek, the benefit of Platform Development is a "*reduction in the TTM for individual projects*" and shrunk TBSP, propelled by "*the parallel development inherent in paradigm II*" [Jandurek 1996].

Mechanical engineering stages

Similar paradigm levels can be found in the product development of mechanical and mechatronics products. The development stages of modular engineering systematics are [Riitahuhta et al. 1998]:

1. Manufacturing of independent products
2. Product families as a market strategy
3. Architectures related manufacturing
4. Configuration oriented manufacturing
5. Dynamic Modularisation

According to [Riitahuhta et al. 1998] the difference between the second and the third stages is the **architectural definition of a product family**, which is directly linked to the configuration support system in the fourth stage.

The first and the second stages are similar to the description of first paradigm by [Jandurek 1996]. The third stage is close to Jandurek's second paradigm and finally, the fourth stage is similar to Jandurek's third paradigm. The dynamic modularisation is a paradigm beyond Jandurek's contemplations.

Relation to projecting

In the case of projecting engineered-to-order products an equivalent of TTM is the project lead-time, which ideally is dependent on the similarities of the consecutive projects. However, the time between successive sales-delivery projects, a counterpart of TBSP, is heavily dependent on the markets and the resources available. Our experience is that projecting companies often have to subcontract engineering (see page 10), which effectively prevents organizational learning and leverage between successive projects.

UNSCALABLE ENGINEERING. Generally, it is very difficult to manage a situation where the volume of throughput (e.g. the number of projects) increases in the projecting business. If the issues related to project complexity, iteration in engineering, personal and organisational learning are neglected, the volume of projects has a direct relation to the workload in a projecting company. This may not apply to the all functions of a projecting company. For example, even if the sales department could sell two times faster and the production could increase its throughput to bouble the original situation, the manual, work-intensive engineering function would suffer from the heavy overload.

PROBLEMS WITH PRODUCTIVITY. Means for increasing the production productivity have been developed during the past century. A number of them are based on the economies of scale in mass production. Also in a number of projecting companies the production function has bigger capacity than the engineering functions. Thus, the entire interpretation from the sales specification to the production order, i.e. the engineering function, can become a bottleneck in projecting company. From the engineer's viewpoint this means that (s)he is often overloaded in projects.

Corrective interventions mode of operation

To solve this problem, three different corrective/manual solution concepts emerge. Corrective means that in all of them, the cause of the problem is not solved, but the effect is being corrected. Manual denotes the fact that in all solution concepts more manpower is needed. Thus, the problems related to cost would be directly aggravated with these solutions.

First, the engineers could do overtime work, which is actually the case in a number of projecting companies. Second, the company could hire more personnel in the engineering department. This is seldom the case, because experienced people with the required abilities are hardly available. Also, no company is willing to hire personnel in businesses that are susceptible to economic fluctuations. Instead, companies often decompose engineering tasks according to specific fields, such as electrical, mechanical, and automation engineering, and then outsource or subcontract engineering work. A third solution option would be that companies could negotiate longer delivery times. This is hardly ever possible, because short lead-time is often a competitive edge for the company.

The first corrective/manual solution creates a twofold problem: the decrease in long-term efficiency and possible burnouts among engineers – the problems F3 and F4 of Table 2 on page 60. Usually, the decomposition of engineering tasks is hardly ever so simple that e.g. mechanical and electrical engineering could proceed independently. Thus, the second corrective/ manual solution leads to a number of coordination problems, because the iteration problems become aggravated when frequent information exchange needs to take place across the organizational borders. In the worst case, the different organisations end up having redundant versions of the same information as the input for the tasks and the end results are not compatible. The problems related to communication would be aggravated – the row C of Table 2 on page 60. The third corrective/manual solution is not possible in practice, as it aggravates the problem of an executive and external stakeholders. Thus, none of the solutions is satisfactory in the long run.

Having personnel working overtime, hiring more people or intense subcontracting generally leads to a situation where the number of people working for the project increases and the overall costs increase: the efficiency of employees is reduced. In an intense competition, the projecting company cannot charge the customer more and the project's profit is reduced.

Furthermore, to prolong a project also means decrease in the customer satisfaction. Also, if the results of the engineering work are not compatible with each other, the product itself is hardly compatible with customer expectations. The complex product design process is both time consuming and error-prone.

The issues explained above can be regarded as a “corrective action mode”. Its characteristics include the organisation spending a significant percentage of the resources on rescuing quality and schedules [CM II 2003]. Thus, resources are being spent on interventions. The curve in Figure 20 shows the relation between the number of different data sets, their integrity, and employee effectiveness. These concepts from systems engineering can be interpreted in engineering design as a set of design data, such as documents, their interdependencies, and the performance of an engineer. All in all, resources are being used in non value-adding (auxiliary) tasks such as data handling and manual version management.

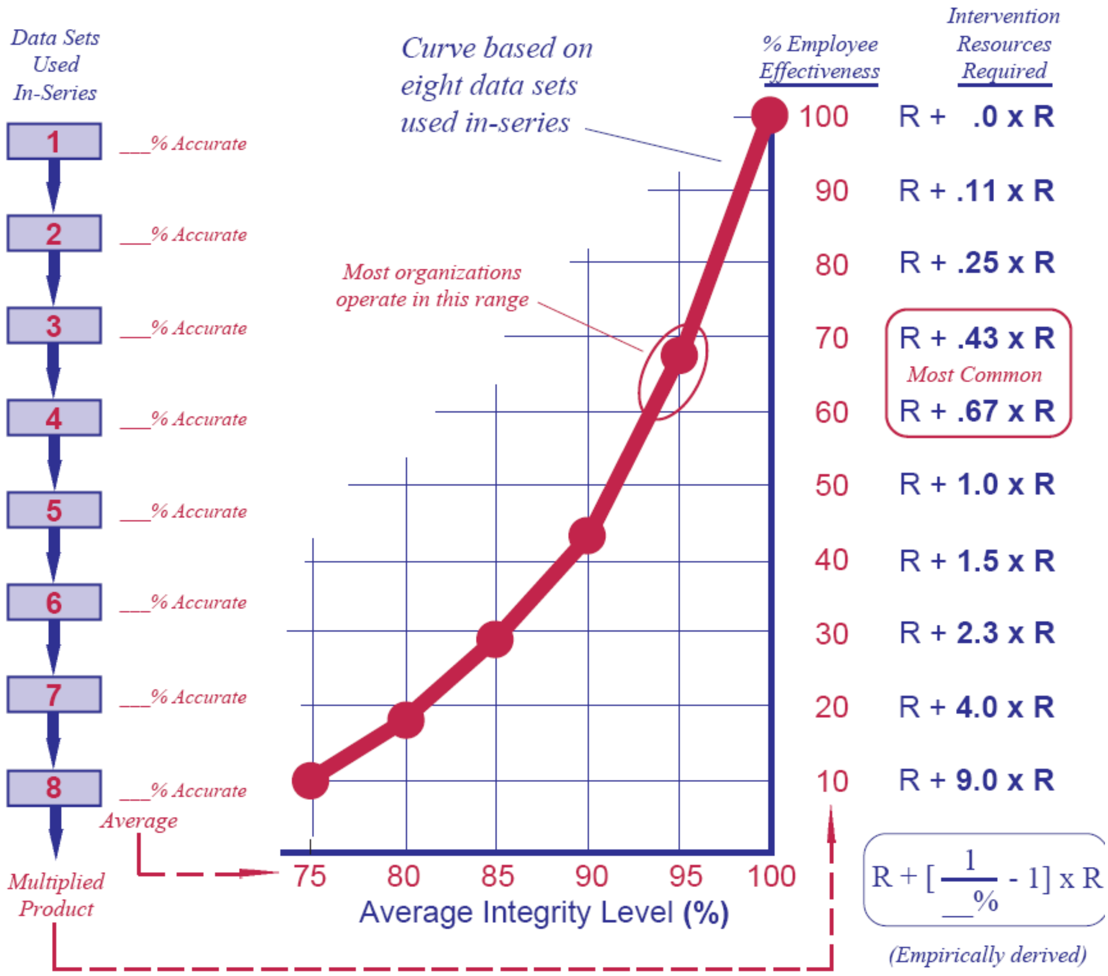

Figure 20. Productivity relative to data integrity [CM II 2003]

Design reuse

Altogether, the suggested (corrective/manual) solutions seem to lead to problems with the coping of the management and the personnel, co-ordination, time, quality and cost – similar problems of IPD (Table 2 on page 60).

Also, systematic design reuse has been suggested to provide remarkable time, cost, quality, and performance benefits [Duffy et al. 1999]. Thus, it appears to a potential solution for to the causes of above-mentioned problems. Moreover, it is known that the product design process can be enhanced with computerized design reuse methods, such as parametrization and configuration – also in projecting business [Riitahuhta 1988].

In order to solve the time pressure engineers often try to utilize knowledge from the past by copying the pre-existing designs from the past delivery projects, similarly to "Serial development projects" on page 63. This, is however not systematic, but relies on the individual experience of personnel. For example, it is lacking the the reuse library of the design reuse framework by [Duffy et al. 1995].

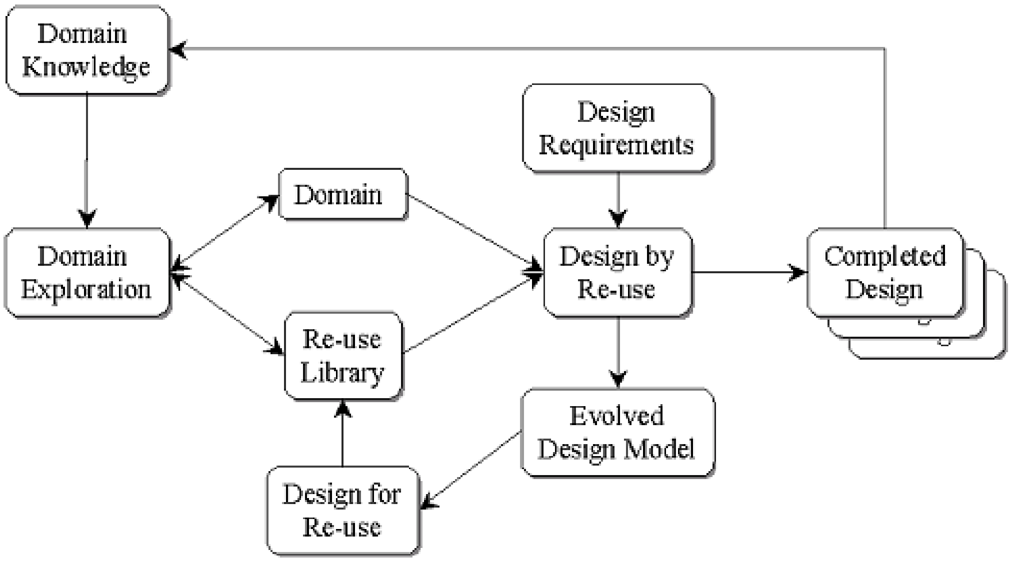

Figure 21. Design reuse framework - from [Duffy et al. 1995]

Configuring is one of the design reuse methods. In projecting business, the engineering design productivity should be improved with a structured and predesigned product family that enables configuring in the sales-delivery processes.

However, the effort taken in structuring and modularisation for configuring can be overwhelming for a company. Also, some companies claim that their products cannot be modularised because of special, case specific customer requirements. Therefore, we claim partial configuring is a valid approach for improving engineering in projecting. In partial configuring, the balancing between the design for reuse and design by reuse efforts (see Figure 21) must be decided for the sake of not only flexibility but also economy.

Configuration

Configuration, similar to design, has two meanings, which refer either the activity or the object, the result of an activity. Here, the former is defined as a configuring or a configuration task. The latter is defined as a configuration or a product individual. These redundant terms are used because of the literature and the viewpoint. With the concepts configuring and configuration the numeral aspect is plural and the viewpoint is more in the overall process than it is with the configuration task and the product individual, which refer to the specific task and the outcome of it. Similarly we may use the concepts assembly, assembling and assembly task whenreferring to objects, processes, and operations.

Defining configuration

The term configuration comes from late Latin, where the noun *configuratio* meant a similar formation. The verb *configurare – to model on something* – is a derivative from *figurare*, which means to shape, fashion [Collins 2000]. A quick search on the Internet gives a large number of defintions for configuration, with more than 25 million hits. Thus, it is worth of studying the topic and of making an effort to capture something essential about the configuration for defining the subject.

In the following paragraphs the concept of product configuration is reviewed. First, a review of the definitions of configuration and especially on the task of defining configurations, i.e. configuring, is made and a synthesis of the review is given. A brief summary on the methods of capturing the configuration knowledge is given along with an overview of different kind of sub-tasks of configuration.

Then, the configuration is reviewed in a more precisive manner concerning the narrowing of the sales-delivery process from engineered-to-order products to configurable product families. Thus, the viewpoint is first on the generic, but atomic activities and properties of configuration. In the later phase, the focus is on a more specific issue, but at the same time the issue will be examined from a broader viewpoint.

Configuration as an object

Some first notes about the concept of configuration are in the field of aerospace engineering [Glover 2006]. There, the term is comprehended in the following way:

1. Relative position or disposition of various things, or the figure or pattern so formed.
2. A geometric figure, usually consisting principally of points and connecting lines.
3. Planetary configuration, which is the apparent positions of the planets relative to each other and to other bodies of the solar system, as seen from the earth.
4. A particular type of a specific aircraft, rocket, etc., which differs from others of the same model by a virtue of the arrangement of its components or by the addition or omission of auxiliary equipment as long-range configuration, cargo configuration.

According to some dictionaries a configuration is "*the arrangement of the parts of something*" [Collins 2000] or "*the relative disposition of the parts or elements of a thing*" [Webster 1989]. By the term configuration a mathematician would mean "*an arrangement of geometric objects*" [Parker 1984] and systems engineer would intend "*a group of machines interconnected and programmed to operate as a system*"[Parker 1984]. In computer engineering, a configuration is usually comprehended as the way in which a computer is set up, which includes the hardware (the type of CPU, peripherals, etc.) and the software (the operating system preferences such as printing drivers, etc.). The term (or its synonym: conformation) has two meanings in chemistry and in physics. First, it defines a three-dimensional (i.e. spatial) arrangement of atoms in a stable or isolable molecule that differs in which atoms are attached to each other, i.e. the shape of a molecule as determined by the arrangement of its atoms. Secondly, configuration is the structure of an atom or molecule as determined by the arrangement of its electrons and nucleons. In electrical engineering configuration is "*a group of components interconnected to perform a desired circuit function*"[Parker 1984]. In mechanical engineering the term can be understood as "*the position of all the particles in a system*" [Parker 1984].

In knowledge engineering, a product configuration is derived from a predefined set of design units, such as building blocks, parts, modules, and assemblies, by relating them [Brown 1998]. In addition, the ways of relating the design units have been previously defined. In the manual configuring, a person (sometimes referred to as the configurer) is making the configuration. The task is often computerized by a specific software, namely a configurator. Only previously specified and documented configuration knowledge is used, especially in the case of the configurator. [Mittal et al. 1989, Tiihonen 1999, Soininen 2000].

OTHER DISCIPLINES. The term configuration is not only reserved to restricted sciences or engineering, but it appears also in art and human sciences. In the former it means an "*arrangement of parts or elements of a shape, a form, or of a figure, especially the pattern formed by the arrangement of parts within a form*" [Delahunt 2006]. In psychology, there exists a branch called configurationism or Gestalt psychology. Gestalt means "*a unified whole; a configuration, pattern, or organised field having specific properties that cannot be derived from summation of it's component parts*" and "*an instance or example of such a unified whole*" [Webster 1989].

From the dictionary definitions we can derive some aspects of configuration:

1. A configuration consists of a group of components and their relations.
2. It is a special arrangement of the set of possible arrangements.
3. A configuration has a purpose in itself – as the interpretation 4. of the aerospace discipline indicates: the long range configuration of an aeroplane implies to the use of that specific plane configuration.
4. The purpose is somewhat similar to the purposes of configurations of the same kind, e.g. the purpose of the long range and the cargo configurations of an aeroplane are generally related.

Thus, a configuration is a structurally varied object that is a composition of related sub-elements (aspects 1 and 2). The term varied means that the configuration is different from another configuration (of the same kind – aspect 2). The differences appear both in the structure and in the function of the configuration (aspects 2 and 3). However, there are generic similarities between configurations (of the same kind), which can be classified as generic attributes, i.e. structural characteristics and functional properties, of the configuration (aspects 3 and 4).

The activity of configuring

Product configuring uses the customer requirements as an input and produces an individual product definition that is a member of the product family as an output. In the task, the configuration knowledge is applied, but normally not increased: the knowledge remains intact. Thus, configuring is a matter of tearing down the customer requirements into the corresponding selections of components (or modules) and relating the selected elements as a configuration [Brown 1998].

The concept of product configuration has had a slightly different flavor during the past 20 years. In the late 1980's the definition on the concept focused on the describing the configuration task precisely [Mittal et al. 1989, p.1396]:

> "Given: (A) a fixed, pre-defined set of components, where a component is described by a set of properties, ports for connecting it to other components, constraints at each port that describe the components that can be connected at that port, and other structural constraints; (B) some description of the desired configuration; and (C) possibly some criteria for making optimal selections."
>
> "Build: One or more configurations that satisfy all the requirements, where a configuration is a set of components and a description of the connections between the components in the set, or, detect inconsistencies in the requirements."

SELECTION AND RELATION. Yu, condensed the definition of configuring as: "*From given set of elements, to create an arrangement by defining a set of relationships between selected elements that satisfies the design requirements and constraints*" [Yu 1996, p.23]. This definition complies with the definition by Mittal and Frayman. Furthermore, Yu [1996] regards configuration as a twofold activity consisting of configuration design and management. The configuration design is a specific kind of design activity, where the specific solution is created through selecting and relating elements. The configuration management is an activity where "*...the consistency amoung configuration desicions and selected/identified elements so that a consistentent configuration solution under change is maintained*" [Yu 1996, p.24]. However, the configuration management is also a term in software engineerzing and in product lifecycle management (PLM), where it has a slightly different meaning. In Software Configuration Management (SCM) and in PLM the term refers to similar kind of management activitity than Yu [1996], but the perspective is much longer and does not neccesarily relate to the product configuration as an activity.

Brown [1998] pointed out the sub-tasks of configuring, i.e. deriving a specific configuration, as:

1. choosing components,
2. establishing both abstract and specific relationships between components,
3. testing compatibility and goal satisfaction.

Configuring may also include laying-out, i.e. arranging the components in space. Carrying out these tasks is not always a sequential process. For example, component selection and compatibility testing is often a combined task and a number of the configurators support only these two tasks.

The configuration task is illustrated in the Figure 22, which is taken from [Soininen 2000]. The task combines three issues, where needs are the input, adaptation possibilities form the controlling element, and the output is the description of a product individual. The task relates the properties as requirements, the configuration model as knowledge on the components, relations (ports and constraints) as well as configuration(s) as results of the task.

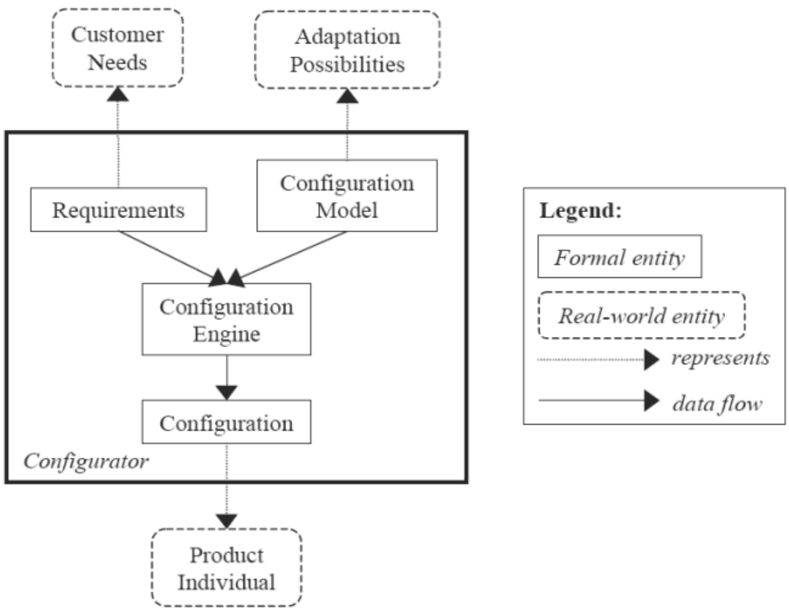

Figure 22. A configuration task carried out by a configurator - according to Soininen [2000, p.9]

RESTRICTIONS ON THE CONFIGURATION TASK. Brown [1998] has criticised the definition by Mittal et al. [1989] as being "*...influenced by the computer configuration domain in which they were working.*" However, he finds three important aspects that are included in the definition and generalises:

- One cannot design new components during the configuration task.
- Each component is restricted in advance to only be able to "connect" to other certain components in fixed ways.
- The solution specifies both the components in the configuration as well as how they are related.

The research group of the Design for Configuration project defined that five constraints apply with the configurable product families [Tiihonen et al. 1996, 1998, Pulkkinen et al. 1999b, Tiihonen 1999]:

1. Each delivered product individual is fitted to the specific needs of a customer.
2. Each product individual is specified as a combination of the pre-designed components or modules. Thus, no new components are designed as a part of the sales-delivery process.
3. There is a pre-designed general product structure and it has been pre-designed to meet a given range of specific requirements.
4. The sales-delivery process requires only systematic variant design, not adaptive or original design in the sense of [Pahl et al. 1996].
5. Since the delivered product individuals are based on the common general structure, we consider the combination of them as a product family.

Is configuration a design activity?

RELAXED DEFINITIONS. In discussion with the colleagues, debate on the characteristics of the task of configuring has been vivid. Is it a design task or does the definition exclude designing from the task? Sabin and Weigel [l998, p.42-43] emphasized that the "*artifact being configured is assembled from instances of a fixed set of well-defined component types, and components interact with each other in predefined ways*". They regarded the task as a specific kind of design task. Also, in [Brown 1998, Yu 1996] ,the task was considered as an essential ingredient of the complete design task.

STRICT DEFINITIONS. Due to the restrictive characterisation (section 4 in the above definitions by Tiihonen et al.), the definition can be characterised as exclusive. This means that the design activities are narrowed (or excluded) from the configuration task. However, others have considered configuration as a part of design process. These definitions can be characterised as the relaxed definitions of configuration as an alternative to the exlusive, strict definition of configuration.

Relation to design. The task of product configuration is similar to design, because it is a directed and progressive transformation of information with a same purpose, i.e. the definition of a product. Usually, though, the configuration task is not contingent neither iterative and it is also well-defined. The problem space and the solution space are pre-defined. In addition, the increase of knowledge typically occurs with engineering, but not with configuring. Thus, product configuration may appear superficially similar to product design, but there are fundamental differences between these two.

Relation to assembly. The task of assembly is also similar to product configuration, since it is about bringing the parts together and relating them with a predefined manner. In respect to configuration, the sub-tasks of an assembly are similar, such as relating parts is to orienting and fixing the parts with each [Boothroyd et al. 1994, Whitney 2004]. Also, in both tasks, it has to be analysed how a configuration or an assembly meets either the customer or assembly requirements.

However, in a configuration task the inputs and the outputs are the items of information, while in assembly the corresponding issues are of more concrete as well as of a specific kind. As mentioned, a configuration task is controlled and guided by generic configuration knowledge as well as part and system information. An assembly task is controlled by knowledge and data related to specific details such as clearances, measures, tolerances and capabilities as well as knowledge on the capabilities of the processes [Booker et al. 2001].

The aspect of knowledge modelling

Relation with real world entities. The task of configuration is related to customer needs, adaptation possibilities, and product individual, as is illustrated in the Figure 22 on page 73. The interface to these real world entities is arranged with the corresponding pieces of knowledge [Soininen 2000]. Thus, the configuration task deals with knowledge on the variations of (structured) possibilities and requirements as well as with the compabilities between these variations.

Capturing knowledge into a model. From the viewpoint of the development of a configurator, i.e. the application of support, different kinds of tasks and corresponding types of support can be categorized. Dym and Levitt have specified the tasks into four groups [Dym et al. 1991, p.293-294]:

- **Component selection**, which corresponds to picking up a one component from the set of available components.
- **Component parameter design**, where the focus is "*on choosing values of parameters for a component in order to meet some requirements*".
- **Configuration selection**, when the task is about the organising or assembling "*a known set of components into a topological structure to meet some performance specification*".

- **Configuration design** encompasses the other three, when "*the structure into which the components are to be inserted may not be rigidly defined in advance*".

Some of the pioneers in knowledge based systems have defined the different approaches of modelling knowledge in a similar way: the low-road, the middle-road and the high-road approach [Bobrov et al. 1988]. The low-road approach refers to the direct utilisation of a symbolic programming language, like LISP. The high-road refers to a conceptual modelling method containing pre-defined concepts specific for the domain of knowledge, such as medical diagnosis. The middle-road is something in between. After this clasification, i.e. during 1990s, a number of middle-road approaches were developed for configuration task. The configuration ontology by [Soininen 2000] compiles most of them.

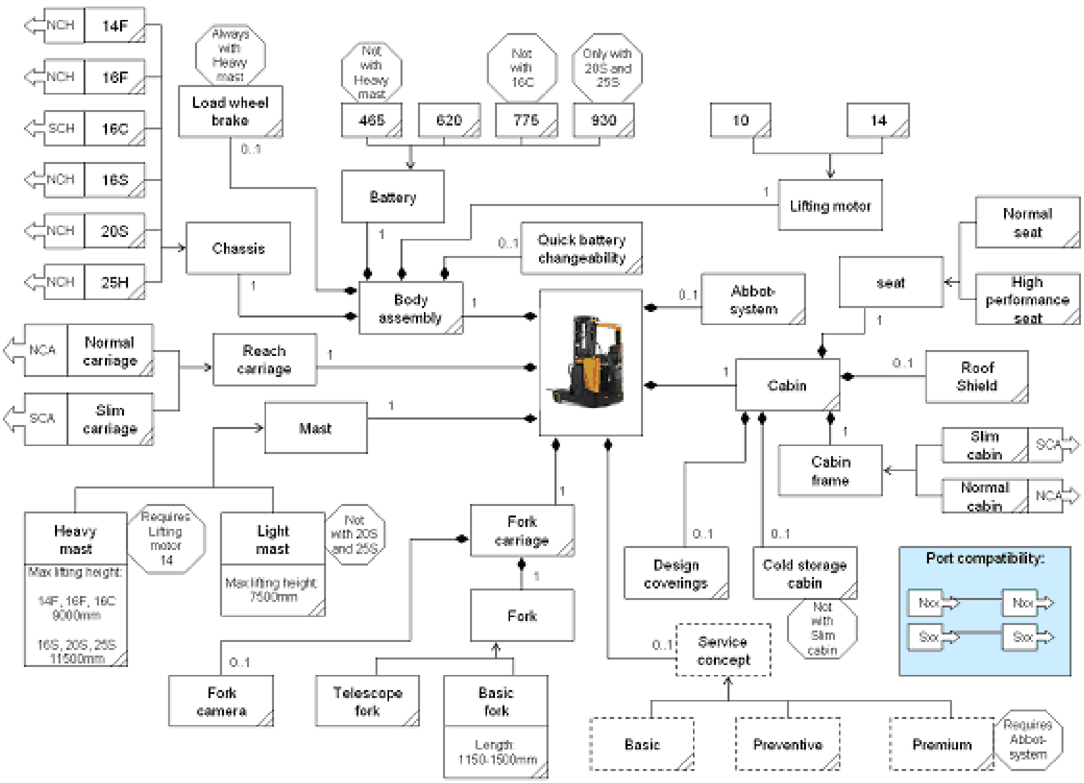

Figure 23. An example of the graphical notation of configuration ontology by Soininen [2000]– The Humanic reach truck configuration model [Niemi 2007]

The elements of configuration knowledge may or may not have concrete material counterparts. Apart from technical systems, a configurator may also generate services, documents, or softwares [Schwarze 1996, Niemi 2007]. In these cases the applied elements are abstractions of the objects of configuring, such as bank account variables. However, the configuration of mechanical product is usually a description of an arrangement analogous to a set of the physical elements of a part structure.

PRACTICAL APPROACHES. A set of practical methods for representing the configuration knowledge have been developed. Among these approaches are methods based on lists and matrices. When configuration is understood as a specific bill of materials (BOM) derived from Generic BOM (GBOM) [van Veen et al. 1987, Hegge et al. 1991, Stonebaker 1996], some descriptive documents of the configuration, e.g. an assembly drawing, are left out from the result.

Lately the application of matrices as an interface to low-road approach has gained popularity [Bongulielmi 2003, Nummela 2006]. These approaches are problematic, when the assembly structure is not common to all of the configurations of the product family, because it is often impossible to derive the explicit assembly drawings that correspond to certain configurations. Also their power of expression does not comply with the methods like the configuration ontology by [Soininen 2000]. For example, the resource-constraint cannot be presented with matrices.

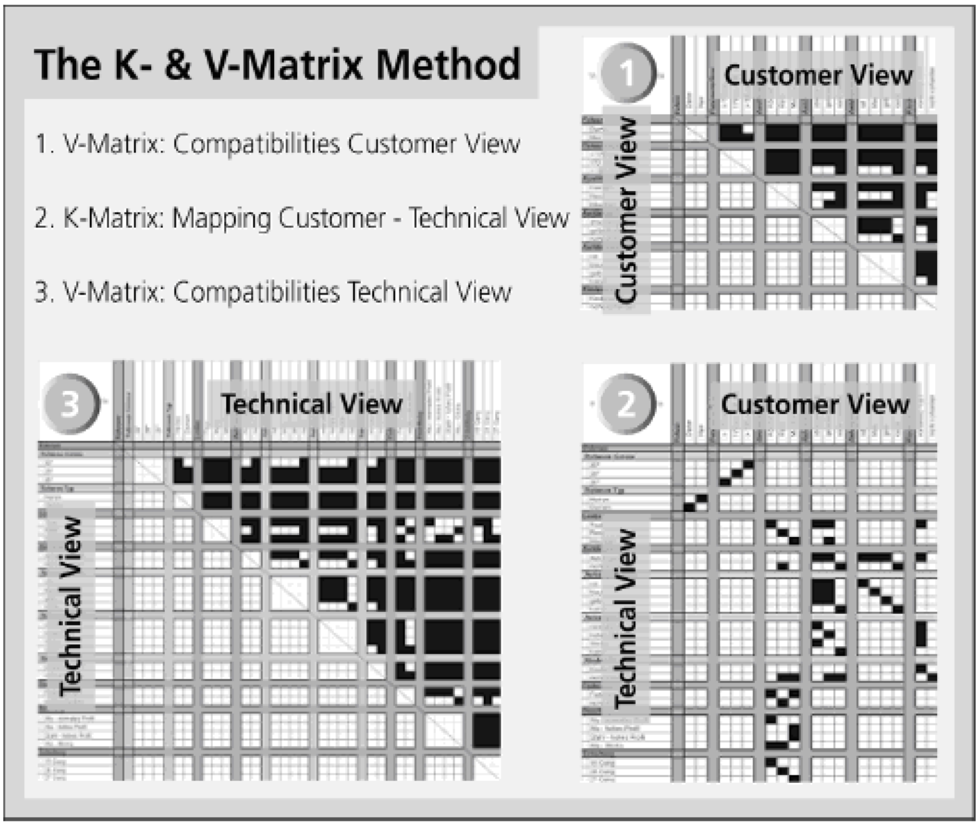

Figure 24. The K-&V-Matrix method [Bongulielmi et al. 2002, p. 12]

ADVANCED METHODS. In computer science and literature, the means for capturing and utilising the knowledge that combines these variations follows predominantly the paradigm of model based reasoning (MBR) [Dym et al. 1991]. It employs a set of representation and reasoning techniques that can be traced back the concepts of representing knowledge, such as the semantic nets and frames [Minsky 1974] as well as rules and object-oriented programming. According to [Dym et al. 1991] the MBR is a suitable technique "*to problems that involve the formation of solutions from primitive elements*" [Dym et al. 1991, p.181]. They continue that these kind of problems occur in designing and planning.

In the early applications of configuration [e.g. Riitahuhta 1988, Karras 1988 and Baker et al. 1989], rule based knowledge modelling techniques were common. Replacing rule based reasoning by constrains and constraint satisfaction systems gained popularity in the research and development of configurators during the 1990s, to such an extent that [Veron et al. 2001] titled their article "Yet Another Approach to CCSP for Configuration" – CCSP equals Conditional Constraint Satisfaction Problem. An exception of model based approaches might have been the utilisation of Case Based Reasoning for configuration [Inakoshi et al 2001]. However, their approach is a combination with the Constraint Satisfaction Problem (CSP).

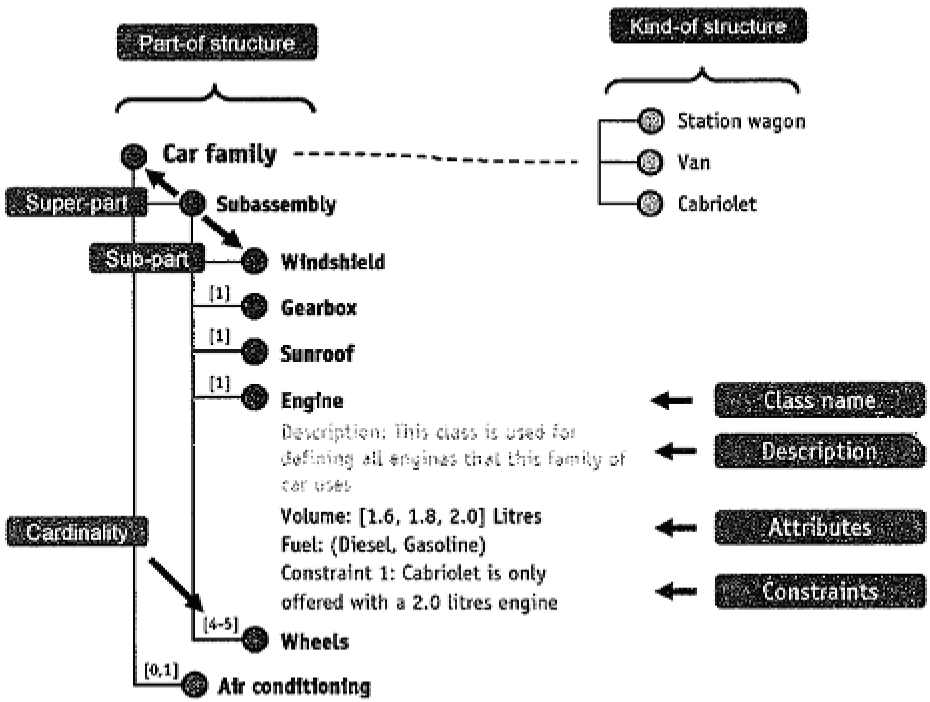

Figure 25. Notation used in PFMP [Harlou 2006, p.111-112]

Recently modelling techniques have evolved into such stage that a conceptual model has become the form of documentation for the designs of complex systems. For example, in [Felfering et al. 2001] using Unified Modelling

Language (UML) for modelling configuration knowledge is suggested. UML was originally developed as a unified means of documenting conceptual models in systems engineering and in software applications [Holt 2001, Siegel 2005]. Mortensen and Harlou have adopted the object-oriented techniques of software engineering the method they call product family masterplan. Central to their method is the generalisation and classification trees, as shown in the Figure 25.

Product configuration in sales-delivery

Sales-delivery process

From the above definitions, it is evident that configuring is a means for defining products for assemble-to-order (ATO) processes. However, it is possible to utilise it also in the engineer-to-order (ETO) processes [Brown 1998]. An exception of configuration in ETO processes is "*when the components have parameters that need values, but no additional refinement is needed for the relationships between components*" [Brown, p.303]. However, it is more likely Brown [1998] intended a make-to-order process. The quote corresponded to parametric design, even though in practice it may be regarded as a sub-task of configuring.

Nowadays, product configuration is commonly known for the potential provided for customers to choose different kinds of modular features for their products [see e.g. Pine 1993]. Product configuration is typically seen as a means of mass customization. There, the customers select optional components and accessories, such as different kinds of braking, entertainment and storage systems, for products such as bicycles, cars, and personal computers. However, the early cases of configuration present a somewhat different kind of a business context than mass customization.

Successful cases of configuration

Product configuration has been the topic of academic studies and industrial applications for at least 30 years. Probably, the first industrial application and the best documented case about the topic is the XCON of Digital Equipment Corporation for the configuring of VAX computer systems during the 1980s. In the case the company applied rule-based methods for capturing configuration knowledge into a number of knowledge bases and utilised them in recurring configuration processes [Baker et al. 1989].

Actually, at its pinnacle the system consisted of different subsystems for different users, such as the interface for sales, XSEL. Finally, Digital ended up with the largest set of captured configuration knowledge even up to date. Eventually the set of knowledge bases comprised of 31 000 components and approximately of 17 500 rules. [Baker et al. 1989]

ENHANCING SALES-DELIVERY PROCESSES. The created expert system, XCON/ XSEL, was intended to replace a massive effort needed in final assembly and testing of computer system installations. Already in 1975 the company had recognised the foreseen fourfold increase of order volume. With such an increase "*tens of millions of dollars would be tied up in plant, equipment and inventory simply to support the assembly operation*" [Sviokla 1990, p. 131].

The development of the system was a success. For example, the corporation estimated savings of about 15 million USD during the first five year period of the utilisation the system [Sviokla 1990]. Also, the estimated fourfold increase in the configuration personnel was avoided, task performance at least trebled, as well as the management and the distribution of configuration knowledge was standardised and enhanced. Moreover, the quality of order processing increased, i.e. the correctness of configurations rose from 65 - 90% to 95 - 98% (depending on the source). At the same time, the business environment changed from stable to more turbulent, as the even distribution of order input and the backlog of orders had vanished. Instead, the customers were expecting and getting faster deliveries. However, the organisation could handle them with the XCON and actually the throughput time decreased from 10-12 weeks to 2-3 weeks. [Sviokla 1990]

SOME PROBLEMS. However, with successful utilisation the XCON case presented some fundamental problems in product configuration. Sections of collected knowledge were perpetually outdated: for example approximately 40% of rules were revised annually. Within the decade of XCON, the company's business grew four times as large as originally. At the same time the personnel needed for maintaining the system increased from 2 to 59. The maintenance of the knowledgebase was tedious, the testing of the configuration systems was problematic, and the reliability of new kinds of configurations was unsure. [Baker et al. 1989]

The number of manual configurers (titled as Technical Editors in Digital) decreased, but was not completely eliminated. Their work became more monotonous, as the system was the mediator of configuration knowledge. In some cases, they had to manually update and rectify the output of XCON. This was tedious, as the output was a large piece of information, from which the false or outdated parts or modules had to be scanned and changed manually. However, most responsibility for correctness was shifted from manual configurers to the development and maintenance of the configuration, as a formal maintenance system was developed. Also, progressive structuring of configuration knowledge enabled the above mentioned increases in efficiency. [Sviokla 1990]

In another early case with a completely different kind of business and products an advanced knowledge based engineering system [Karras 1988] with an object-oriented flavour was successfully implemented in the design engineering of documentation for the sales and manufacturing of power plants [Riitahuhta 1988]. Similarly to the case of XCON a rule based system was created for the same kind of transformation of sales information to order delivery documentation, but it did not last as long as the XCON.

In the case by Riitahuhta, there were no increases of personnel, like in the case of Digital Equipment Corporation. On the contrary, the development group was progressively disbanded within a few years, when the members had transferred to new positions. Also, the application of the developed system became gradually infrequent.

The early cases [Riitahuhta 1988, Baker et al. 1989, Sviokla 1990] give reason to believe that major organizational changes should take place with the application of configuration. Also, the characteristics of the effects on engineering and sales-delivery process are in general identifiable, but the structure seems to be obscure. Moreover, it is not possible to make a definitive model on the cause-effect chain of the configuration in engineered-to-order environment

The mutual characteristics of both of the cases was that there was a strong belief on the capability of knowledge based expert systems to manage the definition of complicated products. Also, both projects resulted in large rule bases. The cases were different in the size of development and maintenance organizations. However, in general it is evident that such an application requires substantial investment in further development. Otherwise, the vitality of the application in an organisation will fade away and the life cycle of the application is short.

The position of configuration in sales-delivery process

Configuration is often divided into sales and engineering configuration [Tiihonen 1999], while sometimes these two different approaches are called front- and back-office configuration [Harlou 2006]. The distinctive aspect is the organisation responsible for the generation of configurations. With the former approaches the customer defines the configuration with or without the assistance of the sales people. Thus, the documentation of the configuration has to be transferred to the company, where the corresponding people fit the configuration to the production plan.

With the back office configuration the particular customer reguirements are handed over to the company, where sales engineers define corresponding configurations. The latter appoach is typical when advanced expert systems are involved, like in the above cases by [Riitahuhta 1988, Baker et al. 1989, Sviokla 1990].

One might think that the selection between the approaches is mainly constrained by the capabilities of information technology, because the transactions between customers, sales representatives and the company's production control are different in the transfer of data volume with the approaches. However, the approaches are fundamentally different, because with back-office configuration a separate sales specification does initiate the process, while with the front-office configuration the communication is based on an actual configuration.

BACK OFFICE CONFIGURATION WITH PROJECTING. For a company transforming from engineering in projecting to configuration in systemic customization, it might appear natural to start the utilization of configurable product families with the back-office approach. First, the products are so complex that only an advanced knowledge-based engineering system (KBES) appear to valid. Second, the company does not have to engage into a demanding change in the sales engineering and quotation processes, while the KBES is operated by experienced engineers who can correct the possible errors in the specifications and check the validity of the quotations.

CONCLUDING CONFIGURATIONS. Design synthesis and analysis, product configuration and assembly tasks are characterised in the following table. It is evident that the configuration task resembles more the design analysis than the synthesis.

Table 3. Relation between the different tasks of sales-delivery process

Task	Synthesis	Analysis	Configuration	Assembly
Input / Output	Knowledge, information	Knowledge, information	Information	Materials and information
Controlled / Contingent	Loosely Controlled to Contingent	Controlled	Controlled	Controlled
Directed / Iterative	Iterative	Usually directed	Usually directed	Directed
Problem / Solution space	Ill-defined	Well-defined	Well-defined	Pre-determined
Knowledge	Increased, learning possible	Increased, learning possible	Usually intact	Usually intact, learning possible

In the configuration task is the problem and solution spaces are well-defined, in contrast to design synthesis. This and other differences between configuration and design synthesis, indicate that the management of configuration task and its relations to other activies of sales-delivery process are more simple than in design synthesis.

Due to the characteristics of configuration, the knowledge of product family has to be defined as well as captured and documented into a chosen form before the application of product configuration in a sales delivery process is possible. This presupposes that a number of product family development activities have been carried out succesfully. The actual derivation of the configurations requires the precedence of planning, developing, and documenting tasks, which result with the knowledge of configurable product family. Also, the selection of configuration modelling method has to be done, before the application. Logically, the instances of product family cannot be derived systematically, with any other order of tasks.

In addition to configuring, the sales-delivery process has to have the capability to make quotations, produce the individual members of a product family, related documentation, and so on. The individuals have to correspond to the configuration, which is an instance of configuration knowledge. As the knowledge evolves, updating and maintaining become problematic [Aaltonen 1996, Männistö 2000].

The constraints for sales and marketing are laid by product technology and production capabilities. Therefore, these have to be pre-developed and documented. Otherwise, it is plausible that such kind of configuration will be defined, which is correct but the producing of corresponding product individual is impossible or tedious. Therefore, the relations between sales and marketing, product development and the process development have to be strong.

The different viewpoints of sales-delivery process

In literature, the business paradigms are described by the certain stragic or operational characteristics of customization in the value chain.

Here the characteristics are dealt within three dimensions:

- the variation in value chain, i.e. the sales delivery,
- the variation of product definition (by design, configuration, etc.),
- the type or the characteristics of production.

The variation of processes

Three generic business approaches are related to the above categorization of products and to the production volume [Verho et al. 1993]. These are serial (mass) production, customisation by applying configuration and/or parametrization, as well as developing engineered-to-order products. The corresponding actions in the task of product definition, which is inherently dependent on marketing and design, are selection from a set of standard products, defining a configuration from company- or customer-defined variants and options or design, respectively.

Product customization can take place at a number of stages in the sales-delivery process. According to Lampel and Mintzberg there is a continuum of strategies, where the point of product differentiation or decoupling is located either in design or in one of the subprocesses of production. The customisation strategies vary from pure standardisation to pure customization. [Lampel et al. 1996]

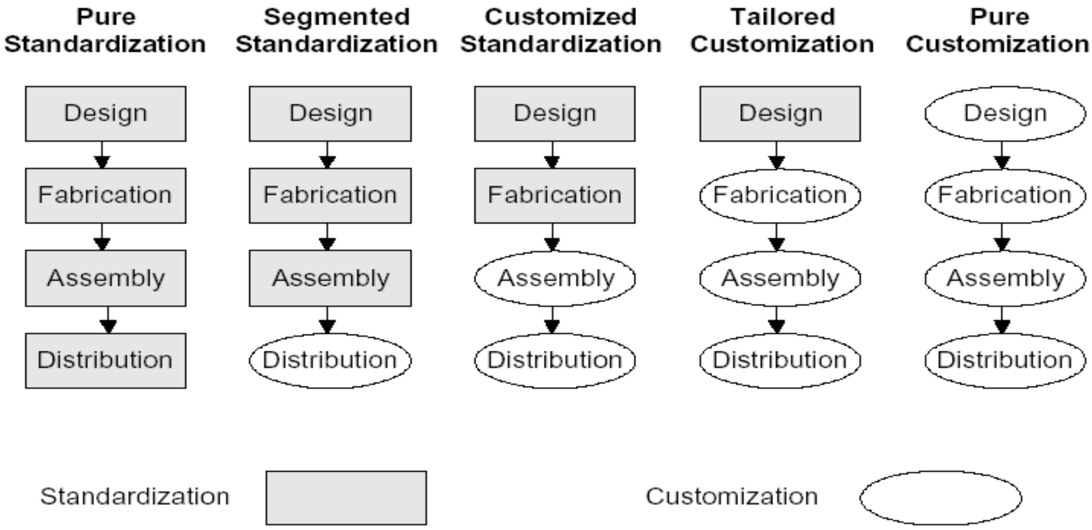

Figure 26. The continuum of customization by Lampel and Mintzberg [1996]

In the operation of sales delivery processes these categories appear quite differently. For example, the physical location of product differentiation may be very close to customer, e.g. in a shop, or may take place in a different continent, where the utmost point of supply chain is located. Time involved in the material, cash and information flow in these extremes is visible to the customer in the latter case, but unnoticeable in the former case.

The variation of product definition

Traditionally, four different product types with different kinds of varying attributes within a product structure are presented [Schomburg 1980]:

A. Standard products,

B. Standard products with variants defined by the company,

C. Standard products with variants defined by the customer, and

D. One-of-a-kind product.

In Figure 27, the classes of products are characterised with some examples. The classification is theoretical by its nature, since one-of-a-kind products (type D) contain sections of types A, B, and C. Also a product of type C contains elements of the types A and B. However, standard products do not comprise of varied parts and, therefore, the classification is unidirectional.

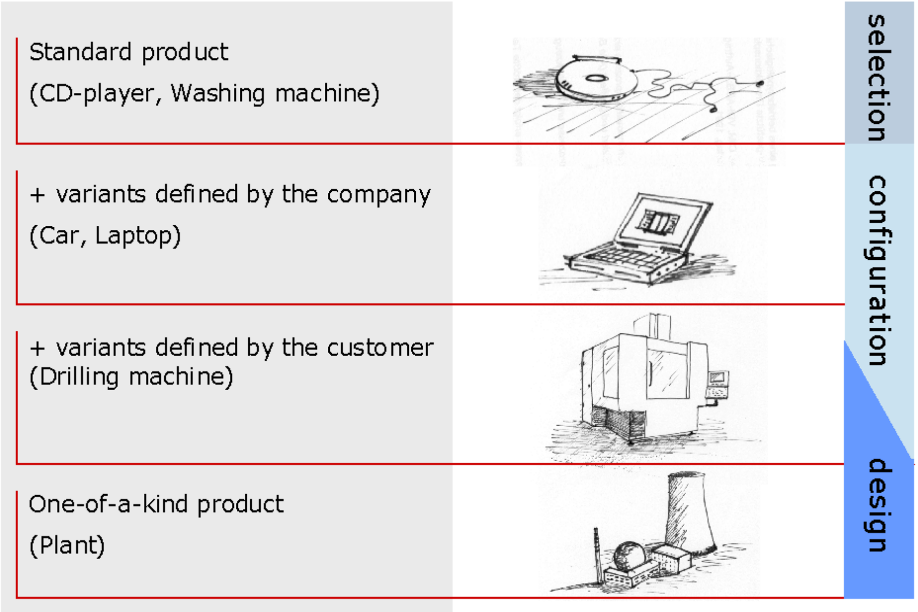

Figure 27. Types of products and the relation to the product definition in sales - according to Schomburg [1980]

Despite the theoretical nature of the characterisation, it is inevitable that the case of design is different in all of the situations. With standard products the customer oriented design is reduced to selection that can be often performed by non-professional personnel. With variants, product design becomes more challenging, as it is configuration (including selections) or setting and deriving values to parametric components. One-of-a-kind products require customer oriented engineering at many stages of the sales-delivery project. This is presented with a matrix in Table 4.

Table 4. The relation of product type and possible sales-delivery process

Type vs. Sales-delivery process	A	A & B	A & B & C	A & B & C & D
MTS				
ATO				
MTO				
ETO				

In the table above the suitable sales-delivery processes are presented with shadings. The light-grey shadings of combinations A vs. ATO and MTO indicate that they are less plausible than the MTS sales-delivery process.

Type of production

The type of production [Wortmann 1992, according to Laursen 1996 & Ørum-Hansen 1996] is related to

1. Which activities in the primary production process are customer-order driven?
2. Which investments are customer order driven?

Four classes of production arise from the answer to first question: engineered-to-order (ETO), made-to-order (MTO), assembled-to-order (ATO) and made-to-stock (MTS). Secondly, the relation between production investments and customer orders dictates if the production is product, process, or capability oriented. These two – the relation of customer order and production process as well as the orientation – classify by type the production situations.

Table 5. Typology of production situations [Wortmann 1992, Ørum-Hansen 1996, Laursen 1996]

The emphasis of investments	The orientation in production	ETO	MTO	ATO	MTS
Production facilities	**Process**	Printing	Paper	Steel-making	Subcontractor of car-outlets
Product develop-ment	**Product**	Aeroplanes, Ships	Machine tools, Vessel engines	Trucks, Computer systems	Commodities
Resources	**Capability**	Aero Space, Software develop-ment, Civil engineering	Foundry, Forge Shop, Maintenance shop	Construc-tion, Building	Repetitive manual assembly subcontrac-tor

In Table 5 the production situations are characterised with examples by [Laursen 1996 and Ørum-Hansen 1996]. As illustrated by the examples, the most volume intensive production is sought after with process orientation and lowest volumes are made with capability oriented production facilities. Paper- as well as steelmaking industry actually measure production by masses, while aeroplanes, machine tools, and trucks measure production by the numbers of produced items. In aerospace, software development as well as in construction industry, the numbers of produced items are low and in foundries the batches of material define the production.

It may be difficult to understand how printing belongs to engineer-to-order products. Also, paper making has been dominated by the make-to-stock paradigm. Previously, the printing facilities had to engineer the printing plates for a specific print-out, but with digital printing this situation has changed. Table 5 the products are presented similarly as in Figure 27 on page 85. However, as the paradigms in the different fields evolve, the examples grow old.

Relating production and design

An interesting question then is, how to classify the case of production paradigm independently from the examples? An attempt for this is made in following when the variation of design is related to the variation of product. We recognize four possible cases that exemplify the situation of variation both in design and in production activities.

DEFINITION OF THE RELATIONS. The case of one design to one product (1:1) is a situation of the last kind in the Figure 27. There, a one-of-a-kind product is usually engineered and made-to-order. Thus, a product is the result of an ad hoc realization project, which is seldom systematic and hardly optimized. In the case of many copies (1:n) from the same design, a number of similar products are produced, typically with an optimised production system. Apparently, this is the case of printing as the number of print-outs are possible from one product design.

Table 6. Product variation versus design variation - adapted from Pavlic et al. [2006]

	A single, separate design (1)	**A number of related designs (n)**
Single, separate product (1)	One design for one product (1:1 = one-of-a-kind, i.e. type D)	Many designs for one product (n:1 = a number of versions, type D)
A number of related products (n)	One design for many products (1:n = a number of copies, i.e. type A)	Many related design for many products of the same kind (n:n = the multi-product approach, types B and C)

In the case (n:1), a number of diverse, but related designs for one product are developed. In design projects alternative revisions are sought after for the same purpose, which is a typical situation in prototyping. It is also related to the situation of “Serial development projects” on page 63 and, thereafter, projecting. The products are substantially different and the production system does not recognize the commonality between designs. Thus, production process can hardly be optimized in the case of n:1.

Finally, in a multi-product approach (n:n), a number of products are made or assembled to order as variants, i.e. instances of a family. The designs are typically derived with a systematic manner from the generic description of the product family. The production can also be systemized for making a product variant, as presented in the theory of ideal factory [Lapinleimu 2001].

The way in which designs and production meet dictate the point of differentation in the continuum of customization, by [Lampel et al. 1996]. For example, if one design is produced as a one product (1:1), the case is pure customization. Similarly, one design is used continuosly in the production of a number of similar items (1:n), the case is pure or segmented standardisation. The case of prototyping (n:1) falls to the category of pure customization, even it is close to tailored customization or customized standardisation. The multi-product approach (n:n) is either tailored customization or customized standardisation, as it depends on the dimension of the product variation (see page 55).

EFFECTS ON PRODUCTION. The main difference between engineer-to-order, make-to-order and assemble-to-order is that in the latter two cases knowledge needed for product design is standardised – it exists for use of the sales-delivery process. In assemble-to-order production the parts and/or subassemblies are stocked in some facility of a supply chain, while the primary process assembles the final product. In make-to-stock the final product is stocked within the supply chain, while the customer driven delivery is reduced only to distribution.

The point of decoupling/differentiation in production process, the volume of produced items and the organisation of production dictates the way in which a customer order is responded to in a company. In all the orientations of engineer-to-order production, customer orders initiate negotiations and iterations in order to define a delivery project. Moreover, especially in the capability oriented cases of engineer-to-order production, the product design is involved in sales negotiations as well as in delivery project.

As one-of-a-kind product has to be engineered-to-order and customized products either made or assembled toorder, standard products can be made-to-stock, but not engineered-to-order. Making products to stock, however, may not be economically feasible, even if it would be possible [Womack et al. 1990, Lapinleimu 2001]. This, because the objectives of an ideal production facility are operability and controllability, quality as well as cost efficiency. Furthermore, one of the sub-objectives of operability is the operational flexibility that can be attained with short lead times, making batch sizes to order as well as increasing volume flexibility [Lapinleimu 2001]. These objectives cannot be attained with large batches of finished products.

Pure and segmented standardization are customization strategies that rely on standard products and make-to-stock production. In this case, no engineering is involved in the sales-delivery process. Customized standardisation is related to products with variants defined by the company and assembled-to-order.

Here, customization means systematic variation, by pure configuration that can be automated. Tailored customization involves products with variants defined by the customer that are made-to-order (often by computerized) parametrization. Pure customization is related to one-of-a-kind, engineered-to-order products.

Results from the literature

In an earlier study on literature [Pulkkinen 2000], I claimed that the product configuration can and should be studied from three different standpoints:

1. The **activities of configuring** include modelling the configuration knowledge, the utilization of the knowledge in sales-delivery process and maintaining the configuration knowledge,
2. the development of the generic **product structures** for configurable product families,
3. the utilization of **IT-support for configuration** as a specific set of information technologies technology.

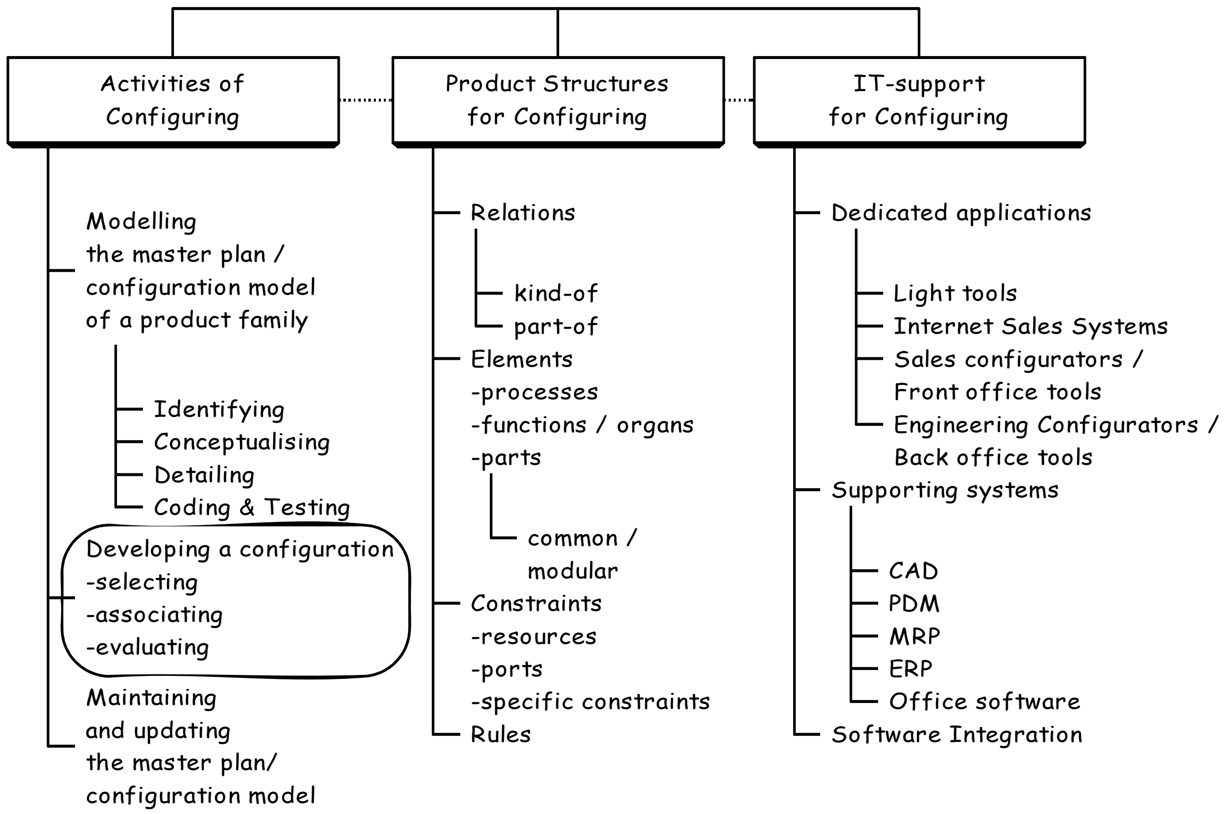

Figure 28. The framework of product configuration [Pulkkinen 2000]

As drawn in the Figure 28 development of the product structures the configuration modelling is reltaed both to the actitivities of and the IT support for configuring. Before the modelling may take place, the product structures have to designed. The knowledge engineering tools can be decided on at the same time with the conceptual modelling of configuration knowledge. The configuration task (developing a configuration in Figure 28) may take place only after the structuring and modelling of configuration knowledge. The configuration, i.e. the specific structure defining the product individual, is stored in the PDM and/or ERP systems of the company for the use of sales-delivery process.

INDIRECT EFFECTS. This appears to be valid, if the interest of research is only on the product configuration and directly related issues. However, the effects of product configuration are indirect in a company, which is transforming from projecting to systemic customization, according to the theory of dispositions. For example, product configuration enable the utilization of product (design) commonalities in the design of production processes, but does not ensure it.

Therefore, different production paradigms, especially from the variation viewpoint were being studied. The task of product configuration, i.e. the development of a configuration in Figure 28, is a part of sales-delivery process where the knowledge of configurable product family meets sales-delivery process. It is a method for defining the individual product to a family. In the literature review, another acknowledged method for the same task is the product design. The differences of product configuration and design were reviewed. It is concluded that the management of configuration task and its relations to other activies of sales-delivery process are more simple than in design synthesis. Thus, the first research question is partially answered (see page 14).

SALES DELIVERY PROCESS. The results of the literature review is illustrated in Figure 29, where at the top-left corner the process of sales delivery is presented as a circle. At the top of the circle there is an interface to the customer, where the inquiries enter to and the finalised products exit of the circle. Different stages of process are represented with segments, the lanes of the circle, so that the involvement of different functions is visualized.

The different types of products are represented with lanes having different diameters. The categories of “The variation of product definition” on page 84 are related to the lanes of the circle. Standard products are the result of the most inner lane and one-of-a-kind products come from the most outer lane. The sales-delivery process cannot take an inner lane when the sales-delivery process has started in one of the lanes. For example, an engineered to order product cannot be produced with a production line of standard product. This is a disposition within the sales-delivery process.

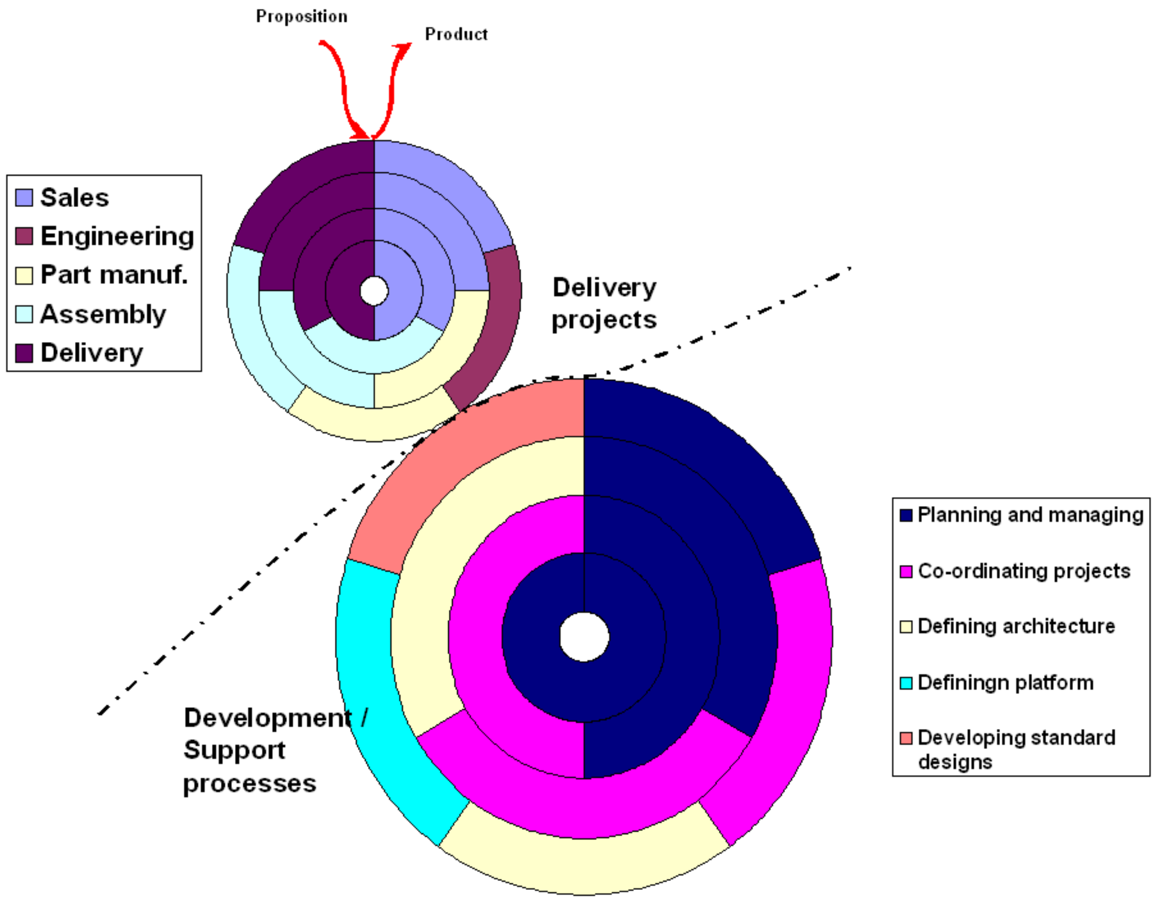

Figure 29. Different strategies in sales delivery processes and product development

The utmost lane of the Figure 29 represents projecting: pure customization, where engineer-to-order process producess one-of-a-kind products, which are supposed to meet the detailed sales specifications. Between the sales and the delivery there is the stage of engineering as well as the part manufacturing and assembly. The most inner lane represents the situations of pure and segmented standardization; make-to-stock process produces standard products from where the customer makes a selection. Between these two extremes there are other classes of customization. Configuring is illustrated with the second lane (from the center): customized standardisation means the selection of properties or directly the modules in sales, the modules are assembled, and delivered as a product. The third lane represents the case of tailored customization; the parameters of parts and assemblies are being defined in sales and the corresponding parameterized components are being manufactured as well as assembled as a product, which is then delivered.

The product configuration can be approached from both standard and unique products, i.e. the inner and outer lane in sales delivery model of figure

29. Therefore, the approaches are called as the widening and narrowing of sales delivery process.

PRODUCT DEVELOPMENT. The product development process is represented with another circle in the lower right corner of the Figure 29 There the different stages of product development are represented with lanes that have different diameters. Starting from the centre, these lanes represent the four stages of product development; independent development projects, (parametric) product families as a market strategy, architectures related manufacturing and configuration oriented manufacturing.

With the independent projects, at the most inner lane, only few supporting activities, e.g. planning and managing, are provided for the sales-delivery projects that include the majority of engineering activities. Therefore the support requires less effort and resources than the other stages, the lane is also shorter than the lanes representing the other stages. For example, configuration oriented manufacturing requires not only the basic support for sales projects, but the activities of co-ordination and the development of architectures, platforms and modules as well as configuration support. Thus, the overall effort of support is multiplied. However, the effort is reused and therefore the overall utlilization of resources becomes usually more efficient.

THE CONCEPT OF MEETING. The result of configurable product family is the set of articulated pieces of knowledge, an artefact in itself. The meeting of the lanes is where the result of development project is given for the use of sales delivery project. In figure 29. it is represented with dotted line between the circles. If the circle do not meet, the development project cannot hand over the deliverables. Thus, the type of sales-delivery and the stage of development projects must be aligned.

The sizes of the circles represent the focus of the company, i.e. where the company organises its resources. In figure 30. the continuous change of the focus in sales delivery is represented with a the set of circles that follow the trace of meetings. In the left of the figure there is an illustration of the company focusing on systematic customization, when delivery projects are represented with small circles. In the right part of the figure a company is focusing on smaller number of sales-delivery projects, illustrated with large circles. The product development is minimized to the supporting of project planning and management.

THE CONCEPT OF DISPOSITION. The development process of configurable product families produces knowledge on the product family. In the configuration task, within a sales delivery process, this knowledge is being used repeatedly. Thus, the processes meet in pure configuration only in this aspects, as the sales-delivery is done independently form product development. This is represented in figures 29 and 30, where circles meet

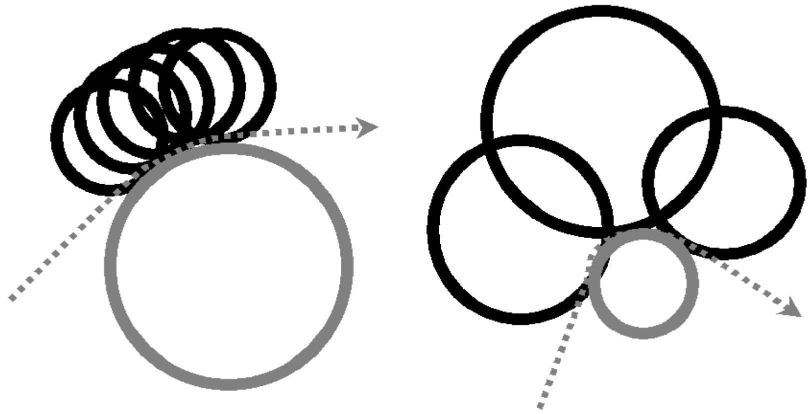

Figure 30. Aligned processes create the focus of a company

only in the nip, which is the configuration knowledge, i.e. the configuration model in a configurator.

In the case of engineering in projecting the mode of operation is typically interventive. Moreover, the engineering changes and their propagation typically increase project uncertainty, which has an effect on the variation of performance in projecting. Together product design and the inbuild uncertainty with projects, the propagation of change as well as the dispositional mechanisms, cause not only problems of defining and managing the state of project, but also cause inefficiency, which is unveiled in re-work and mistakes.

The inefficiency of projecting can be minimized by the reuse of standard designs of different kind. The configuration knowledge has direct relation to the sales-delivery process. Moreover, the characteristics of product family design define the type and operation of sales-delivery project. For example, the applied type of variation in the product family restricts the actions of production in the sales delivery process.

The sales-delivery project begins and ends in the transactions with customer. Therefore, the properties of not only product but also process itself are experienced by the customer. Thus, product family development and configuration model have a dispositional effect on the external properties, such as effectiveness, competitiveness and market share, of a company.

INTEGRATED PRODUCT FAMILY DEVELOPMENT. It is arqued that the three kinds of dispositions have to be taken into account in the development of product family and in the documentation of the configuration knowledge:

1. Dispositions between the development of configurable product family and sales-delivery process, such as the meeting of configuration knowledge from the user point of view.
2. Dispositions within the sales-delivery process, such as product definition and production process relations.
3. Dispositions external to sales-delivery process, such as market and supplier relations.

If the sales-delivery process and product family are being developed independently of each other, there is a danger that the meeting does not occur nor the effects of the meeting are anticipated. Moreover, the applicability of configuration knowledge is difficult to foresee without the participation of the users. Also, the utilization and updating of the configuration knowledge can be endangered, if the responsible organisations are not integrated in the product family development. Thus, it is possible to give an answer to the second research question with the presented model. However, the third research question is not answered.

Results and analysis

This chapter begins with the presentations of the results of the interviews and the case studies. The analysis of the results combines both the interviews and the cases. It is made in accordance with the previously presented framework. Thus, a number of viewpoints are presented.

"Experto crede"
-Virgil

Direct and Commensurated results

This research has yielded two kinds of results. First, there are direct results from the interviews and the cases. Second, the commensurated results refer to the indirect implications of the studied phenomenon. Direct results refer to the set of facts, opinions, and statements from the industrial practices. A part of this chapter is a mere compilation of documentation from the interviews and the cases. Therefore, it can be regarded as hearsay, but still, it represents the experiences of the practitioners. As such, they are valuable and deserve to be noted.

The commensurated results are the outcome of analysing the interviews and the cases from the points of view described in the chapter "Literature review" from page 37 on. Thus, it is more objective than the first category, as it shows the results in the light of the literature review. Thus, the results represent the deliberated synthesis of the interviews and the cases.

In reporting direct results, our intention is to be deliberately factual and subjective. Instead, the commensurated results presuppose a more analytic insight in the case. Taking into account the methodological contemplations presented in "Scientific approach" on page 18, this approach is valid.

Analysis on the results

The chapter describing the results will end up with an analysis of the transformation sales-delivery process with the development of a configurable product family, from the viewpoint of product structure and configuration knowledge in particular.

Results from the interviews

Direct definitions on configuration

MINIMUM AMOUNT OF EMPLOYEES IN SALES-DELIVERY. Interviewees suggested that the main indicator of configurable products was that no people from the design department need to take part in the sales-delivery process. According to [Jokisalo et al. 1998], configuration meant that not too many employees had to be engaged in both product engineering and production planning for a single delivery. However, the precise definition of a configurable product appeared irrelevant for most of the companies, because the differences between deliveries were large and often a subset of the whole delivery was being configured. For example, in one company, the amount of engineering hours in sales-delivery projects varied from 50 to 5 000 [Storholm et al. 1998].

PARTIALLY CONFIGURED PRODUCTS. The absolute rating of deliveries either as configured-to-order or as engineered-to-order was regarded artificial. Instead, the term **partial configuration** appeared in the discussions. Partial configuration appeared as a definition for such product deliveries where a separate set of engineering design tasks was involved. There, an open, mixed module system was the basis for the configuration, and the members of the product family could contain non-modules in their configurations.

CONFIGURABILITY. However, defining the characteristics of configurability, such as the limit of engineering hours per delivery, were not considered applicable. In one case, an indication of partially configurable product was the number of pre-designed parts/production items in relation to all items of the product. According to the company, sales-delivery was based on configuration if 80-90% of all manufacturing items were defined by configuration and other items were engineered to order. [Storholm et al. 1998]

CRITICAL VOLUMES NEEDED FOR REUSE. Along with product and production type, the sales volume (in a number of deliveries) was considered critical. In one company [Mäkinen et al. 1999], the volume was 40 000 delivered products (often combined into delivery packages). These products varied from retailed, fixed products to engineered-to-order, one-of-a-kind products. In this case, the strict, exclusive definition of configurable product families (see page 74) also appeared to be unusable. For pure configuration, a suitable sales volume per year appeared to be from 300 to 9 000.[Jokisalo et al. 1998, Pekkarinen et al. 1999 and Huuskonen 1998]

Derived definitions on configuration

It is evident that product configuration is related to a specific kind of a sales-delivery process. The type of a sales-delivery process may be considered the direct result of the application of configuration in the product definition. Therefore, it is not a surprise that configuration is considered a way of selling and delivering product individuals or instances. This holistic interpretation is apparent in the academic definitions that emphasize the separate characteristics of configuration from the “usual” design task (see page 74).

The effects attained

To increase configuration activities as well as to decrease engineering activities in sales-delivery processes was the generic objective in companies that had been projecting one-of-a-kind-products.

Direct observations of narrowing business focus

RAPID SALES AND DELIVERY PROCESS. Projecting companies in particular reported that short delivery times were strongly and positively related to customer satisfaction. Generally, a short delivery time was considered a competitive advantage when compared to the projecting of engineered-to-order, one-of-a-kind products. Some interviewees [Storholm et al. 1998] also emphasized that a short delivery time also means the decrease of work in each delivery. This can be summed up as a more rational utilization of employees.

DECREASE OF COSTS AND WASTE. For a projecting company, one reason for beginning to configure products are the savings in indirect costs of each delivery process. Often, not only the amount of engineering design was minimized, but also a number of management tasks decreased when the company begun to apply configuration. In a number of cases, futile iteration and redesign in engineering and project management had been eradicated and processes had become clear and manageable. One interviewee reported ”We have reached 100% reliability and double volume in deliveries” [Henrikson 1998]. He also argued that ”the profit of a sales is known precisely due to configuration and configurator”.

ATTAINING RELIABLE SALES ESTIMATES AND MARGINS. Typically the sales margin for each mass produced is quite low on a mature market. Some of the companies expressed their belief that with configurable products the sales margin typically arises (customers are willing to pay extra for customization). Also, as an engineered to order product is supposedly an exact counterpart to specific customer requirements, it might be supposed that with increased customization the sales margin could be even higher.

Derived effects of narrowing focus

The uncertainties related to projecting often consume the sales margin. A heuristic (rule of thumb) of this was presented by Jokisalo et al. [1998]. According to them, with an engineered-to-order product, there should be a high (preferably more than 15%) initial estimate on the sales margin, because of the uncertainties related to projecting. However, it is questionnable if this approach is sustainable. The demand for higher estimations on the sales margin hides the root of the problems, see “Uncertainty with projects: the state of project” on page 43.

Generally, a couple of the companies had experienced margin fluctuation that was related to increased customisation, e.g. with movement from variation specified by the company to variation specified by the customer [Jokisalo et al. 1998, Storholm et al. 1998]. According to this kind of reasoning (see Figure 31), business may eventually become close to gambling when a company is getting involved in the projecting of one-of-a-kind products.

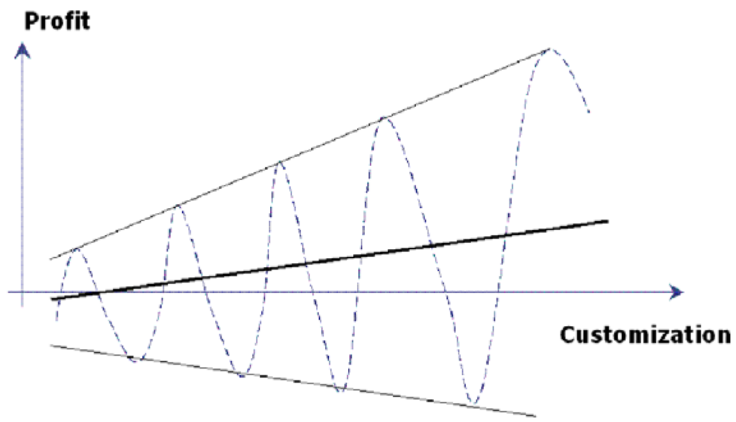

Figure 31. Profit in relation to increased customization

The figure above is only a schematic illustration where the solid line represents the mentioned assumption of higher profits with a higher degree of customization. The dotted line represents the "real" case of varying profits, i.e. the experience of the interviewees, which indicated that with increased variation, the profits could be better (upper thin and solid line) and the losses worse (lower thin and solid line).

It is doubtful that customization *per se* is a virtue and increases the profits. More likely the customization of some characteristics of CPF will have an effect on the overall productivity as well as on the profits. At the same time, customizing some characteristics is not required or even not desired, e.g. the thread of a screw is usually expected to meet the value given in the standard. Also, some characteristics make the sales-delivery process more uncertain and, therefore, have an effect on the margin of the project. At the same time, varying an independent characteristic may not have any significant effect on the way how a process is carried out or on the properties of the process.

However, customizing in general may have an effect on the profit, as illustrated in the Figure 31. The customization of an arbitrary product characteristic may be either desired, unwanted, or indifferent. These signals should come from the outside of the company. Therefore, they are called external effects. Also, the customization of an arbitrary product characteristic may not have an effect on the company or a positive or a negative effect, such as the reduction of lead time or an increase in the engineering hours in each sales-delivery project.

Table 7. The external and internal effects of customization

The customization of a product characteristic	is wanted,	is indifferent or	is not wanted by external stakeholders
is related to positive,	modularise	modularise	hide
is not related any kinds of or	modularise	standardise	standardise
is related to negative internal effects.	is the customer willing to bear the cost of negative effects?	standardise	standardise

In Table 7, the external and the internal effects of customization are related to the customization of a product characteristic. Basically, nine different pairs can be found, depending on the effects of customization. Customization is desirable, if it is desired (the external effect) and it will not have negative internal effects. In the table, the cells representing these cases are white, while the other cases are shaded.

If the customization of a product characteristic is desired but difficult to be realised, the company has to study if the customer is willing to bear the result of negative internal effects, such as a longer lead time or a higher price due to the increased cost. Finding examples where customization is indifferent to or not desired by the customers, but has positive internal effects is nearly impossible. In these cases, the company probably has difficulties in producing an even quality and there is confusion about the concepts of variation and customization. However, if that is the case, customization should be hidden from the customers.

In the remaining cases, where customization is indifferent or not desired and the internal effects are irrelevant or negative, the characteristic should be standardised. These are represented with dark shading in Table 7.

Widening business focus

ATTAINING THE SHARE OF NICHE MARKET. Despite the supposed effect to sales margins, the interviewed companies assured that a customer will not pay more for a configured product than for the fixed or an engineered-to-order product of a competitor. In fact, customers hardly care about the way of delivering the product; their concern is related to the properties and the effects of the delivery process, such as cost, time, and quality. Instead, customers often experience the increase in the level of service and quality, which is a vantage in a sales situation. However, prestige products, made for lead users were omitted from the contemplations of the interviewees.

MAINTAINING THE EFFICIENCY OF SALES-DELIVERY PROCESSES. According to a company that had broadened its focus to configurable products, the main reasons of configuration were cost efficiency and customer orientation [Jokisalo et al. 1998]. Configuration had also strengthened the companies so that they were able to share market with large international competitors and still keep production in a developed country, where production costs are considerably higher than in developing countries [Huuskonen 1998, Jokisalo et al. 1998]. Interviewees from companies widening their business focus, also emphasized the agility of product development as a counterpart to configuration.

Increasing possibilities to focus investments

Apparently, there can also be drastic changes within supply networks where increased quality requirements may eliminate the weaker suppliers. One of the companies noted that they were able to concentrate on core competencies in production and outsource the less essential activities. An enhanced use of subcontracting had also made it possible for contractors to increase their efficiency, because lot sizes had rosen and variation decreased. Eventually, this had created a situation where a subcontrator had a possibility for a higher degree of capacity utilization. With outsourcing, the company did not have to care about the utilization of capacity and the depreciation of expensive investments. The business mode of a subcontractor was also moving towards a more focused approach. [Jokisalo et al. 1998]

With the focusing of assets in product and production engineering, there should be positive effects in the life-cycle of a product family and individual products. Above, we have mentioned speed, cost, and more reliable estimations on sales margins. Other aspects include quality and productivity.

ELEVATED QUALITY. The elevation of product quality was seen as an advantage in two of the most successful projecting companies [Pekkarinen et al. 1999 and Storholm et al. 1998]. This may be surprising, since the usual thought about a modular, configurable product family is that it hardly ever meets the specific customer requirements as well as an engineered to order product.

The mechanism behind the increase of quality was regarded as follows. A configurable product may be regarded as a compromise as well as a standard product even more a compromise for a set of customers. According to this kind of reasoning, the quality of a configured product is never optimal (for a specific customer). However, in projecting, it is usually impossible to ensure quality management and assurance measures as well as in mass production, because of the lack of time and resources. Morover, an engineered to order product may be weak in detailed design. Also, the principles of Total Quality Management, such as designing quality into a product, are hardly fulfilled in an intense engineering process of a one-of-a-kind product.

Thus, the internal quality, little-q according to [Mørup 1993], is weaker in engineered to order products than in configurable products. Consequently, the external quality, i.e. the quality experienced by customers, big-Q according to [Mørup 1993], is higher with individuals of configurable product families than with mass produced products, since a configuration fits more closely the specific customer requirements. This is illustrated in Figure 32 below.

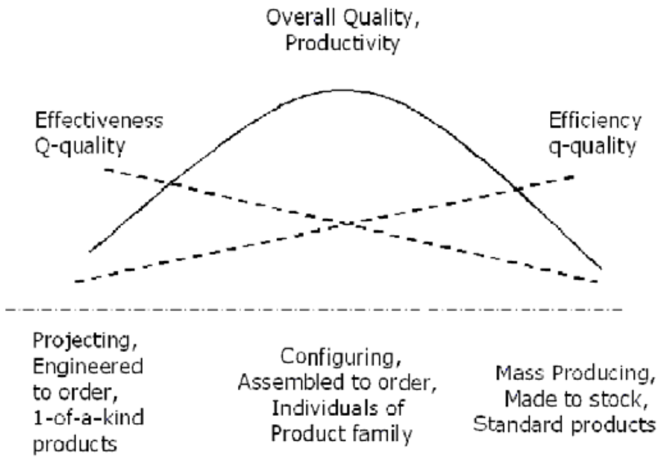

Figure 32. Customization in relation to product quality

The degree of product customization is supposed to decrease from left to right along with the change from one-of-a-kind-products to standard (i.e. fixed) products, in the figure above. The configurable products are in the middle, where the dashed lines representing external guality (big-Q) and internal quality (little-q) meet.

Supposedly, the former, external factor of quality (Q) usually decreases when the customer is offered only one, standardised product and often increases if more customer-oriented solutions are available. Also, the latter, internal factor of quality (q) is supposed to decrease along with product variations defined by the customer and vague specifications of projecting and increase if a high number of standardised products are being delivered. This is illustrated with the slopes of the lines in the figure above. As the overall quality is not the sum of the different aspects of quality, but more likely a product of the aspects, the overall quality is probably the highest in the middle. There, with configurable product families, "*solutions (modules) are tested and proven, not unique prototypes*" [Storholm et al. 1998].

DESIGN PERFORMANCE. Therefore, overall quality should be elevated with configurable product families, because more time and resources can be allocated to developing reusable standard designs (modules) for configuration, when compared to projecting. Also, engineering efficiency should be increased along with design reuse. Compared to standard products, the effectiveness of a solution, i.e. the product configuration, to a particular problem is higher. Thus, engineering productivity was usually enhanced with configurable product families. Furthermore, positive indications from after sales were being collected, because it is easier to maintain a product which is not made out of unique elements. [Storholm et al. 1998 and Pekkarinen et al. 1999]

ENABLE SUSTAINABLE GROWTH OF BUSINESS. Generally, two kinds of effects favor the application of configurable product families. First, there is a direct impact in the productivity of the company's processes, which is most apparent in the desired changes in the sales-delivery processes of a company that has been previously projecting engineered to order products. An evidence of this is the fact that most of the interviewed companies reported that configuration has been a key element in enabling business growth. With a traditional projecting approach, these companies would simply have encountered a lack of capable personnel to take care of the increased sales volume. Another generic impact is in the positioning on the market. In particular, companies that had previously been making standard products, re-established themselves on the global market. These companies claimed that, for example, they would not have enough strength in the product development for making new products for the market. Eventually, they would have vanished from the market with products either outdated or covering only niche segments.

For a projecting company, configuration appeared as a means to increase their market share. For example, the company [Storholm et al. 1998] reported a growth of market share from 5% to 50% within ten years. People in the company believed that without their product structuring systematics and the delivery system based on configuration, this growth would have been impossible. Within a shorter time span, another company reported that they had attained 100% security in delivery time and cost, with double the volume when compared to the projecting based approach [Henrikson 1998]. In that company, the sales margin became fixed already in the sales phase, which had not been the state with preceeding projecting approach.

The relation between increased market share and configuration was also acknowledged in two companies [Jokisalo et al. 1998, von Bonsdorff 1998] where the approach had taken place from the serial production of standard products. Generally, the companies that had been successful in developing configurable product families considered configuration as the best option for competition. Therefore, the transition to configuration (regardless of the original approach) had usually been a necessity. Afterwards, most companies had not recognised any viable options for configuration. [Jokisalo et al. 1998, Storholm et al. 1998].

Dynamic situation

CEASE OF BUSINESS GROWTH. However, one of the companies recognised that the situation had changed so that the margins had started to decrease. Actually, this was notable in the company's yearly turnover and profit, where growth had ceased to exist and losses begun to emerge. It was plausible that the competitors had also begun to apply configurable product families. An emerging challenge then was to re-engineer the existing system and bring totally new features into the product family [Storholm et al. 1998].

DEGRADATION OF CPF. Another negative remark came from a company that had been producing fixed products. They noted that margins are small with configuring and sometimes competitors are offering configurable options as standard features in their products [Jokisalo et al. 1998]. Thus, the competitive edge related to configuration options is unlikely to be stable, but evolves according to the market situation and the product portfolio of the competitors.

SHORTER LIFE-CYCLES OF PRODUCT FAMILIES. According to two companies, the objective of configuration had not been to pursue a longer life-cycle of product families. According to their experiences, a configurable product family is not necessarily used in sales any longer than a single, fixed product [Jokisalo et al. 1998, Huuskonen 1998]. Instead, a single module may be used in assembly for a long time. For example, one company reported that they were having some modules older than ten years still in production [Huuskonen 1998].

Of course, the above statements depend on the definition of a product family. From a marketing and sales point of view, a product family may be considered as new, even if it is based on old technology and contains most of the same parts and assemblies. From the market point of view, the new model is the one that has been labelled as new and contains some distinctive features, such as new styling in automotive industry. From the design point of view a product family may be totally different if the family is defined, e.g. according to Tichem et al. [1999].

Immutable architecture

For example, in the case of Valtra [Huuskonen 1998], the generic architecture of product families had remained substantially the same for years. Therefore, the revisions of the related generic configuration knowledge could be minor and encapsulated according to the architecture. This allowed the company to develop their product families gradually in the sense of [Baldwin et al. 2000].

The cease of growth at a certain stage of the CPF life-cycle as well as the degradation of competitiveness related to configuration options were recognised as challenges. These issues force companies to actively manage and re-engineer the product families and long-term success is probably based on the company's capabilities related to the management and re-engineering of the product families. The capability is, of course, a matter of the availability and allocation of scarce resources. When the companies were being followed after the interviews, most of them (five out of seven) had been gaining resources and growth with mergers and other business arrangements.

...provide means for CPF management

Because of the limited resources in product and production development, the paradox of productivity (i.e. increasing variety and throughput with the same personnel) was attained by the successful companies. This was possible due to the reuse of structures with minor and encapsulated changes in the product family architectures as well as in configuration knowledge. For example, a company reported that they "*are be able to carry on with current product development recources*" [Huuskonen 1998], because the development efforts are directed on one module at a time. This is an advantage that has also been acknowledged in other disciplines, such as the electronics industry and software engineering with product platforms [Jandurek 1996] and modularity [Baldwin et al. 2000, Gamma et al. 1995].

The characteristics of transformation

As there are a number of approaches to configuration, there appears to be a lot of options on how to initiate the transition process. Companies often find it difficult to manage transition processes, probably because their experience is from the

- development of independent, fixed products for mass production
- definition of (seemingly) unique designs in the projects of engineered-to-order products.

Product development in key role

However, product development is a key process that cannot be omitted in the development of configurable product families. For example, when a company broadened the business focus, the product development offered configuration as an option by developing a modular product family [von Bonsdorff 1998]. Later on, this option was approved by the stakeholders of other processes. In the development, a clean-sheet approach was used and it appears that the success with the product family relied solely on the awareness of the product development. However, afterwards, the existing product family was considered as a legacy that could not be omitted when new options and product families were to be developed. [von Bonsdorff 1998]

In another company which was narrowing its business focus, it was claimed that product development should develop the configuration model [Storholm et al. 1998]. Otherwise, there would be problems if a single function, such as product or production engineering, would develop it. In that company, the situation had been such that the sales department was developing as well as using the configuration model. Some problems had occurred, since the required technical knowledge was not explicitly documented in product development.

Integration in development and documentation...

Based on these experiences, it is clear that product development should integrate the requirements and opinions of different business functions. This should happen not only in the sense of traditional integrated product development [Andreasen et al. 1987] or concurrent engineering [Dwivedi et al. 1991, Cleetus 1992], but also by keeping in mind that the documentation of a product family is a means for communicating and documenting the necessary information for seamless business operations, since a configuration is being defined and delivered by different processes.

ESPECIALLY IN NARROWING. The integrated development approach is crucial in projecting companies, because the development of a configurable product family was characterised as a quick and intense process. Furthermore, "*commitment of whole staff... teamwork and concentration on … rationalization of processes*" [Pekkarinen et al. 1999] where the characteristics of the transition. As the integrated product development is abundantly a matter of attitudes and management [Andreasen et al. 1987], the transition into configurable product families was regarded as being even more an issue of such kind [Pekkarinen et al. 1999, Storholm et al. 1998]. Therefore, the transition process should be the interest of and supported by everyone from top managers to engineers.

PROCESS RE-ENGINEERING AND ORIENTATION. Particularly in narrowing the business focus, the commitment to certain kinds of processes and responsibilities has appeared to be difficult. Sometimes, the intervention of top management has been needed in order to ensure that people operate according to the new processes [Pekkarinen et al. 1999]. This has been the case particularly in the sales processes where the people are accustomed with the best service sales strategy [Storholm et al. 1998].

The management of companies narrowing business focus emphasized the importance of systematic approaches in developing products and modules as well as process thinking [Storholm et al. 1998, Jokisalo et al. 1998]. It was even denoted that "*competitiveness is closely related to the business awareness of engineering rather than to technical innovations*"[Storholm et al. 1998].] In staying competitive, the management of processes was regarded crucial, since "*it is more difficult to copy processes than innovations*" [Jokisalo et al. 1998]. However, no indication of any structured method for Business process re-engineering was presented. Rather, the re-engineering appeared as a change in the company culture, which is emphasized by [Hammer et al. 1993]

Discrete transition steps

The transition appears to be such a process that cannot be executed gradually. Yet, a company which had widened the business focus into configuration, reported that the transition into modular engineering was a slow process [Huuskonen 1998]. However, in that company, the application of product configuration in the sales delivery was not gradual.

Some companies reported that the development of a configurable product family intensevily consumed time and resources. Actually, in one company, the resources needed in modularisation were underestimated twice [Henrikson 1998]. However, two of the most successful companies emphasized the speed of the transition [Pekkarinen et al. 1999, Storholm et al. 1998].

FAST PACE AND INTENSE RHYTHM. In a successful case of narrowing business focus, the transition was very intensive. In making the transition, all the stakeholders were activated with product development methods normally used for the search of solution principles to fulfil the sub-functions [Pahl et al. 1996]. The methods, such as Dephi, vere used in order to collect the necessary opinions of all the stakeholders, also “the unobtrusive ones” [Pekkarinen et al. 1999]. The use of these methods appeared to be quite an intelligible approach, because the idea is to collect tacit knowledge from a company. Other companies with a similar approach also emphasized teamwork and processes [Storholm et al. 1998, Jokisalo et al. 1998]. These also served in ensuring the necessary commitment which was needed to make the transition persistent and competitive.

From the interviews of all companies, it become clear that it is important to consider the transition from several points of view and in a number of contexts. In order to ensure (the occurrence of) this, people from a number of different disciplines should be involved and activated. It is also quite necessary to take the opinion of the personnel into account, since

- the meaning is to collect tacit knowledge
- instead of only developing products it may be even more important to develop the company’s processes
- people have to prefer the new way of action rather than to stick with the old ones
- best commitment is attained by involving people

It become quite clear that it is not a matter of a usual product design task, because the effects of the dispositions are very important (see page 61). Therefore, the required effort is different by nature and by magnitude. If the business culture (attitudes and the ways of action) is old-fashioned and stagnant, it is quite difficult to create such a situation where an opportunity exists and the transition is possible.

CPF planning and policies

The concept of a product policy is described in this chapter first. Then, the importance of having a clear product policy is discussed and finally, the means for product policies are described.

Disposition for the offering

Product policy has a disposition on the sales-delivery processes and therefore it is the subject of company management. In short, it is the constraints for the offering that dispose the desired effects to the market as well as the company's own operations, such as sales, engineering, production, and supply management. With CPFs in particular, it is important to have well defined policies which are outlined in the planning stage of CFP. The policy gives the means for top management to trim the company's operation according to its strategy.

REDUCTION OF UNNECESSARY VARIETY. The interviewees in most advanced companies [Pekkarinen et al. 1999, Huuskonen 1998, Storholm et al. 1998] also emphasized the issues related to unnecessary variation in product family structures, which in their opinion also had a direct relation to the size and the complexity of a configuration model. In a company that has been projecting one-of-a-kind products, the variety of legacy parts and the number of stock items is usually large (see page 123). With strict product policies, it is essential not to offer the variants that are increasing the effort of maintenance in data and knowledge bases as well as the stock of spare parts.

Minimizing the configuration model was considered the result of a policy of not offering any sales feature that is unnecessary for the existing and/or future customer. It was regarded as a virtue *per se*, since a large configuration model would potentially cause problems in the maintenance of the model. Moreover, it was stated that an excessive configuration model would include inconsistencies hidden within it (e.g. the large knowledge-base). An experience was that when a model grows, the one who maintains it will omit some existing rules by creating a duplicate or a contradictory rule. Eventually, a configuration which is based on a large model will probably have inconsistent or even false selections and combinations. [Jokisalo et al. 1998]

It was also stated that developing and maintaining a range of variants generate costs. As too large a range is easily redundant, the costs are often unnecessary and could be avoided with a good policy. There is also a danger of having to make compromises in developing and maintaining the variety. They may be directly related to the product or the production technology. Eventually, the qualities (e.g. size and redundancy matters) of the configuration model were regarded as merely one piece in the larger puzzle of product policies. [Jokisalo et al. 1998, Storholm et al. 1998]

To summarize the reduction of variety was regarded as a virtue in itself, due to the redundancies and the related activities and costs. A configuration model may be minimized with a number of approaches. First, unnecessary (part) variations may be removed or combined as one default component. Second, the functional as well as assembly interrelations between the organs, components, and parts may be reduced by modularization. Apparently, the first approach is easier from the engineering point of view, because it mostly involves policy decisions while the other requires a more fundamental re-engineering of the product structure.

Generalisation and Integration in reduction of variety. One company emphasized the converge of functional variants into one coherent module. In that company, six functional variants of an essential organ/assembly component were converged into one universal assembly [Jokisalo et al. 1998]. Afterwards, the universal assembly has proven to be a very successful idea, together with an innovation integrating the assembly, reducing the part count, and making it functionally more viable [Mikkonen 2005]. The company regards the integrated universal assembly as a strategic asset. Moreover, the company claimed that the assembly could be quite easily fitted to most of the existing products, globally. This refers to a high degree of independence in re-configuration, an aspect of modularity for configuration, as presented in “Modularity in relation to life-cycle” on page 55. Moreover, the convergence of variants in the development of a product family is similar to the concept of part consolidation in design for assembly.

Product structures as a means of policies. Another important issue, mentioned at least in three companies [Jokisalo et al. 1998, Storholm et al. 1998, Pekkarinen et al. 1999], was that a modular organ/component was closed from customers. This meant that the properties of a module or a combination of modules were shown to the customer, but they could not be defined separately. If a component that fulfils the combination of selected sales features was not found, a new component was not defined in the sales-delivery process (i.e. the sales process was not allowed to define the new versions of the component). Instead, the wish of property combinations had to be recorded and brought to notice for the product development process. Product development was supposed to combine and evaluate the unfulfilled wishes and develop re-usable modular components. The rationale behind this policy is to have separate product development and sales-delivery process. [Huuskonen 1998, Pekkarinen et al. 1999],

Differentiation of sales and technology features

Generally, companies that were narrowing their focus, considered it essential to differentiate sales features from the technical representation of a product [Jokisalo et al. 1998, Pekkarinen et al. 1999]. Thus, at least two views to product families had to be provided, but at the same time, it is important to maintain a clear, preferably one-to-one relation between the items of these two views. This can be regarded as a formal means of separating the sales and the production processes.

Customers may have generic preferences on part attributes such as material and geometry. These situations were regarded problematic for configuration, because these parts and consequently the attributes may appear all over the products resulting in a large number of component variants. For example, even if the size ranges, the materials as well as the thread geometries of screws were standardised, a very high number of combinatons could be possible. For maintenance reasons, the customer wishes to have a certain sub-set of all the possible screws to be used in a configuration. Since all customers wish to have their own sub-sets of variant combinations, the problem easily becomes unmanageable to a company which wants to offer ”functional sales features” instead of configuring based on the selections of part definitions. The conclusion in the company [Mäkinen et al. 1999] was that it is difficult to standardise already standardised parts.

Different kinds of product policies

In general, the interviewees understood the questions about product policies from the point-of-view of marketing and the constraints for sales set by configurable product families. Basically, two kinds of opinions about the policies were discovered. According to the first, strict policies were regarded as an imperative with configurable product families. According to these opinions, strict policies enable pure configuration in sales delivery processes. Second opinions stressed flexible coping strategies to non-predictable customer requirements, such as having engineereed-to-order sales delivery projects and the management of unfulfilled customer requirements. Also, cravings and approaches to simplify and to rationalise product families as well as to differentiate product and process categories were recognised.

STRICT, PURE CONFIGURATION. A company has to keep control on offerings so that one-of-a-kind products are not sold, specified, or quoted as configurations. The alternative selections of the sales properties with which a company provides its customers reflect their policies. For example, two companies emphasized that the selection ”other” should not exist in the configurator [Jokisalo et al. 1998, Mäkinen et al. 1999]. With this opportunity, the customers have a chance to freely define the product similarly to projecting one-of-a-kind-products (or in the case of partial configuration). According to the interviewees, such sales properties will eventually decay configuration processes.

One company even recognised a clear parity between product policies and the price setting [Jokisalo et al. 1998]. A rule of thumb regarding this matter was given in one company which sold made-to-stock as well as assembled-to and engineereed-to-order products. According to this rule, the estimated profit of an engineered to order product should be 15% higher than that of a configured product (in the sales phase). [Jokisalo et al. 1998] This is due to the uncertainties of projecting, described in the literature review. With this approach, the selections of the customer more or less automatically define the product categories. However, there is a danger that other characteristics of the sales-delivery process, such as time and controllability, may be omitted.

FLEXIBLE, PROJECTING OR PARTIAL CONFIGURATION. In other companies, the strictness of the product policy was seen from different points of view. Instead of putting surcharge on undesired customization demands, such as open sales properties, they emphasized more pro-active approaches. In these approaches, the customer is not given an opportunity to select properties which would be difficult to attain in the delivery process [Storholm et al. 1998, Pekkarinen et al. 1999].

Instead of trying to convince customers on the company's product policies, the product policy is a matter that should not be shown to a customer (as a constraint factor). At all events, the loyalty of the customers is vital, especially in Business-to-Business market, which is usually the case of a projecting company [Storholm et al. 1998]. Therefore, it can be of utmost importance to a projecting company to be able to offer engineered-to-order products in addition to configurable product families.

If a company has a variety of product categories which indicate both a narrow and a large business focus, it is very important to be able to recognise and differentiate these categories in the sales phase. There are multiple means to enounce the differentiation. Especially the price of engineered-to-order products should be kept notably higher with the open properties than with the well-defined properties, which preferably have a clear relation to the product/module characteristics.

Development of product families

The development of product families for configuration can be divided into two different kinds of development processes [Pulkkinen et al. 1999b]:

1. the initial development of generic, preferably modular, structures, and
2. the continuous development of variant solutions that fit into the generic structures.

Only a few interviewees were able to describe the initial development processes and methods in detail. This was due to the fact that they had not participated in it [e.g von Bonsdorff 1998] and/or it was done a long time ago [Storholm et al. 1998, Huuskonen 1998]. In one case, the development was cited as an "evolution" towards the mutually accepted architecture of CPF, rather than a clear, distinct project [Huuskonen 1998]. This may also be the case in the other interviewed companies, but no records of this were attained.

Integrated CPF development

In some cases there were several failed attempts [Mäkinen et al. 1999] and eventual successes [Henrikson 1998]. What seemed to be common for the failed attempts was the underestimation of capabilities and participants. Also, the development was sometimes so much integrated into the transition process and CPF planning as well as to product structuring that separate descriptions were hardly found [Pekkarinen et al. 1999]. In the development of a configurable product family, the characteristics of concurrent engineering [Dwivedi et al. 1991, Cleetus 1992] such as team values and multidisciplinary teams, a rapid and continuous exchange of information in relatively small packages as well as the simultaneous progress of activities, appear to be profitable.

Thus, the way of action in the continuous part of product development should be integrated. The possibilities and requirements should be collected and analysed from different stakeholders, such as customers, sales and marketing, product design and development, production engineering, as well as management. This process should be continuous as well as systematic, and it should provide signals for product planning and development. Otherwise, the configurable product family is not evolving according to the surrounding environment and will be close to an extinction.

NEED OF MULTIPLE REPRESENTATIONS AND VIEWS TO CPF. The representation of different kinds of sales properties, such as product aesthetics and other emotional issues as well as raw technical details, was regarded important in configuration [Storholm et al. 1998, Huuskonen 1998]. Also, the configuration process is characteristically a process binding the sales properties and features to the characteristics of assemblies and parts. Thus, product development was supposed to be able to produce the information in a number of forms and combinations.

To be able to deliver the instructions for production is essential, but not adequate anymore. Rather, the products have to be demonstrated from a variety of viewpoints. For example, the current requirements for the marketing material and the user instructions were regarded higher than a decade ago [Huuskonen 1998, Mäkinen et al. 1999]. Moreover, the interviewees expressed a wish to have these documents in a configurable form, similarly to the physical products [von Bonsdorff 1998].

VOICE OF CUSTOMER. Two of the most advanced companies emphasized the impact of customers on the product development [Storholm et al. 1998, Huuskonen 1998]. Eventually, customers should have an effect on the configuration model. The model should be defined and updated by the product design and development and not as a separate activity carried out by, e.g. sales of IT support [Storholm et al. 1998]. Otherwise, a configurable product family would not be developed for the market and the product family could go astray.

One company presented a method for capturing and managing individual customer needs [Huuskonen 1998]. In their product planning process, the unfulfilled customer requirements were systematically collected from all sales offices. Furthermore, the requirements were evaluated by an integrated product planning team, which consisted of members from different functions of a company. The evaluation took place two times a year and its emphasis was on the verification and validation of the generalisability and persistence of a singular requirement. This process as well as traditional customer surveys and market researches gave input for the product development process.

Enhanced design productivity

A number of the interviewed companies reported many improvements in engineering design activities, such as a transition from fixing day-to-day problems with *ad hoc* solutions to the generalisation of problems and the corresponding long-term solutions [Henrikson 1998, Pekkarinen et al. 1999, Jokisalo et al. 1998]. More generally, the most advanced companies indicated that the enhanced productivity of product development is a fact related to configuration [Storholm et al. 1998, Pekkarinen et al. 1999, Jokisalo et al. 1998, von Bonsdorff 1998]. The companies did not indicate how they measured overall productivity, but according to the interviewees, configuration enables the adequacy of resources, when the life cycles of product designs are becoming shorter and shorter [Storholm et al. 1998, Huuskonen 1998, Jokisalo et al. 1998, von Bonsdorff 1998]. For example, one interviewee [Henrikson 1998] reported that 40% of the designers were transferred from sales-delivery projects to product development.

Adequacy is gained by a divide-and-rule method in product development. Instead of trying to design an entirely new product line, the efforts are addressed on the development of singular solutions or their variants (i.e. modules) which are added to the product family (i.e. module system). As a sum, with the mentioned transition, this focusing of efforts had provided a very positive impact on the product development organisations. Apart from the resource adequacy, the interviewees mentioned issues such as the improved ease of development and more even workload in design, which result in the improved organisation of product development and eventually a peace of mind among the employees. These, of course, are positive matters for knowledge-intensive work such as product development and innovation.

Sales processes

Generally, whatever the configuration approach is, the essential task is to define a product individual (i.e. the configuration) and the corresponding quotation. Thus, it is vital that these definitions are correct in the sales .

Quotations based on actual cost information

In particular, being able to define the correct price for a configuration was considered essential by [Henrikson 1998, Storholm et al. 1998]. In fact, one interviewee [Henrikson 1998] stated that the company was able to correctly define the profit of a quotation already with the sales configuration. Activity-based costing [von Bonsdorff 1998, Storholm et al. 1998] and value engineering, similar to the "Case Tamrock" on page 123, were considered the tools to provide the right costing information for the pricing of different features.

MANUAL PROCESS. However with the company narrowing sales-delivery from engineer-to-order to configuration, this did not appear to be the case. Sales representatives were usually responsible for the definition of configuration, and advanced KBES were in use in none of those companies, but mostly the configuration was specified with simple tools, such as structured sales forms or spreadsheet solutions. Still, the companies claimed that their sales and quotation processes were based on configuring rather than engineering. Apparently, the approaches were more based on the mutual acceptance of the mode of operation in selling and bidding products. However, two companies were planning to implement a configurator.

DEFINING VALUES FOR PROPERTIES. Typically, the selections done in the configuration were directly related to the properties of the processes or functions. The categories of these properties as well as the values or the ranges of values had been pre-defined. Also, the means for realizing the properties had been defined and related to the values. Thus, the processes were supposed to be initially deterministic.

In one company, the definition of configuration begun with the definition of the required process parameters [Storholm et al. 1998]. As the company was producing small volumes of business-to-business products, the interviewees estimated that in the future the definition of the customers' business requirements would be the initial values for configuring. For example, these values would include the annual production rates or the degree of capacity utilization. Even the period of repayment in a certain market situation was mentioned as a parameter for configuration. [Storholm et al. 1998]

RELATING PROPERTIES TO ITEMS. In some cases, it was stated that the sales attributes are directly related to the variants of module types [Jokisalo et al. 1998, Pekkarinen et al. 1999]. The relation was easily presented with spreadsheets [Jokisalo et al. 1998]. However, the concept of a module was typically very unsettled.

RELATION TO CHARACTERISTICS OF PRODUCTION. In two companies [Henrikson 1998, Jokisalo et al. 1998], it was emphasized that the properties of sales options have to be related to the configuration structures and their properties, such as delivery time. One of them used the price list as a configuration presentation tool and linked the items on the list to the product structures, i.e. the items on the generic bill of material. Thus, the whole quotation was created alongside the actual configuration.

Likewise, the lead time for a particular configuration could be defined during the configuration, because the sales personnel had information on the lead time of each module, separately [Henrikson 1998, Jokisalo et al. 1998]. In the other company [Henrikson 1998], the assembly time of each configuration was virtually the same, due to the plus-modularisation approach. Actually, all modules were independent from each other, so that they were only added to an assembly.

In one company, front-office configuration without an expensive configurator was considered possible due to two issues. First, the personnel in sales had expertise on the products as well as on the customers' business. They were also employed by the product manufacturing company, i.e. no independent sales agents were hired. The sales personnel also had a connection to the enterprise resource planning (ERP) and product data management (PDM) software. This provided them with accurate information on both the sales-delivery process and the characteristics of a particular configuration. The sales support was considered a vital activity to the company, because ”the sales is delivering the money”. [Pekkarinen et al. 1999]

Production processes

A transformation to configuration is related to the control of the production process as well as to overall productivity. The relation has been quite positive in companies which have narrowed their sales-delivery process from projecting to configuration [Henrikson 1998, Jokisalo et al. 1998, Pekkarinen et al. 1999, Storholm et al. 1998]. Reciprocally, one would assume that a widening transition would have a negative effect on the production, since Mass Production is sometimes (in practice) considered as the most efficient production philosophy. However, companies who widened their sales-delivery process did not indicate this in the interviews [Huuskonen 1998, von Bonsdorff 1998]. Instead, the old mass production systems were considered to merely cause unnecessary bulk of unwanted products in the stock [Huuskonen 1998]. This indicates that the theory of ideal factory and CPFs are in line with each other.

PRODUCTIVITY AND CONTROL. Another implication of this were the improvements of overall productivity and production control. In one company, the expensive machining centre had been dominating the production planning, because the depreciation of the investment required a high degree of utilization. Eventually, the operations of the the machining centre dominated production planning instead of vice versa. Sales were not able to produce quotations that would ensure a high degree of utilisation for the machining centre and the overall productivity of the factory was not high. Within the transition to configuration, the dilemma of productivity was solved by outsourcing the machining centre and creating another link to the supply chain. [Jokisalo et al. 1998]

Aligning market needs, CPF development and production

In another company [Huuskonen 1998], the compatibilities of the modules allowed dynamic changes in the introduction of new modules to production. The new, improved versions of modules were designed as compatible with the old existing structures. Thus, product development was not only organised module-wise, but also the changes in the configurable product family were made separately. Also, the scheduling of the changes in production was enabled by adopting the Just-in-Time philosophy in the production changes. In the introduction of a module revision to production use, this meant the adoption of kind-of pull system: the assemblers were able to use up the stock of old module revisions before shifting to the use of the new revision. Production had the freedom to choose between the two revisions of same module for a limited period of time.

The system was dynamic and it even allowed the recall of a module version (e.g. in the case when unexpected problems would have happened in the quality of the new version of a module). With this approach, the company was able to have short delivery times and a low percentage of unsaleable materials in stock as well as improved control on the material flow and stock. [Huuskonen 1998] Thus, the activities of market needs, addressed on the development of the corresponding modules and production control based on modularity were aligned in the company.

It is surprising that no advanced or computerised method supported the procedure presented above. What could be called lean version management and module introduction rather relied on the skills and the attitudes of the production personnel as well as on the medium volume of production (less than 10 000 end products annually) than on the advanced information exchange between Product Data Management (PDM) and Materials Resource Planning (MRP) systems.

Configuration and Networking

More generally, it seems that with a transformation to configuration companies have been rationalising their production by developing supply chains and networks [Storholm et al. 1998, Jokisalo et al. 1998] – see also “Case Tamrock” on page 123. Factories with operations varying from part production as well as finishing to assembly have transformed into assembly factories with supply networks. At the same time, companies reported that they have been able to reduce part inventories and the work in process (WIP).

DETAILED ESTIMATIONS. Probably the most generic effect on production is the estimation of demand, which becomes more precise. This is possible because the company is able to decompose the demand according the product decompositions which are mapped to the corresponding sales properties. Thus, a company no longer needed to estimate the demand on the product level, but merely to estimate the overall sales (and the corresponding common product structures) as well as the sales of the different properties separately (and the corresponding production items) [Henrikson 1998]. These items were referred to as modules, assemblies, and separate assembly sets. Similar results were attained in the "Case Fastems" on page 128.

LEAN PRODUCTION. At least in two of the companies [Huuskonen 1998, Pekkarinen et al. 1999] with opposite approaches (a widening/narrowing business focus), the result of the transformation was quite similar: a flexible production line that adopted the Just-in-Time (JIT) production control approach. Also, other issues of the lean production philosophy [Womack et al. 1990], such as improved quality, were reported [Storholm et al. 1998, Jokisalo et al. 1998].

LATE-POINT DIFFERENTIATION. In companies that had advanced to the implementation of configurable product families, the order penetration point varied from component manufacturing, i.e. make-to-order, [e.g. Storholm et al. 1998] to reconfiguration in use [von Bonsdorff 1998]. In the companies which had narrowed their processes from projecting to configuration, the ideal order penetration point was assembly, i.e. assemble-to-order [e.g. Pekkarinen et al. 1999] or even plant erection, i.e. final assembly on site [Storholm et al. 1998].

Problems

DISCOUNTS. The drawback of configuration was that offering quantity discounts for a set of similar products was no longer profitable [Jokisalo et al. 1998]. This is due to the fact that with configuration the production batch size is one. This was noticed in one company that had had a number of different product lines, varying from fixed to one-of-a-kind products.

OFFICIALLY OR LEGALLY CONTROLLED PROCESSES. Another problem noticed with the production of configurations were the legacy processes related to official protocols and regulations. For example, the documentation of one-of-a-kind products, such as the material certificates and the quality assurance certificates of valves for high pressure pipelines. The management of this data has to be performed similarly to one-of-a-kind products, while the rest of the documentation can be maintained as configurations. Having distinct, but integrated documentation processes had caused problems for a company planning a narrowing approach. [Mäkinen et al. 1999]

The supporting tools

IT support in sales

Some of the interviewees considered information technology (IT) as an enabler for defining configurations. Manual definition would have been a process too tedious as well as complex. For example, the manual generation of the bill of materials (BOM), which matches for different requirements, would not have been an option since it was considered inefficient [Pekkarinen et al. 1999]. The generation of BOM was done automatically, based on simple relations between the sales properties and the configuration decisions. However, it was held that a capable personnel can patch up the problems due to inadequate configuration models and instructions.

MINIMUM SUPPORT FOR CONFIGURATION. According to the interviewees [Pekkarinen et al. 1999] in an advanced company, one implication of product configurability is the fact that simple support for configuration is adequate. For example, a structured sales form with a connection to a product data management (PDM) system can be adequate support for configuring [Pekkarinen et al. 1999]. However, a configurator, which is aligned with company strategy, the approach of product structuring and sales-delivery process, may be a competitive advantage. In another advanced company this was the case, since they had developed an in-house configurator, which met their user requirements. The personnel experienced the configurator as an important tool in a situation, where manual transformation of sales requirements to quotations and production orders would have been slow, cumbersome and error-prone. [Storholm et al. 1998]]

CORRECT PART DATA AS MINIMUM REQUIREMENT. However, the relation to the context of the company's business, e.g. its processes and market, should not be omitted, because they have an effect on configuring. One company faced problems with defining the concepts and the classes of components and standards, which eventually was considered as preventing to the transformation to configuration [Mäkinen et al. 1999]. In supporting the sales-delivery process, the version management and change control were considered essential issues in an advanced company [Huuskonen 1998]. Otherwise, the alignment of market needs, CPF development, and production (see page 115) could not be attained.

Different approaches regarding PDM

In one company [Pekkarinen et al. 1999], the concurrent implementation of a PDM system was regarded as an advantage for the transition to configuration. It was stated that PDM "...forces the engineers to think about the structures" [Pekkarinen et al. 1999]. Another company [Storholm et al. 1998] had not implemented any PDM/PLM software, but instead it applied configuration. They had found out the contemporary PDM systems unsuitable for supporting their processes. The company [Storholm et al. 1998] decided to rather have the processes as they had planned, even without the PDM support, than change the plans.

Also, in another company [Mäkinen et al. 1999], problems related to the selection of PDM support had been recognised. The interviewees pointed out that "*the legacy coding system of the company prohibited the application of PDM system*". To the interviewers, the coding systematics appeared to contain redundancy. In another case of the narrowing approach, no PDM system was implemented and no reason for this was given. In the opposite approaches (of the widening focus), the application of PDM software had been successful [Huuskonen 1998] or the company was planning to implement an application.

Table 8. The experience of PDM support

Company	utilisation of PDM support	Experiences
A	an ongoing project at 1998	at the time of interview selection of vendor, implementation in year 2000
B	not in 1998	implementation in 2001, common platform for IT-support
C	in use 1998	emphasis in PLM, about 8000 end products annually with 8000 items
D	no solution found	not an applicable solution found even though several vendors and software had been evaluated, later a light system for transferring data implemented
E	an ongoing project at 1998	implementation by the year 2000, a successful case with out-of-the box approach
F	in use 1998	an important enabler for the approach
G	no solution found at 1998	legacy item coding system prohibited the implementations and applications, however after merger an implementation in 2001

For companies with a common projecting background, the approach to configuration was different if the objective was different. The focus of business was more narrowed in the former [Pekkarinen et al. 1999] company than in the latter ones [Storholm et al. 1998, Mäkinen et al. 1999]. No design activities were part of the sales-delivery process in the former, while the sales-delivery relied on partial configuration in the latter.

The successful companies also made a fast transformation (within a year). Thus, a company with a narrowing approach usually benefits from the PDM/PLM applications, while with the widening approach benefit can be gained from the enhanced transactions of documents and the information flow.

The comparisons above give reason to believe that an aspect of configurability is the degree of conceptual simplicity/complexity related to product structures and the support of documenting configuration knowledge, i.e. the modeling of CPF. Apparently, the former has a disposition mechanism to the latter. With a more configurable product, less advanced support is needed. A relation to Product Data Management and configuration can also be found. To ensure a feasible configuration, correct component data is as relevant as the relations between the configuration options and the components. However, companies have utilised configuration with or without PDM applications.

Generally, finding a proper software for the company-specific way of action is difficult because of two reasons. First, the way of action is company-specific and should not be easy to duplicate in another company, which encourages to select *ad hoc* solutions. However, the maintenance of an *ad hoc* solution, which is often made by consultants or by the company's own personnel, is difficult. The aspect of maintenance disencourages the selection of an *ad hod* solution.

The experiences of the two companies above give reason to believe that a number of approaches and IT solutions are possible if the business focus is properly defined. Generally, the different aspects of configuration should not be planned in isolation from each other, but the sales-delivery processes, how product families are developed and the configurations are varied from each other, as well as the software support have to be aligned.

Case studies

Case power plants

Each power plant delivery is an individual project that has set business requirements, such as profitability and return on investment. Similarly, a singular project organisation is being set up for producing the deliverables of a project. Nowadays, the organisation is a network of companies, focusing on the different stages, such as design, system production, part supply, etc. and/or the structure of the plant. The companies create sub-projects around certain topics, such as the project management or the piping system. [Aaltonen 1995, Pulkkinen 1998]

When the productivity of the operations in these projects is to be improved, there are many means that aim at improving the efficiency of the existing ways of carrying out the sub-projects. For example, the author has studied the potential of co-ordinating the sub-functions of a piping project as well as the enhancement of the distribution of the plant design data by utilizing the STEP standard [Pulkkinen 1998, Skeels et al 1994].

However, a pervasive characteristic of projecting is the uncertainty (see "Uncertainty with projects: the state of project" on page 43). Therefore, a study on the source and the effects of uncertainty on the activities in power plant projects was carried out in 2000 and 2001 [Pulkkinen 2001]. In the study, interviews were carried out in three companies that operated at the different stages of the project and delivered the different sub-systems of the plant. All of the seven interviewees were experienced in project management and plant engineering. One of the companies operated as the main contractor of projects, another one as a subcontractor of the boiler and recovery units, and one as the supplier of the piping systems that integrate the plant as a functioning facility.

All of the organisations participated the design of the plant as far as it remained within the scope of their delivery. However, all parties had to have large data sets outside their scope, since their work relied heavily on the preliminary results of the other plant design parties. Thus, the plant as a product can be characterised as integral from the design and delivery point of view.

Basically, the plant design was separated into the stages of preliminary, basic, and detail design. The stages were similar to the VDI 2221 model by Pahl and Beitz, which includes the consecutive phases of conceptual, embodiment, and detail design [Pahl et al. 1996]. However, the supply and the procurements of some materials and parts had to be started on the basis of preliminary design data, since the delivery times of some critical materials were long. Thus, the data was susceptible to engineering changes.

The collected data was analysed by modelling the results of the interviews with cause-effect chains between the activities. Modelling includes the utilization of a design structure matrix [Steward 1981, Eppinger et al. 1996]. In the analysis the activities were categorized in to two distinct areas: the product and the process domains (see Figure 33 on page 122). Generally, it was observed that changes in the requirements, estimations, and/or assumptions cause re-work, which is not surprising. However, the re-work did not just take place in product engineering and manufacturing but also in the project management.

UNCERTAINTIES IN BIDDING AND QUOTATION. At the very beginning of a project, there is a lack of time, because the estimates have to be ready very soon in order to make a bid. Sales engineering was based on varying data as the customers had very diverse ways of making inquiries. Actually, the provided data for sales engineering varied from a single piece of paper to numbers of binders specifying the type of technology to be applied. This in general caused assumptions and neglection of important aspects and affected the definition of scope. Eventually, this led to changes and uncertainties in the project plan and the design data.

UNCERTAINTIES IN DESIGN AND SUPPLY. As mentioned, a plant is a complex and integral product from the design point of view. For example, the lay-out of piping systems not only has an effect on the geometry and the functioning of the system, but also numerous side-effects such as thermal extension and supporting structures. In this situation, the changes of requirements had led to delays, multiple versions, and incompleteness. The requirments are often changed as the personnel in the customer's side changes from engineering and management to users. The ensuing delays and mistakes were multiplied when design and purchasing were carried out by separate organisations. Thus, unexpected engineering changes had remarkable effects on the operations of other functions. Purchasing and the suppliers particularly suffered from inaccurate and unstable product definition data, which led to delays. These, along with contingent problems, increased the delivery times as well as the costs.

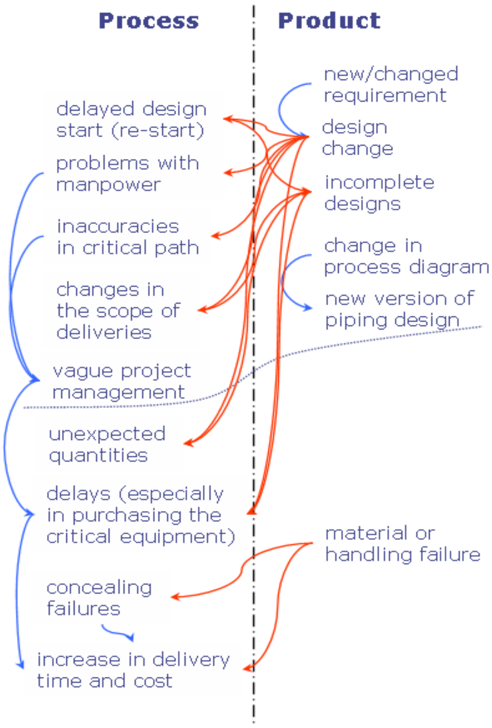

Figure 33.
The cause and effect of uncertainty in design and production

Uncertainties in production. In manufacturing potential problems were recognised with obsolete part production due to changes and errors. This had led the production management to anticipate the production with resource utilization estimates and storages, which typically cause a bullwhip effect in the production with a number of disadvantages [Lee et al. 1997]. In the assembly and erection of the plant, i.e. on-site final assembly, changes and delays were often cumulated, which lead to additional expenses. This was due to the typical coping reaction of the project management to utilise overtime work and new jobbing sub-contracts from site surroundings. These, in turn, had sometimes poor working morale that caused errors and sometimes even hiding errors that lead to further delays.

Problems in relation to economic surroundings. One might suggest the hiring of more employees in sales engineering as a remedy to the presented chain of problems. However, this does not remove the root of the problems. Moreover, it is often impossible to carry out with a large number of employees on a fluctuating market. In a downswing, the companies had a dilemma of employing their current resources. It was stated that in times of recession, the total cost of a plant becomes more critical than the delivery time. Therefore, companies tended to downsize their organisations in order to meet the market demand. Another effect of a downswing was that the engineering tasks were collected and consolidated to the main supplier's project. When the recession was over, in the upswing, there was often a lack of available resources, as the delivery time became more critical than the cost. The companies often tended to respond to this by outsourcing the tasks of projects to a large set of suppliers in design, manufacturing and assembly. The speed of the project was often increased by concurrency, i.e. merely overlapping the tasks, but the complexity, communication, and coordination problems remained the same. This leads to the conclusion that engineering problems may be recognized in the upswing, but there are no resources to remedy the situation.

RESULTS AND THEIR RELATION TO LITERATURE. From the experience of interviewed project managers, we can conclude that the management situation often evolves gradually during the course of a project. Also, in the worst cases, evolution is built on the complexity and variation to risk, ambiguity, and even chaos (see page 43). This due to the management of changes and the propagation of chages is related not only to product but also to process issues (see page 51). The problem becomes worse in the scattered project organisations (see page 66).

In the worst situation the emergent changes arise at a very late phase of a project. As the changes emerge, the sales delivery projects often proceed from one management state to another. Initially, a project may be in a state of complexity or variation, where traditional project management methods are applicable, but soon the situation is being shifted to a state of ambiguity or even chaos. The result is a quickly-changing situation, where updating the project plan becomes an overwhelming task. Often management tries to stick with instructionistic management methods, but soon lacks an overview and loses control over the project.

As stated before (see page 10) a projecting company often makes intended, deliberate and typically minor engineering changes. The propagation of the changes may be prevented due to a number of reasons. Therefore uncertainties manifest not only in product design but through dispositional mechanisms [Olesen 1993] also in the latter stages of the project.

Case Tamrock

In 1998 and 1999 the author participated in the analysis of product structures and parts standardisation in Tamrock (established in 1969), which at the beginning of the project became Sandvik Mining and Construction Finland Oy, as Sandvik Corporation acquired Tamrock as a part of its mining and construction business area. Sandvik itself had started with rock drilling technology at the beginning of the 20th century. Both of the merged companies had incorporated a number of other companies in the previous mergers. In fact, within the preceeding decade, a dozen companies had been merged with either Tamrock or Sandvik. Today, Sandvik Mining and Construction has approximately 12 200 employees and operations in 130 countries. The net sales of the business area in 2006 was approximately SEK 25 billion (EUR 2.7 billion). The headquarters are located in Sandviken, Sweden. The company was and is selling and producing rock tools and systems, drill rigs and rock drills, load and haul machines, coninuous minging and tunneling machines, chrushers and screens for the mining and construction industry. The product lines in which we were interested are divided into underground and surface drilling equipments (see the figure above). The market of these two deviated from each other significantly. Also, the development and the production of surface drilling rigs was separate from underground devices, such as tunneling jumbos. At the same time, the company was making a major factory re-engineering project in the direction of an ideal factory [Lapinleimu 2001] and introduced the methods of value analysis and value engineering as well as target costing in the product development.Also a number of suppliers were integrated in the product development processes. [Koski 2001]

Figure 34. The product lines of Case Tamrock

MERGERS CAUSE PROLIFERATION OF PRODUCTS. As the company had grown to the larger market through mergers, the legacy of market- and customer-specific solutions and products existed. In some sites, the existing product lines had remained intact as the affiliates kept on selling and delivering the products according to the existing designs. Therefore, the product portfolio appeared scattered: it contained overlapping product lines, solutions, and redundant parts. Thus, a global part standardisation project had been prepared [Korpela 1999].

MANUAL SALES SPECIFICATIONS AND QUOTATIONS FOR DELIVERIES. The sales-delivery procedures started with pre-sales inquiries that were taken into account in operative production planning, in the company. The salesmen had paper-based documentation that contained descriptions of the product families [Tamrock 1996]. In an actual sales situation, they filled in a pre-structured sales form. The form was returned to the company and handed over to the manual configurers. They refined and translated the specifications into the production bill of material and the related orders. Production had been arranged around the material supply into two different assembly lines.

ENHANCING CUSTOMIZATION ORIENTED SALES DELIVERY. New technologies had also been applied in product development projects as well as in the deliveries of customer-specific solutions. The company operated on a market where customization was the tradition. This meant that most of the deliveries were fitted to the specific requirements of the customers whether the requirements were related to the compatibility of a pre-existing or pre-designed infrastructure or the variant functionality of a product individual. For example, a customer had a specific electrical system with its characteristics, i.e. voltages, currencies, and frequencies, in his mine. Also, the tunneling procedures and, therefore, the related number and type of booms in a drilling rig were market area specific. Moreover, the level of automation varied according to the availabilities and capabilities as well as the costs of the local workforce. Thus, the product structures were ill-defined and required clarification. [Järventausta 1998]

The overall objective of the company was to attain shorter lead times with less costs. The objective and the situation of the company, the proliferation of products and parts together with customization, can be seen as two opposite elements in a projecting business. Apart from having a global standardisation project for reducing the part count, the company was aiming at having the two opposites by defining modularity for configuring.

DEVELOPMENT CASE. As the company already had a PDM system and was practising manual configuration in product delivery projects, a short project for analysing the modularity of the two existing product lines was launched. The aim was to develop modularity and configurability in two product lines of one factory and then extend it globally to other products and factories. Simultaneously, the company was also changing its PDM, ERP, and CAD systems. Thus, the requirements and the possibilities from IT were supposed to be taken into account.

In the case company the development project was clearly defined and it had rather a small scope and a short time span in the continuum of development efforts. The development efforts were stepwise and an integrated approach committing engineering design, production, and marketing was favoured. Not much attention was paid to re-engineering the delivery processes during the project. However, as stated above, the company had been re-engineering its production to fit configuration just before the development. After the project, the company has shown success both in the product development and the projecting activities.

PRODUCT STRUCTURE. The targeted module system consisted of assembly elements clustered according to product functions, which corresponded to the sales properties. Thus, the modularity scheme followed the approach of e.g. Pahl and Beitz [1996]. The embodiment was not particularly modular, as the functions were related to systems, such as the drilling control system, which manifested all around the whole of the drilling machine. However, component sharing and swapping modularity existed. The personnel were interviewed and a DSM was developed for representing the functional relations of the assemblies and clustering them according to the relations. The idea was not to design a new embodiment, but to analyse the modularity from the existing products. The DSM indicated the integral embodiment of one of the analysed two products. However, the project suggested that configurability could be enhanced without re-engineering the parts by depicting the existing relations and improving the understanding of the product.

Computer support. In the case Tamrock, no configurator was being developed, nor the configuration process directly altered. Instead, modularisation guidelines were being developed for the company and the configuration knowledge was being systemised. In the end of the project, a PDM system (Product Data Management) was suggested as the enabling software for modular engineering in the company. Moreover, the company decided to evaluate the utilisation of configurators. The effects on engineering and project deliveries were not direct and therefore the overall influence of the project could not be directly measured.

Results of the case. After almost ten years of the project, the company's procedures in sales-delivery process have not changed much. Thus, the project did not have any persistent effect on the company. However, some positive indications from the product development processes have been noticed, but it is questionable if they are related to the analysis and standardisation projects that were examined.

Case KCI Konecranes

In 1998 and 1999, the author also participated in a project for configuring the electric designs in KCI Konecranes (now Konecranes). The history of the company dates back to 1933 when KONE Corporation started to build sizeable Electric Overhead Travelling Cranes. KCI Konecranes was formed in 1994, when KONE Corporation sold the operations of its crane division as a part of its structural changes. Konecranes sales totalled EUR 1 472.8 million in 2006, and it has approximately 7 500 employees in 41 countries. The headquarters of the company are located in Hyvinkää, Finland.

Figure 35. The product of the case of KCI Konecranes

The objective of the project was to improve and systemize the reuse of the electric design of the cranes. In practice, the aim was to shorten the design project to one tenth of the typical case of *ad hoc* reuse [Jyväsjärvi 2000]. The context of the case was the electric engineering of modular cranes used in paper mills, power stations, workshops, steel storages, waste-to-energy plants, etc. (see the upper right corner in Figure 35)

OBJECTIVE: ENHANCING REUSE. In the case, there was an attempt to change the way of engineering reuse, which had been based on the archives of individual engineers. The aim was partial configuration in which the configurations of electric drawings would have been checked and finalised by engineers. The case was supposed to have an effect mainly on one discipline in one engineering office, but it required systematisation in sales offices and a number of engineering disciplines globally. The company also expected this to yield results rapidly. Thus, the project can be categorized as being small in scope and short in length when compared to the company as a whole. It is noteworthy that the development project was the third attempt to modularise electric engineering in the company.

PLANNING AND EXECUTION OF THE PROJECT. Some general plans for the KCI Konecranes development project had been defined, but the project execution was actually quite iterative and a number of issues emerged during the project. For example, both the need for the guidelines of module engineering and management as well as the need for structured sales material were recognised and developed rather late in the project. Also, it was recognised that some unneccesary variants had been involved in the product family in the sence of [Elgård & Miller 1998]. For example, one variant in the user interface, one selection of radio controllers, caused about 160 rules in the knowledge base, but was expected to occur in the configurations roughly once in a decade [Sarinko 1999].

PRODUCT STRUCTURE. The case project resulted in a circuit diagram module system, software and an entirely new way for designing the electric controls of cranes. A typical feature of the project was that it was planned and executed by experts in electric engineering and IT from the company. Thus, it is not a surprise that much attention was paid to developing a module system and the enabling software, but hardly any business re-engineering and very little internal marketing (to sales and engineers) efforts were being done. All of the participants were also simultaneously involved in other projects, such as sales-delivery projects and the implementation of an ERP system as well as the management of the research project, carrying out other case projects and so on.

In the KCI case, the target was a mixed module system. The embodiment was a set of electric circuit diagram drawings with component sharing and swapping, sectional and cut-to-fit modularity. The system had a pre-designed structure and the modules were on the one hand functional units (related to the actual controlling functions of a crane) and on the other hand units of an electric CAD system. Cut-to-fit modularity meant in the case modules referred to parametric parts. The part parameters in the bill-of-materials could be varied according to the specific requirements of the configuration case, while the requirements were set by e.g. the environmental conditions and the local legislation at the crane site.

For representing the compatibility of modules, we developed a Design Structure Matrix (DSM), but it was not regarded a better tool than the selection tables developed in the company. For structuring the module documentation guidelines, a method called information mapping was used. Altogether, no sophisticated tools were used in the modularisation case. Moreover, the modularisation case was based on the experiences of the participating electric engineers.

COMPUTER SUPPORT. The configuration context was the parametric electric drawing modules, while the parameters were defined in a structured sales form. For this, a module library containing the drawing modules and the configuration software (called composer) were being developed. During the project, no link between the sales form and the composer were developed. The composer was basically combining modules to an ASCII file corresponding to the definitions in the sales form. Then, the file could be imported to the CAD system as a starting point for manual customisation. While some of the modules were pre-designed, most of them were supposed to be designed in the customisation phase and then added to the module library for further reuse. People from the case company and an external consultant developed the software for the library and the composer in the project. The configuration rules were documented separately and programmed into the composer. [Jyväsjärvi 2000]

RESULTS OF THE CASE. The company did not reach the utilisation phase. This was due to a number of reasons, but the most essential issue was the usability of the configured electric documents. The structuring of the documents had changed and the configurations contained a number of references between the sheets of electric drawings. It became very difficult for the assembly to read and understand the cumbersome drawings. However, first trials indicated that the objective to reduce electric engineering to one tenth from the original situation was attainable. [Jyväsjärvi 2005]

Case Fastems

The case took place in 2001, and the author's participation in it was supervising and instructing three M.Sc. theses. Today, Fastems has 340 employees. It has regional offices in 8 countries, all except one in Europe, while the headquarters and production is located in Tampere, Finland. It is one of the two subsidiaries of Helvar Merca Oy Ab, a privately owned Finnish company. In 2006, the net sales of Helvar Merca was EUR 159 million.

At the time of the project, the company was developing in a number of directions. On the one hand, design tools were considered for engineering in general as well as for all of the product lines. On the other hand, in one product line major changes in design, sales, and delivery were anticipated. One of the actions for the first challenge was the evaluation, selection, and implementation of a 3D computer-aided design (CAD) system, in order to enhance the engineering design process [Laakso 2001]. The second challenge took place when the sales-delivery process was analysed and automated in the product line of the machining centres [Lindqvist 2001]. The latter challenge also involved the development of modular structures for configuration [Malvisalo 2001].

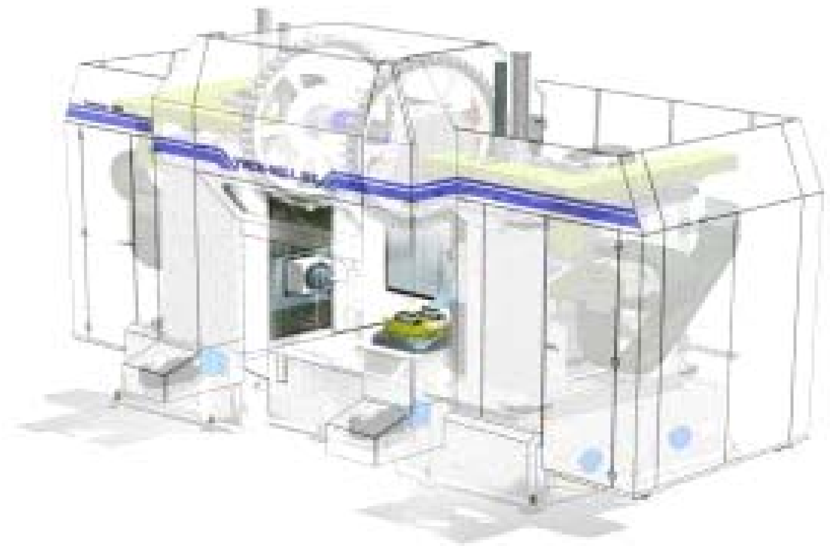

Figure 36. The product of case Fastems [Pulkkinen et al. 2003]

ENHANCING THE SALES-DELIVERY PROCESS. As a part of its business, the case company had been projecting specialized, innovative horizontal machining centres [Fastems 2001] over a three-year-period and had delivered a dozen of product individuals (see Figure 36). In order to accelerate the delivery projects and improve the estimation accuracy, the company decided to change the way of projecting by introducing systematic design reuse. For this, a development project with a tight schedule and budget was set up. However, the first delivery projects indicated that the objectives had been attained well. A more detailed description of the case is in [Pulkkinen et al. 2003]

THE DEVELOPMENT PROJECT. The development project was clearly defined and managed. The organisation consisted of a group of three new employers under the direct supervision of the engineering manager, who reported to the chief executive officer of the company. The members of the group had separate projects and goals serving the overall objective, but their sub-projects were carried out in an integrated, concurrent way. While one project was mostly concerned with design support and CAD, the other was developing a configuration procedure and support, and the third project concentrated on the development of product family structures and configuration knowledge. Experts outside the group were consulted frequently and several meetings of the supervising group created commitment to the development. The project scope was quite limited and the time span short.

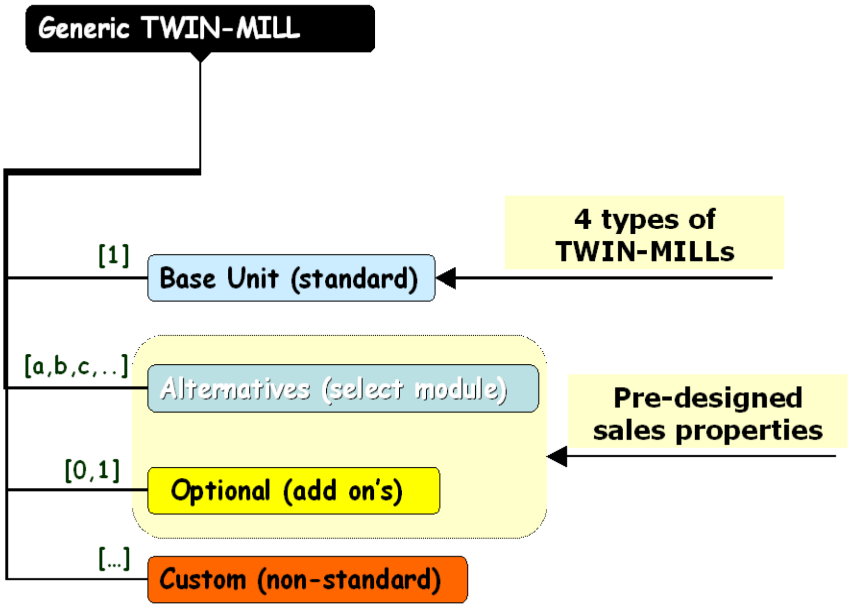

Figure 37. The scheme for the structural elements of the module system [Pulkkinen et al. 2003]

PRODUCT STRUCTURES. The management had recognised that these engineered-to-order deliveries could be categorised into four types which basically differed from each other as having dissimilarities in the main property requirements. In the development of a modular product family for configuring, a mixed module system was defined. The embodiment type of the developed system indicated characteristics of component sharing and swapping modularity in a pre-designed architecture. However, none of the embodiment types suited exactly to the classification of [Ulrich & Tung 1991], because the embodiment was actually similar to the Tamrock case. In the development of the system, the functions and the assemblies of the targeted product structure were specified and analysed. In this task, the varieties in the already delivered products were recognized as a useful source of product and market knowledge. However, the potential customers and competitors were also studied, and experienced engineers were being interviewed. Lists were used to represent the product part-of structures and its sales properties. Design Structure and Late Point Differentiation Matrices [Eppinger et al. 1996, Malvisalo 2001, Lehtonen et al. 2001] were used in documenting the relations between the different items on the lists. This approach seems similar to the K & V matrix method by Bongulielmi [2003].

The module system comprised of four classes of structural elements which formed the configuration context. First, four alternative standard base units, from which one base unit was to be chosen for a particular configuration, were being defined. Second, standardised solutions were pre-designed for selectable sales properties. Furthermore, the sub-classes of the standardised solutions were alternative and optional modules. In a configuration, one selection from each set of alternative modules should exist. A configuration could also include number options, e.g. from the option module class zero, one or multiple modules can exist in a configuration. A particular product individual could also contain some non-modules that had not been pre-designed. As the module system composed of standard base units, alternative, optional and non-modules, engineering composed of reusing standard parts, configuring and customisation efforts. At the end of the development project engineering work had also been organised according to module types.

CONFIGURATION SUPPORT IN CASE FASTEMS.

The module system was explicit and no configurator was required. Instead, the idea was to embed the configuration knowledge into the product structures and to use part of and kind-of lists and matrices as the knowledge representation tools for configuring. However, some concern for the long-term configuration knowledge management was evident. Matrices, however, did cause resistance among the sales personnel and a graphical representation (a decision tree) as the sales view of configuration knowledge was being developed. At the end of the development project, 3 696 distinct paths, i.e. basic configurations, were possible in the graph.

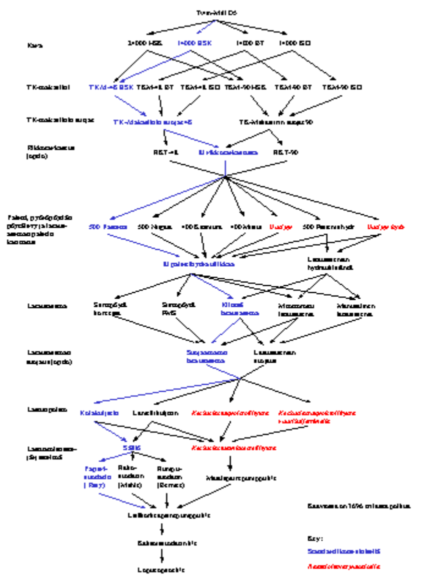

Figure 38. Decision tree as the representation of configuration knowledge [Malvisalo 2001]

RESULTS OF THE CASE. When the new product structuring and sales-delivery concept was introduced and implemented in the company, it was possible to take the advantage of it in a real project. Benefits were studied for three factors: the engineering resources the project consumed, the accuracy of the sales estimate of costs compared to the realization and the changes in the delivery time. The used engineering resources and delivery time were compared to the experience from the past projects.

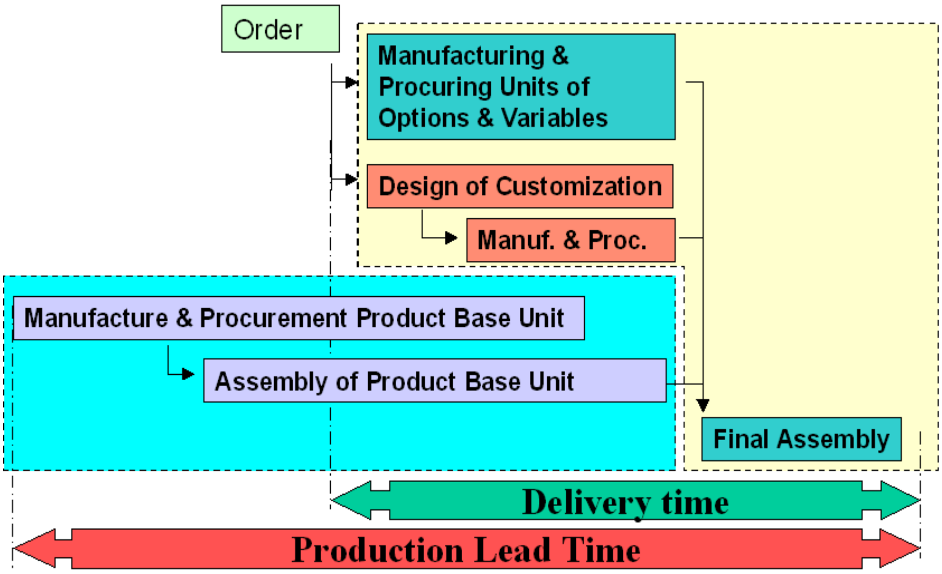

Figure 39. A schematic representation of the attained result in the case Fastems [Pulkkinen et al. 2003]

The company reported that a substantial reduction in the engineering resources used in the project when compared to the past projects was achieved. In the previous projects, as many as 60 man-months had been used in engineering design. The first project with the presented approach was realized with only a fraction of that amount, i.e. within weeks. Also, a substantial reduction in the total delivery time was attained, as represented in Figure 39.

The company aimed to **reduce delivery times**, there was a goal of having a correct cost estimation already in the sales phase. The company wanted to

- better grasp the profit per project as soon as possible and, consequently,
- better **control the business** in general.

The company reported the actual occurred costs were almost exactly the same than the cost estimate made in the sales phase, in the first delivery project.

The company was aiming for a fast, economical, and straightforward implementation. Also, the volume of configurations and deliveries was not estimated to arise rapidly (within a year). Thus, one of the requirements was to avoid the expensive implementation of a configuration software – the purchasing of a configurator was intentionally delayed.

However, at the beginning of the year 2002, there was a recession (see Figure 2 on page 7). Therefore, the market of the product family depreciated substantially. At the same time, the companies offshored their production to developing countries (see Figure 1 on page 5) that further reduced the investments of manufacturing technology in Finland. Also, the bigger companies started providing competing technology with the optional and alternative features of Twin Mill as a standard. Thus, the product was not a success on the market and the company has by now discontinued the product line. However, the concepts of configuration as well as systematic sales-delivery have been largely adopted in their other product lines, such as flexible manufacturing systems (FMS) [Fastems 2007].

Case Metso Paper

In 2006, Metso Paper's net sales amounted to EUR 1 947 million and it employs approximately 10 900 people in 30 countries. It is a part of Metso Corporation. The case of Metso Paper was carried out in the winter 2003-2004. The author participated to it by supervising and instructing one M.Sc. thesis [Fischer 2004]. The project was carried out in order to obtain two goals: the analysis of the situation with the sales quotations and the capturing of the related configuration knowledge into computerized format by using a formal method.

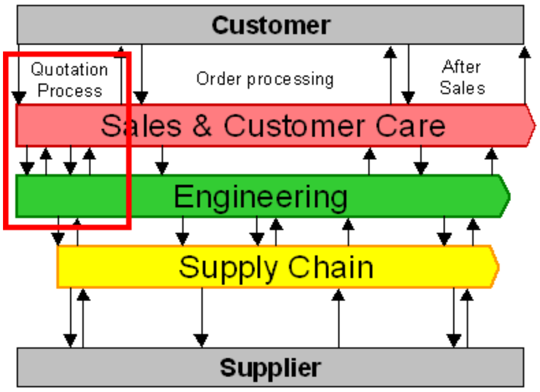

Figure 40. The sales-delivery model, including quotation [Fischer 2004]

THE PROJECT. The project begun with a month of theoretical and methodical studies on configuration modeling, in particular the K- & V matrix method by [Bongulielmi et al. 2002, Bongulielmi 2003]. Then, the situation in the company was studied from various viewpoints, including the existing documentation of the configuration knowledge as well as the quotation and the configuration processes, framed in the upper right corner of Figure 40. This resulted in the analysing of strengths, weaknesses, opportunities and threats in the quotation and the configuration processes. Finally, the studied and collected configuration knowledge was modeled into matrices.

As the paper (making) machine is a very large and complex system, the scope of the project deliberately focused on one of the most complex sub-systems of it, i.e. the pressing system, illustrated in Figure 41. The primary function of the shoe press is to remove water from the wire sieve that carries the paper web. Also, the study was narrowed down to the most modern technology of the company's offering, capable to large process variation as well as to superior performance, in comparison to other concepts [Metso 2006].

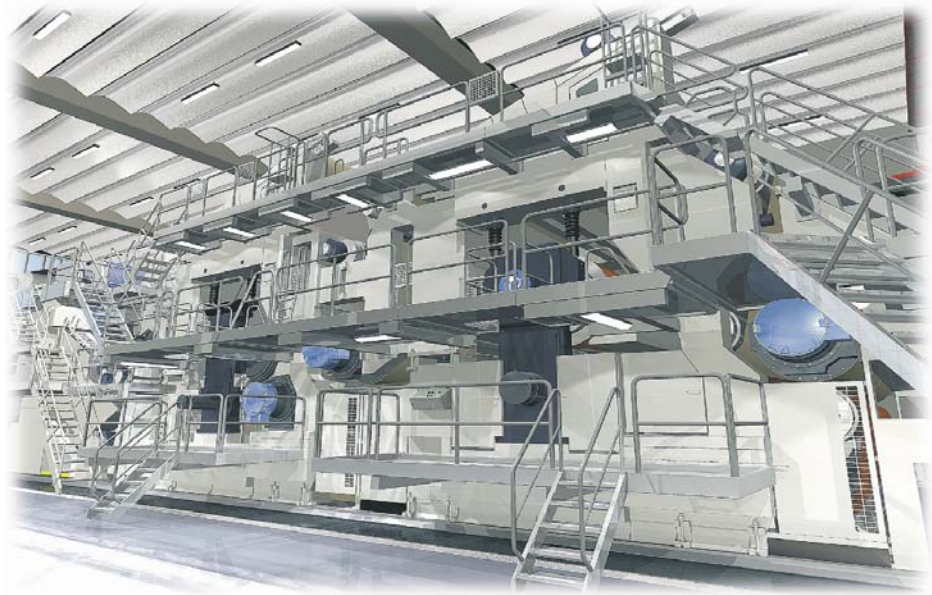

Figure 41. The Optipress double nip shoe press [Fischer 2004]

PRODUCT STRUCTURES. The objective of the project was not the analysis of product structures, even though the K- & V matrix method has been applied for such kind of purposes by [Puls et al. 2003] and later by [Sekolec 2005]. Instead, the analysis concentrated on how sales engineering support performed in the quotation process. Previously, the knowledge was structured as documents in binders. Instead of being interpreted and structured in "marketing language", the knowledge was written in "engineering language". Thus, the relations of the sales properties and the product characteristics did exist before the project, but the form was not easy to access by the sales organisation. In the analysis, we discovered that the sales organisation hardly used the material, but relied on contacting the engineers in order to correct the specifications for the estimates [Fischer 2004].

STUDY ON THE QUOTATION PROCESS. The analysis of the quotation process revealed a chain of problems similar to the "Case power plants" on page 120. The existing documentation was seldom used, but engineering department was usually involved in quotation process. Moreover, often only one concept was taken into further consideration, as the engineers were fully occupied with issues arising in the quotations process. This led to inflexible engineering processes as well as mistakes in technical details. If and when the specifications changed, a large part of engineering work had to be done again at a fast pace. The pervasive problem seemed to be that the engineering was the bottleneck of the quotation process, but the leading of the customer in the kick-off meeting of a sales delivery project was regarded as a root of the

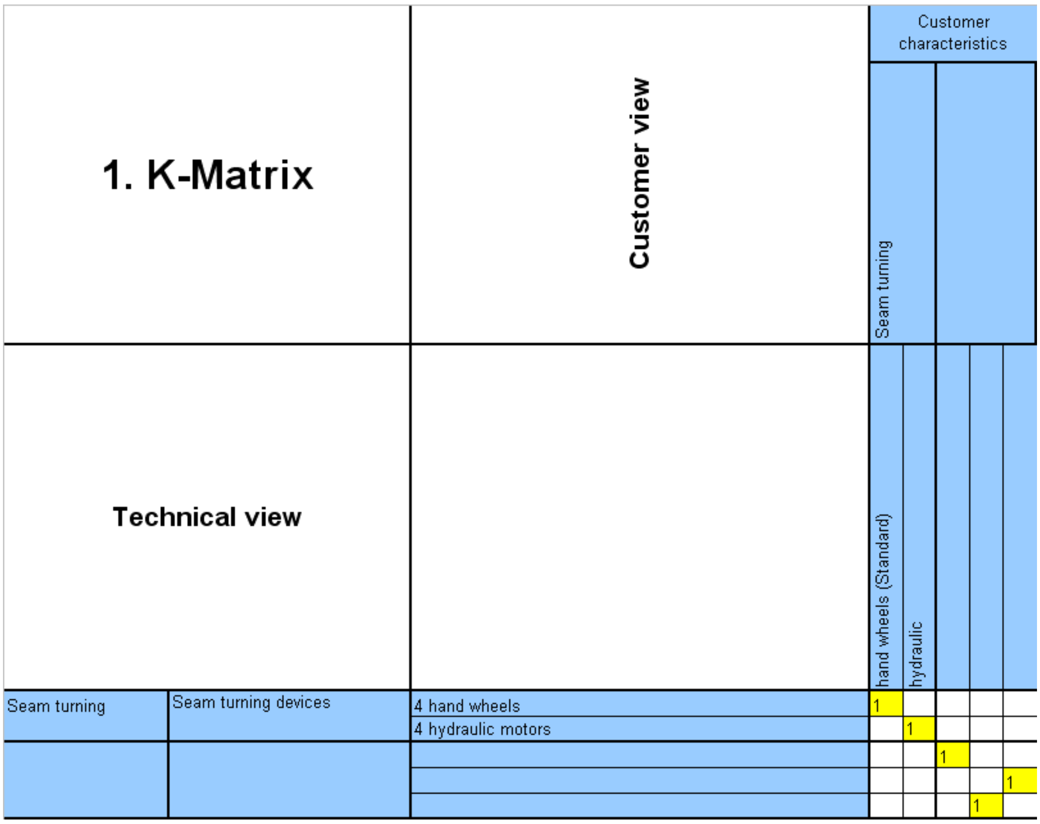

Figure 42. A fragment of the K-matrix in the case of Metso Paper [Fischer 2004]

problem. Also, increasing the number of employees in sales engineering was out of the question. [Fischer 2004]

QUOTATION AND CONFIGURATION SUPPORT. As mentioned, the knowledge was documented in the form of matrices. In Figure 42 a fragment of a K-matrix (**K***onfigurazions matrix*) is presented. It relates two alternative solutions for the felt pick-up function. Altogether the width and the height of the K-matrix was larger than 50 columns and 70 rows. However, the matrices are not very easily undestrood nor readable, as presented already in the section "Configuration support in case Fastems" on page 131. Hence, the Coma server, by ETH Zürich [Bongulielmi 2001], was being applied. In the closing session of the project, it was regarded as a promising tool for accessing the configuration knowledge. In addition to this, a structured agenda for the kick-off meeting was developed so that the sales would better grasp the meeting. Finally a method for evaluating the correctness of the sales proposals was suggested.

RESULTS OF THE CASE. The problems related to the quotation process within the sales-delivery project were recognised and a set of solutions suggested. These included not only the documentation of the configuration and the scheme of the utilisation of the knowledge, but also a set of suggestions for changes at the beginning of the quotation process. The project was carried out in a short period of time, and the results were promising.

However, the context of the project was only a small section of the configuration knowledge, as the OptiPress is one of the three technical concepts for the function of pressing. Paper machine includes other sections for functions such as forming, drying, coating, calendering and reeling the paper web. Plenty of auxiliary systems for e.g. automation and condition monitoring make configuration knowledge and the configuration task more complex than it appears from the rather narrow viewpoint that was deliberately adopted in the project.

Even though, the project ended with promising results and a plan of how to continue systemizing the configuration knowledge, remarkable changes in the operations of the company emerged as a result of the project.

Case Profile

In the fall of 2006 the author took part to an education project at Profile Vehicles, which is a company was founded in 1982 to transform vans into smaller-sized special vehicles such as minibuses, crew transport vehicles, and ambulances. Under the name Iikori Ky, the company had specialised in ambulance production, and in the late 1980s became the largest ambulance manufacturer in Finland. During the 1990s the company had taken the number of steps to expand to the neighbouring countries. These included setting up sales aggreements as well as subsidiaries for the sales and component production. The company is owned by the family who is in charge of the operations. A family company has the advantage of agile decision-making when the justification of the decisions does not have to be solely based on monetary terms. The disadvantage of a family company is the personification of the issues to be decided, especially in the cases of disagreement.

The objective of the company had been to enhance its capabilities in production so that

- the activities of production would be more efficient.
- the lead time of production would be shorter.
- with higher sales the existing resources would suffice.
- both capabilities could be transferred to new production facilities.

It had been recognised that the pre-existing capability oriented manner of production was not sufficient in the larger market. So, the company had transformed its production within a year from project oriented-production to systematic assembly lines, which was developed according to lean production principles [Womack & Jones 1996] and the theory of ideal factory [Lapinleimu 2001]. A new enterprise resource planning (ERP) system was also being implemented. The product design had based on an *ad hoc* design that was included in sales-delivery projects. Nonetheless, the need for systematic product development was acknowledged, especially with a new organisation structure including a separate design department.

The product development project. A pilot project for developing a modular ambulance on a new van model had been carried out. It included the application of new capabilities, such as the mentioned organisational change, hiring of an industrial designer, and a sef of new tools, including three dimensional CAD systems. We had been aware of the situation, as the transformation of production systems had been going on with the hands-on guidance of Professor Seppo Torvinen at the department of production engineeering, Tampere University of Technology. Thus, our interference, with the education project, had been planned for a long period of time. Instead of lecturing, it soon took the form of facilitating, coaching, and problem-based learning with the product development organisation of the company.

Figure 43. The concept of pilot project [Profile 2006]

The inference project was short, as it took about two months with a dozen of one- to two-day meetings, especially in comparison to the objectives of setting up systematic product development processes for modular product families. In many occasions it became clear that the organisation had underestimated the effort needed in transfroming the product design from ad hoc projecting to configuration oriented customization. However, the head of the product development organisation felt quite sure about the next steps after the project was over.

Product structures. As the re-engineered production mainly involved assembling of the standard parts into a transformed van, the most part of the development project concentrated on standardising the interfaces for these parts. There appeared a number of lay-out and attachment problems, but the company was able to standardise the locations of standard as well as most of the optional parts. An example of this is presented in Figure 44 where the standardised assembly of the paramedic seat is presented. Notable in the illustration is the standardised method in connecting the attachment and the rails of the floor (another standardised part). This solution allows the flexible positioning of the seat in the paramedic section of an ambulance. The location of oxygen container and the corresponding interfaces were also standardised.

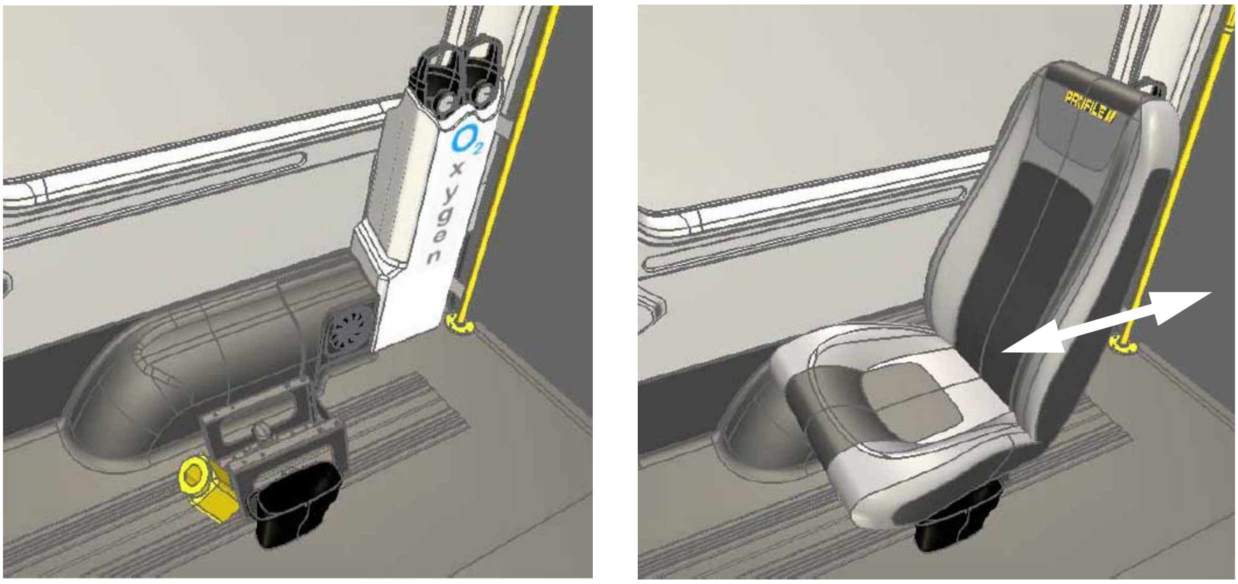

Figure 44. Standard Genios seat attachment and adjustable seat located on it [Profile 2006]

Most of in-house designed components were standardised, which included the walls, floor, roofs with standard options, such as alternative closed panels, windows or compartments for strorage. Customers supplied components, such as stretchers, to ambulances. These were also standard components, from which the options could be selected. Thus, the product appeared very modular from the viewpoints of production and the sales. In fact, the mechanical assembly time did drop down to half of the pre-existing model of a similar van.

CONFIGURATION SUPPORT. However, a configuration support was not established, but it remained as an uncoordinated paper and file based system in the disk server accessed in the company intranet. Therefore, marketing had only the limited possibilites of knowing about the results of the standardisation, but relied on the pre-existing semi-systemized sales catalogue. Thus, the sales process continued to produce ill-defined configurations, as we participated to the case.

As part of education, we attempted to document the configuration knowledge in an easy-to-read and understand form, which we believed to be the matrices. The company had already knowledge on the case of Ponsse by [Nummela 2006], who applied matrices in documenting the configuration knowledge. As the documentation method was introduced and tested, it became clear that some of the components had not been standardised. Instead, in the process of documentation, the decisions about viable variants were made. The technical variants soon settled at 150 to 200, which is feasible when compared to the cases by [Bongulielmi 2003 and Nummela 2006].

RESULTS OF THE CASE. During the meetings it became clear that sales department of the company was not very aware of the decisions made in product development. In reality, the configurations were merely sales specifications, as it had been in the earlier mode of operation. The seemingly configured ambulances did not fit to the production line. Instead, the development team of the configurable product family suffered continuously from design requests from quotation and even production. This was due to inadequate and informal communication between the sales and the product development teams. However, the new product as well as its successor in the smaller class have been successful on the market. The initial problems of transformation ramp-up appear to be solved.

Common to cases

When considering the role of structuring and re-engineering product families for configuration in a projecting company, the common aspect is the rarity of searching for new, more modular, technologies. The concept of modularity here refers to the characteristics of the product family architecture from configuration point of view, so that the required configuration knowledge would be simplified. Only in the “Case Tamrock” on page 123, an analysis was made to reveal the internal dependencies in the pre-existing embodiment of a rock drilling machinery, but even there the aim was not to modularise the product [Järventausta 1998].

Instead, the standardisation of solutions seems to be dominant. It means that standard designs were selected from the existing set of possible designs. For example, these included the lay-out designs and the part designs. Therefore, it seems that the development of product family is not as much a modularisation project as it is a standardisation project. However, this consideration is valid only for the initial phase of the product family development.

In all of the cases, the commitment, or the lack of it, seems to play a key role. For example, if the sales people are not involved, their commitment to the application of the configuration knowledge is minimal. Also, the requirements of the various stakeholders should be taken into account. Otherwise, the utilization may be prohibited by the unsuitability, poor accessibility and, generally, complexity of the configuration knowledge experienced in the sales-delivery process.

Commensurating the results and the analysis of approaches to configuration

As presented in the chapter "Results from the literature" from page 89 on, configuration can be studied as an independent issue from the viewpoints of product structures, activities, and support. However, the approaches to configuration are related to transformation scope, as suggested in the third research question (see page 14). Therefore, the interviewed and the case companies and their approaches are studied in the following from the viewpoints of the scope and the means of transformation.

Commensurating the transformation context

Particularly, the case companies were very different form each other. Three of the companies were large, and operated in global market and two were small, primarily oriented to the market of Nordic countries. Also products, development organisations, production facilities and locations varied heavily from case to another. As the case companies had the similarity, the narrowing transformation, the interviewed companies presented variety even there. Therefore it appears difficult to compare the approaches of the case and interviewed companies with each other.

In order to make the results of the interviews and the case studies comparable, they are commensurated with each other. This is achieved by relating the scope, the objectives, and means of transformation to the overall situation of the company. This is clarified in following.

SCOPE. The scope of transformation was clarified in the literature (see page 40). Here the author has included the product lines and organisations affected to the concept of scope. This refers to the width of the focus of an approach to configuration. It is the breadth of the change in terms of the affected product assortment, as well as the engineering disciplines and the organisations included in transformation. In the results of the interviews and case studies this varied from Ponsse's total change [Pekkarinen et al. 1999] to a number of small steps by other companies such as Neles [Mäkinen et al. 1999] and KCI Konecranes (see page 126) or a small pilot project by Metso Paper (see page 133). In each case, the transformation scope is related to overall situation, e.g. the section of product assortment affected by the transformation vs. the product assortment in general.

OBJECTIVES. The objectives of transformation can be measured in terms of money, lead time and so on. It is possible to measure the effect of transformation with savings in the lead-time, the resources, and costs of sales-delivery process. Actually, a number of the interviews and cases showed the savings in time and resources were remarkable.

However, as presented in the literature, the relation between the effects and the causes is complex and indirect. In order to fully analyse it, other research methods, such as the statistical methods of analysis should be applied. Anyway, the available data and the number of cases is not satisfactory enough for this purpose. Instead, we must first assume that the transformation from design engineering to configuration is feasible in projecting and therefore the objective in itself. Actually, this is also the case in practice, as the results can only be anticipated, since the transformation is a strategic choice.

In practice, the success of transformation is measured as the competitiveness of the company and its approach in the sales-delivery and product development activities. Thus, the measure of transformation can be the viability of the results of transformation. The viability means the survival of the transformed operations in the company in the long run. This can be analysed by the persistence of results in the sales-delivery and in the product development operations. The coherent results of transformation are the form and the content of the articulated knowlede on product family structure and the sales-delivery model. The persistence of the results are measured in the top section of the model of IPD (see Figure 15 on page 57): the success of objectives, policy and strategy. The combined effects of the coherent results in the long run, are the commensurable measure of the objectives.

MEANS. The means of transformation are measured in terms of the skills and knowledge involved, the tools and the supporting methods. The knowledge related to and utilized in the transformation is difficult to be measured, because it is in the tacit form in the minds of the employees in the participating functions and organisations. In order to fully understand the skills and capabilities involved in the transformation, we should interview all the participants and profile their skills as well as analyse their contribution to the different phases of the transformation. As the transformations in the interviewed companies had already been carried out with a varying success, this was not possible. Also the effort required in the monitoring of the people and their contribution would have been vast in comparison to the number of companies.

Instead, the participation of different functions can be regarded as a means of transformation that can be studied on the basis of the interviews as well as the cases. Also, the developed configurable product family in itself and the articulation of the related knowledge, in the supporting methods and tools, are the means of transformation, which can be studied with reasonable time and effort. Moreover, by examining the participation and the results it is possible to from the commensurable measure of the means.

Scope of transformation: direction and commitment

The *status quo ex ante* in the companies was being categorised into three cases, which were make to stock production of standard products, projecting of engineer-to-order, unique products, or a mix of them. This means that in the Figure 29 on page 91, the company's sales-delivery operations could be located either at the inner or at the outer lane or as a set of many lanes, respectively. The last case represents the existence of a variety of product categories and the sales-delivery processes in a company. Thus, the approach to configuration oriented sales-delivery could be characterised as widening, narrowing or multiple depending on the *status quo ex ante*.

The other aspect of transformation scope is the breadth of the change, as suggested above. In practice, this means that the target of change is set in different parties, such as the organisations and locations of a company, market ares, as well as the changes in product lines. This measure is extremely case-specific, as the companies differ considerably in size. Also, their locations varied from domestic market, offices and factories to global presence including not only sales but other operations, such as product development and production, world wide. The breadth of the approach is commensurated as presented above, however.

Table 9. The direction of the approach to configuration in respect to the targeted change

		The direction of approach to configuration		
		-multiple	-narrowing	-widening
The breadth of approach	Total change		I(F) & I(D)	I(C)
	Intermediate change	*C (2)[a], I(G), I(E)*	C(1), C(3), C(5), I(B)	I(A)
	Local change		*C (4)*	

a. The project was about narrowing, but it was constrained by standard products.

In Table 9, the approaches of companies according to the interviews as well as the case studies are structured according to the aim of the approach. The interviewed companies are represented with I(x), when the x refers to a letter of the case company. Similarly the case companies are represented with numbers, C(n). For example, the interview in Ponsse is indicated with I(F), consistently with Figure 8 on page 28 and table 8 on page 118 and the case Profile Vehicles with C(5), as it was the fifth case study. The "Case power plants" on page 120 can be regarded as a case 0, as it provides the point of reference and it does not refer to a single company.

In the table above, the most persistent transformations are indicated in bold letters as the companies had a long history with CPF. The interviewed companies I (**F, D, C,** and **A**) had a clear direction and a substantial transformation from the *ex ante* situation. The case and the interviewed companies with italic letters, i.e. the interviews *I(E)* and *I(G)* as well as cases C*(4)* and *C(2)*, exemplify the situations of complexity in transformation; indefinite direction or indecisive set up for development project. The remaining cases (1, 3, and 5) as well as the interview (B) express the situation somewhat intermediate to these two extremes.

The categorization above is used in the following tables for relating the scope of transformation to the development of configurable product families as well as to the updating of the product family structures and the approach of sales-delivery in each of the companies.

THE DEVELOPMENT OF CPF. The development of configurable product families can be characterised as a project, a number of consecutive projects, or an evolution, where the strict beginning or the end is unclear. Also the long time spent in evolution separate the cases of evolution from the consecutive set of development projects. In Table 10, these characteristics of development are related to the scope of transformation, which are categorized with the above mentioned classes of clear, intermediate, and complex change.

Table 10. The scope of approach to configuration in relation to the development project

		The scope of approach to configuration		
		complex	**intermediate**	**clear**
The development of CPF	**clear project**	4	3, 5, B	F, D, A
	evolution, e.g. through mergers	E	1	C
	many separate attempts	2,G		

Table above shows that the clear or even the intermediate scope of transformation often leads to a clear project. This means that a company makes a relatively quick narrowing or widening approach, but not both at the same time. However, as there are two cases and four interviews to support the statement, there are also two exceptions of it. In Datex-Ohmeda, I(A), the company that kept standard products in their offering, the developed configurable product line represented clearly the widening approach. In

Valtra, I(C), the transformation took a long time and it included a merger with the Swedish competitor, but the approach was clearly a widening one. In the Tamrock case, C(1), the scope of development was unclear, as the company was delivering manually configured and partially engineered products as well as there seemed to be no clear beginning or end of the project. Also in Sisu Terminal Systems, I(B) the development project was prolonged.

However, the rest of the cases and interviews represented the situation of complex scope and/or a number of small attempts to approach configuration. Even a clear project, such as the case Metso Paper, C(4), could not produce a transformation, as the scope of the case was narrow (a subsection in a complex product).

THE UTILIZATION AND THE POLICIES OF UPDATING MODULE SYSTEM. As number of of the projects did not reach the harvesting phase, it may be not correct to refer to this aspect of module system as "updating". However, the created module systems were either very strict, when the developing of new modules as a part to it was clearly constrained, or loose, when *ad hoc* non-modules were frequently used. Thus, the module system is characterised as open or closed.

In the first situation, the product structuring policies dominated design. One example of such kind of policy was the constraint of backward compatibility in Ponsse, I(F), and Valtra, I(C), where the new versions of modules and components were taken into production with a flexible approach. Therefore, in Table 11, the scope of approach is related to the disposition of policies for the module system.

Table 11. The scope of approach to configuration in relation to the updating of product family

		The scope of approach to configuration		
		complex	intermediate	clear
The module system	closed / open to one direction		B	F, C, A
	open / mixed allowing non-modules	2, 4	1, 3, E	5, D
	remained undefined	G		

Three out of four companies with a clear scope ended up with closed module systems, where the updating of modules was to a large extent controlled by internal and even external rules. The latter case applies in Datex, I(A), where the United States Food and Drug Administration (FDA) approves all the medical devices, which are to be used in the country. In the another interviewed company, Valtra, I(C), with widening approach the updating of module system was agreed upon in integrated reviews. The integrated review meetings were held twice a year, The meetings collected, reviewed, and selected for further development the suggestions for modules from sales and marketing, product design and development, as well as from production and supply. The representatives from all the mentioned functions were present in the reviews.

The companies with a narrowing approach had chosen different ways of controlling their module systems. In Ponsse, I(F), the updating was strictly controlled, as presented in the previous page. In Wärtsilä, I(D), the module system was open to non-modules, as the sales-delivery usually included engineering. This was also the case in all the rest of the companies in the same category, i.e. I(E) and C(4, 2 ,3 & 1). This refers to the definition of products in sales-delivery process that is presented in Table 12

The explanation to varying approaches with clear narrowing approaches may be the annual volumes of products as well as the product technology used. Without having the detailed numbers of annual production, it is only an asumption that the annual volume of diesel power plants is smaller than the volume of forestry machines.

CPF IN SALES DELIVERY. In sales, the definition of an individual product, whether it is a result of selection, configuration or design, is related to the scope of approach in Table 12. This relates the articulated knowledge to the sales-delivery process. However, the characteristics of the knowledge, such as the volumes of knowledge bases or the knowledge engineering technology applied, are irrrelevant and not analysed here.

The irrelevance is due to two issues. First, in only one company a configurator was being used at the time of the interviews or the case studies. Second, configuration knowledge dependends on the product family architecture and its complexity, defined from the configuration point of view. So, even if we had that kind of a measure for knowledge, it should be evaluated against the modularity of the case product. These two issues that characterise this research do not underestimate the need for measuring the configuration knowledge and modularity.

However, the scope of transformation is related to the utilization of the knowledge. This refers to the three types of utilization and articulation of knowledge. In first type, the knowledge is provided for the sales delivery process to such extent that no engineering is needed. In the second type, there does exist some articulated knowledge for the use of the sales-delivery process, but it does not suffice in all the sales-delivery processes. Hence, the involvement of engineering is needed, in some delivery projects. In the third situation, configuration knowledge is unarticulated – the sales-delivery process relies on the tacit knowledge the sales engineers.

Table 12. The scope of approach to configuration in relation to the sales processes

		The scope of approach to configuration		
		complex	intermediate	clear
The situation in sales	Selection or pure configuration		5, B	A, C, F
	Partial configuration or parametric components	2, 4	1, 3, E	D
	Engineering with informal support	G		

Table 12 shows that almost all the companies had been able to articulate some configuration knowledge for the use of sales-delivery. Actually, at present the interviewed company, I(G), does not reside in the lowest row. For example, the company provides its customers with a software for selecting the suitable control valve package. However, at the time of the interview, the company was selling and delivering products with many kinds of processes. In some of product lines the support for the sales was rather unarticulated.

From the companies that were applying pure configuration only one, i.e. Ponsse, I(F), had a narrowing approach. As it did not use a configurator at that time, the development project of the company was very successful. However, the product family architecture was not the composition of encapsulated modules in the part domain. Rather, the modules were abstract and usually functional items of sales that were related to parts scattered in the different assemblies. This approach relies heavily on the capabilites of assembly as well as the product data management system, which encompassed the relations between the sales properties and the alternative parts of assemblies. In the case of Profile, C(5), a similar approach was pursued.

Another quite successful company, I(D), with a narrowing approach did not utilize PDM system, but relied on partial configuration. In their case the architecture of a power plant family consisted of sectional modules, such as a filter unit of the fuel supply system. Alternative modules were semi-automatically selected and manually arranged to a lay-out according to the refined design instructions. This “Lego” approach was considered to save a large amount of engineering effort from detail design and also to enable a winning strategy on the market.

A common characteristics to both companies was the strict policy of utilising pre-existing modules instead of recursive inventions of the same kind in sales-delivery projects. Also, the plus modularity utilized by Sisu Terminal Systems, I(B), is actually a strict policy of offering only modules that do not have any constraints for the selection of modules of another type. Other companies, with narrowing approach had had a more vague scope and had not been able to define such kind of policies.

The means of transformation

The relation between development and its results, the means provided for transformation, is analysed next. The categorization remains the same as in the analysis of the scope, which suggested both the direction as well as the pace of change. Therefore, this part of the analysis is shorter.

THE DEVELOPMENT OF MODULE SYSTEM. In Table 13, the case of development is related to the charactistics of a module system.

Table 13. The development of CPF in relation to module system

		The development of CPF		
		many separate attempts	evolution, e.g. through mergers	clear project
The module system	closed / open to one direction		C	A, B, F
	open / mixed allowing non-modules	2	1, E	3, 4, 5, D
	remained undefined	G		

In clear projects with closed module system, interviews (F, A , B) and case (5), there was a strong driver for the project. In Ponsse, the PDM project and the owner of the company were driving the company towards more systematic operations. Also in Sisu Terminal Systems the idea of plus modularisation was assimilated and instituted by the chief excutive officer. In Datex-Ohmeda the development started as a “usual” product development project that addressed specifically to the modularisation. In Profile Vehicles, the systemization of production as well as the new organisational structure drove the product development activities.

Also in Wärtsilä the key to short and effective project were some of the key employees in product development. In the cases of Fastems and Metso Paper the project was carried out by the young lions who were not biased against new ideas, but who at the same time lacked the required authority.

The evolutionary approaches of Tamrock, C(1), and Rocla, I(E), were even more related to key persons. For example, in Rocla, I(E), the head of product development and the early adoption of 3D CAD were regarded as valuable assets for configuration. In Valtra, I(C), the early utilization of both 3D CAD and PDM, was acknowledged, but the integration of product development processes as well as the maturity of them was a conspicuous issue.

In the companies 2 and G, the lack of support from top management as well as the over-the-wall-thinking seemed to inhibit progress. For example, in the former, there were only two persons involved in the development project and both of them had a number of other duties at the same time. In the latter company, the development had frozen not only because of the disagreement of a the meaning of module but also due to the legacy products that prohibited the efficient utilisation of the product data management system.

THE ARTICULATION OF KNOWLEDGE. The result of a product development project is both information on the topic and knowledge of the solution to the case. In the development of a configurable product family, the result is articulated knowledge. The form of knowledge was in all but one cases not documented in a configurator. Instead, the PDM systems were utilized in many companies. In Table 14, the development of configurable product family is related to the utilisation of knowledge.

According to the table below, well-articulated knowledge is seldom the result of evolution or indicisive projects. Actually, four out of five companies with the approach of pure configuration were the results of clear, strategic development projects. Moreover, two of the most successful companies with a narrowing approach, I(F,B), had focused substantial resources in and/or an integrated approach to product development. This was also the case in the successful companies with a widening approach, I(C,A).

In the companies with narrowing approach where this was not the case, the focus of the sales-delivery process remained in partial configuration and/or in project specific engineering. Also, in some companies the clear distinction between different kinds of products, i.e. the classification of products to standard, configured and unique deliveries, was missing.

Table 14. The development of CPF in relation to configuration in sales-delivery process

		The development of CPF		
		many separate attempts	evolution, e.g. through mergers	clear project
The situation in sales	selection or pure configuration		C	5, A, B, F
	partial configuration or parametric components		1, E	3, 4, D
	Engineering with informal support	2, G		

THE RELATION BETWEEN RESULTS. According to the literature and everyday engineering beliefs the module system and the configuration knowledge form a pair in which the latter follows the former in structure as well as in complexity. This relation is being studied with the Table 15. There the articulation of the knowledge is related to the module system.

Table 15. The sales-delivery processes in relation to the updating of product family

		The situation in sales-delivery		
		Engineering with informal support	Partial configuration or parametric components	Selection or pure configuration
The module system	closed / open to one direction			A, B, C, F
	open / mixed allowing non-modules		1, 2, 3, 4, D, E	5
	remained undefined	G		

Among those companies that had progressed to the utilisation of configurable product families in sales-delivery, a distinctive aspect is the relation between pure configuration and a closed system. This means that the fully articulated configuration knowledge would not be possible with dynamic modularisation, i.e. when new modules are being frequently introduced. Rather, it is a case of partial configuration. There, configuration is supported with an incomplete description of the product family.

It is clear that there is a relation between the module system and the configuration approach. The only exception to this is the case C(5). However, the aim of pure configuration did not emerge in the case. Thus, the aim of sales-delivery process should have been moved to partial configuration or the focus of company changed to the stage of the development of independent products.

Observations and conclusions of analysis

From the above analysis it can be observed that ineffective transformations have either vague starting point and/or aim to quite limited change. As referred, common to them is the indefinite direction or indecisive set up. Therefore they are difficult to justify and realise. On the contrary, the effective transformations provide a bigger change with a larger scope. Plausibly, with larger scope the risks are also higher. Therefore, a conclusion is: if the scope is indefinite and there is uncertainty of the transformation, it is better clarify the scope than to make an unjustified effort.

Relational characteristics of transformation to CPFs

IN RELATION TO THE DEVELOPMENT OF CPF. Typically a short development project with large scope provides an effective transformation (see Table 10). An ineffective case of transformation breeds evolutions rather than a deterministic development project. Also, an ineffective case of transformation seems to lead to a number of small projects.

The clear and short CPF development projects often create fixed, closed module and configuration systems with clear and straightforward configuration process (see Table 13 and Table 14). Evolution and consecutive attempts usually end up to either dynamically changing, open module systems and failures to gain a long term benefit of CPF. The successful evolutive process often ends up to partial configuration, which is a typical solution for a projecting company.

IN RELATION TO PRODUCT STRUCTURING. Transformations with effective change and clear goal seem to lead to fixed, closed module systems without non-modules. The cases, which start with many kinds of sales-delivery processes are susceptible to failure in the definition of module system. Projecting companies have often the vaguely justified transformation scope and objectives; and they have to be able to apply non modules. (see Table 11)

However, partial configuration is a favourable option to engineer-to-order projecting, as it provides the standardised set of designs, in the form of sectional modules, as in the case of Wärtsilä, or a standardised architechture for a product family, as in the case of Fastems. The effect of both cases is the reduced amount of engineering required in and the improved situation of management in sales- delivery project. Both of these effects indicate a transformation from "Corrective interventions mode of operation" on page 66 to operations management.

IN RELATION TO CONFIGURATION KNOWLEDGE. A clear configuration process is more usual with an effective than with an ineffective transformation. Some companies still have many processes after the development, which may be an unfeasible situation. There seems to be clear relation between fixed, closed module systems and pure configuration in straightforward sales-delivery processes processes (see Table 15).

Projecting companies have often ended up to open module systems with partial configuration, which is a challenge to configuration management and product policies. However, the effects of partial configuration are positive, in the companies that have managed with this.

Summary of the observations

The companies, which had an effective and justified transformation, often had a short development project with large scope. The result was usually a fixed module system supporting straightforward configuration process.

The companies having ineffective transformation or unjustified project often ended up to an evolutionary development process providing an open module system for partial configuration process (often accompanied with other kinds of processes, e.g. engineering) in sales-delivery projects.

Based on the evidence, it is feasible to postulate that there are strong relations between the transformation of projecting business and its means. Therefore, the transformation from projecting into systematic customization in sales-delivery process has to be aligned with the development of a configurable product family, the product structures of the family and the methods of configuration that define the individual instances of the family.

Conclusion and Discussion

This chapter concludes the results of the previous chapters. It is the moment of looking back and answering the research questions (see page 14). In the following chapter the concluding answers to the research questions are made one by one. Moreover, the validity of evidence and the novelty of the conclusions is being examined and suggestions for further studies indicated. The chapter closes with a set of remarks on the observations, suggesting some common approaches to projecting companies which are aiming at the utilisation of configurable product families.

"If you want a happy ending, that depends, of course, on where you stop your story."

-Orson Welles

Transforming a company from projecting to systemic customization cannot be done gradually with a step-by-step approach. It has to be executed with an integrated manner where the different functions and organisations of a company participate to the transformation. This is the case at least if configurable product families (CPF) are considered as the means of the transformation. However, results from practice indicate that CPF is a viable means of the transformation.

Conclusions on the research questions

First question: Differences in the management situation

The difference of the management situation in the sales-delivery project of an engineered-to-order product and the comparable configured-to-order product can be explained with the dispositions within the sales-delivery process.

An engineering design process is iterative and more time- and resource-consuming than a product configuration task. The engineering changes take time and their propagation cannot be anticipated as the standard product structures, common to all delivery projects, are missing. This leads to the corrective interventions mode of operation that is both inefficient and difficult to manage. The project management situation evolves from one stage to another, as the product design has dispositional relations with the tasks of the project. The management situations include not only complexity and variation, but also risks and ambiguity. The usual project management methods, such as the Critical Path Method, are not adequate means to maintaining control over a project.

Product configuration utilizes standard structures and elements that are common to all the delivered product individuals in a configurable product family. As the changes are automated and their effects can be anticipated, the time required to execute a change is shorter and the management situation of a project is either complex or varying. This indicates that the usual project management methods are sufficient, even when the sales-delivery project applies partial configurations.

Second question: The importance of managing relations

In general, it is important to relate the activities of a sales-delivery process to the development of configurable product families and the related configuration knowledge. The explanation to this comes from the theory of dispositions as well as the alignment of activities, knowledge, and product structures in practice.

Configuring a product definition depends on the configuration model that is applied recursively in the configuration task. The model contains the knowledge on the standardised, common structures and elements of a product family. Both the configuration knowledge model and the product individual produced according to a configuration instance are usually technical systems.

Logically, the relation between these two systems cannot be overlooked/ ignored in the development. The theory of dispositions explains the indirect relation between the activities of the product life-phase system. The dispositions with the development of configurable product families and their utilization in a configuration task are similar to dispositions of product design and the life-cycle stages of the product. Similarly to the life-cycle phases of a product individual, the configurable product family passes through a number of life-cycle phases. The configuration task is a recursive phase in the life-cycle of CPF, similar to the use phase of a product.

As the activities of configuration are dependent on the knowledge model and the knowledge model dependent on the structure of CPF, the relation between them cannot be omitted. Both the cases and the interviews indicate the importance of this relation in the development of CPF. In three of the case studies, the relation was omitted and problems emerged in sales as well as in production. Actually, the problems prevented the utilization of the developed CPF. In one of the cases, the main idea of the project was to improve the co-operation of product design engineering and sales in projecting. Moreover, two of the most successful interviewed companies utilizing a narrowing approach emphasized the importance of integrated CPF development.

Third question: The relation of means and scope in transformation

In this research, the scope of transformation are the product development and sales-delivery processes and the related sub-sets of product assortment. The means of transformation in projecting are the development of CPF, standardisation of CPF structures and the articulation of configuration knowledge. The means are related to the scope of transformation as indicated by interviews and case studies (see: "Summary of the observations" on page 151).

Discussion on the conclusions

The novelty of the research results

As mentioned in the introductory chapter, the author is not alone in this field. The results of other researchers in the overlapping studies are not contradictory with this research. Even as the application of CPFs in the projecting context has been examined by others the transformation of a company in the context has not been the leading theme of the studies mentioned. Probably the most similar studies are the Ph.D. dissertation by Miller, [2000] and the Lic. Tech. thesis by Tiihonen [1999]. The case description of Hollola Roll Finishing plant, see chapter 9 in Victor et al. [1998], presents a similar study. However, the author argues the research is novel in a number of dimensions:

- the number of the examined companies is large in comparison to some of the previous reports
- the differences within the companies are substantial
- not all the cases are successful
- the point of view is different from the above mentioned studies

SWOT-analysis of the research evidence

In Case Study Research, Yin [1994] lists six sources of evidence:

• Documentation	• Interviews
• Physical Artefacts	• Participant Observations
• Archival Records	• Direct Observations

Three sources of evidence from practice were utilized in conducting this research, as indicated with a border on the list above: the seven interviews in companies, direct observations in three cases, and participant observation in two cases.

All sources of evidence, however, have generic strengths and weaknesses, as Yin [1994, p. 80] indicates. The strengths and weaknesses of the applied and the omitted sources of evidence are further classified in a following SWOT analysis. As the other sources provide possibilities for further studies, their strengths and weaknesses are considered opportunities and threats. It is based on the characterisation by Yin [1994] and the observations of the research process.

The strengths of the applied sources of evidence. Interviews have a target and, therefore, they focus directly on the topic of the case study. In this research, the interviews were focused, i.e., a questionnaire was prepared, but the course of the interviews had an open-ended nature. In general, they provide an insight that is necessary at the beginning of the research. The interviews provided a good background for the topic of configurable product families.

The direct observations and the participant observations have firm roots in reality and, therefore, they cover the events of the topic in real time. They are also contextual sources of evidence and, hence, they cover the context of the event. In this case, the event was the development of CPF. On top of this, participant observations asevidence provide an insight into the interpersonal behaviour and motives, as a resercher "*is not merely a passive observer*" Yin [1994, p. 87] . Creating the insight was very valuable at the beginning of the research when the two cases of participation took place. However, the participation could have been more intense, as the meetings typically lasted only a half of a working day. Also, the final case, with Profile Vehicles, was something between direct observation and participant observation, as each of the meetings lasted at least one day. Also, a number of design decisions were being made at a very fast pace. In other companies, this would have taken considerably more time.

The direct observations, i.e., the instructing of M.Sc. students with their projects, were important for this research, as they provided a number of opportunities to actually observe the progress of the development of CPF and the related configuration model. Typically, each case of instructing a thesis required more than half a dozen meetings and intense e-mail discourse over the thesis versions. The theses also provide a formal documentation on the case and, therefore, a valuable source of evidence in the form of documentation is available. However, documentation as a source of evidence is dealt with later in this analysis.

The weaknesses of the sources of evidence. With interviews, there is a possibility of bias due to poorly constructed questions. In this research, however, the questionnaire was constructed and reviewed by a large body of experienced researchers. Thus, it is considered well constructed. However, the emphasis and the content of some of the questions would be different if another round of interviews would take place now. With interviews, there are also the problems of a response bias, inaccuracies due to poor recall, and reflexivity. These are the pitfalls of interpersonal influence. For example, an indication of the reflexivity and the response bias, was that we received a more positive insight of the situation of the company in interviews than in the cases. However, the different factors of the analysis are only related within a case or an interview. Thus, the cases and the interviews are balanced.

Observations, in general, are problematic, because a long time is consumed and only a selective sample of the phenomena is collected. Also, an "*event may proceed differently because it is being observed*" Yin [1994, p. 80]. In a case of an M.Sc. thesis, this drawback of direct observations is evident, as a student is typically not prejudiced and does not have a "not-invented-here" attitude. Usually, he or she does not have other tasks in a company, but a targeted concentration to the problem is available. Thus, the progress of development was in some cases probably faster than in a normal case of an in-house development project. Students also apply the methods which otherwise would have been rejected, because of their tedious and uncertain nature. However, a student is a novice and, therefore, requires support, guidance, and integration for his or her progress. The lack of any of these may delay his or her decisions and make them artificial.

The costliness of the observations is not considered a major problem here, because the development projects would have been carried out with or without the participation of a researcher. Instead, the bias due to the investigator's manipulation of events may take place. However, it is not a major problem here as the author was only one part of the puzzle, i.e., a member of a virtual team in the early development projects.

The opportunities of possible sources of evidence. As was mentioned earlier, the documentation with M.Sc. theses was produced. In general, studying the documentation is advisable, as documents are stable, exact, and they provide a broad coverage. However, one of the strengths of documentation, the unobtrusive character of the documentation as a source of evidence, was not possible. The M.Sc. projects were, of course, targeted to create documentation as a result of the case studies. Therefore, documentation is here considered an opportunity.

The archival records in the research project would be the PDM and CAD systems of the companies. Modern systems provide an interesting possibility to study, for example, the log data. However, in our research, the companies either did not have PDM systems or they remained undisclosed for the researchers. However, the M.Sc. students typically had access to rather confidental information. The PDM systems may provide an interesting source of evidence for further rsearch.

Typically, physical artefacts are a source of evidence in engineering research. They provide insight into technical operations. However, this research does not focus on the products with such a precision as is usually the case in doctoral dissertations. This may be considered a weakness.

The threats of possible sources of evidence. The design documentation of products and the corresponding archival records may pose a threat to research, if it is considered the sole source of evidence. For example, a product alone cannot provide information on the relative properties, such as modularity. Moreover, Yin [1994, p. 80] suggests that the retrievability, biased selectivity, reporting bias, and (the lack of) access are the weaknesses of documentation and archival records as a source of evidence.

Focusing solely on physical artefacts may be overrated in engineering design research, as a product does not contain its design rationale, but the result of it. Yin [1994, p. 80] considers the (poor) selectivity and availability of physical artefacts a weakness of physical artefacts as a source of evidence. This may be a problem with the large investment products of the case companies.

General factors related with the validity of the research

Long period of time. The research was conducted in a long period of time. This has similar characteristics of strengths, weaknesses, opportunities, and threats as the collection of evidence has.

The **strengths** are that the author acquired substantial experience and insight in the field, the topic is still actual and the documentation of the cases is still mostly available.

The **weaknesses** are that the material (the interviews and earlier cases) was becoming old and the documentation of the case studies is not uniform.

Threats to the validity of evidence is that the business context is continuosly changing, as indicated in chapter “Situation in industry” on page 5. There is also a potential personal bias of the author and the limitations of memory.

The **opportunities** provided by the reasearch are that the phenomenom of product configuration as such remains raher the same, with most of the companies, the author has an ongoing relationship via current projects and the author considers the objectivity growing with the time instead of the increase of personal bias.

The analysis method of the results. The method of analysis is not made with a strict protocol or factor analysis.This is due to the variety of situations in companies and the incoherence of the material.

The **strengths** related with this is actually the variety of cases which ensures the qualitative verification of the results.

The **weaknesses** are the inconsistencies: the pieces of material are not proportional to each other.

The **threats** with this are that the idiosyncracies of cases may be dominating and the indipendency and the generality of results may not be sufficient.

The **opportunities** are provided with the commensuration of the results by relating them with the generic business objectives.

Suggestions for further research topics

Instead of a meticulous focus on a small number of aspects on the development of product families, the research presented here is an overview of the achieved insight. It combines the results of a number of case companies and interviews, analyses them from a variety of viewpoints, and ends up with a description of the phenomenon. The need for further studies is therefore evident.

Configuration modelling methods. In the research, the topic of configuration modelling was only briefly reviewed. The complexity of a configuration model, however, is a practical problem in its maintenance and use. Therefore, the configuration modelling methods should be related to the life-cycle of knowledge and the corresponding product family. Also, the usability of configuration models, their interface to sales and production, is an issue that is directly related to the implementation and utilization of configuration in a sales-delivery process. The practical problems related to this should not be passed by with the notions on the resistance of change.

Configuration with design in projecting. Configuration and design are, due to the clarity of expression, often regarded mutually exclusive options in the defining of a product. There are a number of researchers and practitioners who relate product configuration only to mass customization. Here, product configuration has been presented as a viable option in the engineer-to-order approach in projecting. However, it is not a problem for all the solutions related with projecting. Thus, more flexible manners of utilizing configuration as a part of engineering design in projecting should be studied.

Product structuring. In this research, the development of product families has dominated instead of product structures and architectures. However, relating the architectures more precisely to configuration modelling would be necessary. Also, the complexity and usability of product family structures in relation to the activities of the sales-delivery process is a topic worthy of research.

In this research, the author did not recognize product modularity as a decisive factor in the transformation of a company's processes. However, evidence on the topic is scarce and a more specific study on the cause-effect relation between a specific kind of a sales-delivery process and a certain kind of product structure is welcome. From an engineers' point of view, it would be interesting to receive a report on how to systematically innovate product structures and modular architectures that meet the configuration and the sales-delivery processes in such a way that anticipated effects are created.

Common remarks on the observations

The main differences between the development of independent products and the development of configurable product families (CPFs) are the standardisation of the structures and elements as well as the articulation of configuration knowledge in the latter, which is missing from the independent projects.

The problems of a projecting company include the various uncertainties that emerge at the different stages of the sales-delivery process. The problems have an effect on each other in such a way that both the product design and the project plan are under continuous change. Thus, projecting is a very resource-consuming and unproductive way of selling and delivering products. Developing product families was considered as a means of transforming the sales-delivery process towards configuration as well as a means of gaining the improved performance in the sales-delivery process.

In configuration, not only the design reuse but rather the effects created by dispositional mechanisms of reuse improve the overall productivity of a company. Therefore, integrated product development was considered a suitable method for the development of configurable product families. Reasoning based on the characteristics of design, projecting, and configuration as well as the observations from industrial cases support this hypothesis.

The model of integrated product development is considered a suitable method for the development of configurable product families, because it relates the business objectives with product development. Reasoning based on the characteristics of design, projecting, and configuration as well as the observations from industrial cases support this consideration.

The definitions of configuration and configurable product families vary in the industry, as companies are either applying pure configuration or partial configuration. However, configuration is related to a minimum number of employees in sales-delivery. The utilisation of partially configured product families can lower the sales volume needed for justifying the development of configurable product families, even though product design is not entirely removed from the sales-delivery process.

The scope of transformation

The companies that have succeeded with the utilization of configurable product families in sales-delivery processes have been focusing on product development. This seemingly trivial result is not the case in all the companies that had been aspiring for a transformation in projecting. Instead of having a sufficient commitment to a development project, the direction in terms of changes in the sales-delivery process or at least in the sales activities are also necessary.

Apparently, companies do not have a proper understanding of the relations between a configurable product family, produced configuration knowledge, and the documentation of the knowledge as well as the sales-delivery process and the required support. In a development project, the focus often lies in support instead of the processes that require the support.

The objectives of transformation

The direct effects of utilizing configuration include faster sales-delivery processes with reliable sales estimates and margins. The indirect effect is the decrease of costs and waste. Some companies also reported that gaining a share of niche markets is an asset. Maintaining the efficiency of sales-delivery processes as well as increasing possibilities to focus the investments are also considered results of transformation.

From the design point of view, the elevated product quality and improved design performance are considered the enablers of the sustainable growth of business. However, one company emphasizedd that the dynamic situation on the market and in technologies had inhibited the growth of business and started to corrupt the product family. This had caused shorter life-cycles of product families. Yet, a persistent product architecture was considered an asset that provides a means for the management of product families.

In sales and marketing, the gained effects were that the quotations were based on actual information on the product as well as on the related properties, such as cost. However, most of the companies relied on a manual process where values for the set of properties were defined and related to the properties of items.

From the production point of view, productivity and control were the most important benefits of configurable product families. This appeared with the alignment between the market need, the product family, as well as the production capabilities. Also, detailed and reliable estimations, lean production, and late-point differentiation were the results of transformation.

The means of transformation

According to the interviews, the transformation to utilizing configurable product families was characteristically highly dependent on product development. An integrated approach is favourable, not only in the sense of Andreasen et al. [1988], but also in such a way that the development of product families is integrated to the documentation of configuration knowledge. Projecting companies regarded integration in product development as particularly essential. Similarly, inn process re-engineering and transformation, taking discrete steps of change at a fast pace was considered necessary. In the development of configurable product families, multiple representations and views are needed.

The planning of configurable product families is manifested in product family policies. These policies have to have a dispositional effect for the sales in order to reduce unnecessary variety. There, standardisation by the generalisation and integration of properties, structures, and parts was considered the most effective means. Generic product structures, which differentiate the properties of sales and technology, are another means of implementing product policies.

As only one of the interviewed companies was utilizing a commercial configurator software at the time of the interviews, a minimum support for configuration was regarded as product data management. There, the most necessary issue is to have correct and up-to-date part data. Inability to enhance product data management can prevent the transition. Certainly, the development project should not be driven from the perspective of configuration software. Instead, the involvement of business management and his or her leadership is fundamental to ensure the clear target and the commitment of actions for reaching the target.

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