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CHARACTERISTICS OF PRODUCT FAMILY DEVELOPMENT IN INDUSTRY

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Abstract

It is claimed that the characteristics of practical product family development for configuration are not clear enough for the academia. Therefore, the characteristics are studied with three participative case studies and interviews in seven companies. The industrial cases are being studied from four standpoints (as cases of business, development, modularisation and configuration). The summary of the characteristics is reported and an analysis of the cases is given. The need for relating the business process re-engineering to product family architecture is emphasised.

Keywords: Industrial case study, product families, modularity and standardisation, configuration

1 Introduction

Developing a product family and utilising it in configuring has an effect to the strategy and functions of the whole company. There the enabling function is product development, including modular engineering, leading to configuration. The development of product family requires supporting tools, methods and process re-engineering means, in order to enhance the productivity of engineering work [1].

Even though the tools and methods have been proposed for modularisation and configuration (see for instance [2] and [3]), we seem to lack a toolbox. From the appliers' point of view the research results in the field seem to be scattered. Recently some frameworks have started to emerge (see for instance [1] and [4]), but only a little attention on combining an ordered set of tools and methods for developing business with modularisation and configuration. Moreover, the level of utilisation of the existing support is unknown. Besides, the characteristics of development in practice seem to be obscure to the academia.

In this article the experiences from consulting, surveying and observing practical product structuring cases in industry are being compiled. The objective in all these cases has been to compose common origins for a consistent set of potential product family individuals, i.e. configurations or designs.

2 Methods

Participative case studies were utilised as the main research method. In this approach the research process consisted of reciprocal phases for data collection and interpretation. This can be characterised as “…a cyclic or spiral process, which alternated between action and critical reflection” [5].

2.1 Methods in data collection

The data was being collected with two approaches. Our role in the first approach was consulting three development cases; thus, it was a matter of participative action research. In addition to participating into the development work, we also took part into advising, instructing and supervising seven M.Sc. projects. The second approach was to conduct one-day interviews in seven companies. For these interviews a protocol was developed according to case study research principles by Yin [6].

2.2 Approach in data analysis

We studied the product families from four different standpoints: business, development, modularisation and configuration. The business standpoint consists of business case and purpose descriptions, reviews on the effect on the company, business approach and context. In the development standpoint we studied the development process definition, organisation, scope and commitment, proceeding and duration. The modularisation standpoint consists of module system definition (according to classification of [7]), modularity type ([8]) in the embodiment of product families, modularisation methods and tools as well as effects on engineering. The configuration standpoint is characterised by the context of configuration, the knowledge documentation, methods and tools, the point of differentiation and the effect on engineering in the delivery process.

3 Description and analysis of case studies

The mentioned three cases we participated had the projecting business approach in common. In an earlier paper we specified the problems related to the increasing number of projects in projecting business. As a solution to these problems, we suggested a subset of design re-use we call partial configuring [9]. The following cases aimed at partial configuring.

3.1 The case 1

In the company the main idea was to change the way of engineering re-use, which had been based on the archives of individual engineers. The case was supposed to have an effect mainly to the electric engineering in the main engineering office, but it required a global systematisation of technical documentation within the company. The resources allocated for the development project were comparable to a typical delivery project in the company. The development project was a third attempt to modularise electric engineering in the company.

Some general plans for the development project had been defined, but actually the project execution was iterative. Many issues emerged during the project. For instance, the need for the guidelines of module engineering as well as the need for structured sales material were recognised and defined only during the latter half of the project. The project resulted to a circuit diagram module system, a configurator and a totally new way for designing the electric controls of cranes. The project was mainly planned and executed by experts in electric engineering and IT within the company. Thus, attention was paid onto developing the configurator and the module system, but hardly any business re-engineering and very little internal marketing efforts were being done. According to our knowledge the company did not reach the utilisation phase. However, first trials indicated that the objective to reduce electric engineering to one tenth from the original situation was attainable.

The target of the project 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 [8]. The module system had a pre-designed structure. The modules (i.e. the drawings) were on the one hand related to actual controlling functions of a crane and on the other hand elements for an electric CAD system. Cut-to-fit modularity meant in the case modules referred to parametric parts. The part parameters in bill-of-materials could be varied according to the specific requirements of configuration case, while the requirements were set by e.g. environment conditions and local legislation for crane site. 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 participating electric engineers.

In order to support the back office [1] configuration process, a module library containing drawing modules and the configurator were being developed. The configuration rules were documented separately and programmed into the configurator. During the project no link between the sales form and the configurator was made. The configurator 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 for the manual customisation. Some of the modules were pre-designed in the development project. However, many modules were supposed to be designed in the customisation phase and then be added to the module library for further re-use.

3.2 The case 2

The case company had been projecting rock-drilling machinery since 1969. Due to company mergers there were legacy products and redundant parts, which caused unnecessary variety and costs. Nevertheless, the company was aiming to shorter lead times with fewer costs. The company tried to face the problem with a global standardisation project in order to reduce number of parts, and a local project defining modular architecture.

The company was already having a product data management (PDM) system and practising manual configuration in product delivery projects. However, the local project started with an analysis of the modularity of two existing product lines. The aim was to develop modularity and configurability in one factory and then extend it globally. Simultaneously, the company was also changing its PDM, ERP and CAD systems. Thus, the requirements and the possibilities of the IT systems were supposed to be taken into account.

The project was clearly defined; it had rather small scope and short time. The development efforts were organised stepwise. An integrated approach committing engineering design, production and marketing had been favoured. Not much attention was paid onto re-engineering the delivery process of the different product lines. However, the company had been re-engineering production plant just before the project.

The targeted module system consisted of assembly elements clustered according to the product functions and the corresponding sales properties. Thus, the modularity scheme followed the approach of e.g. Pahl and Beitz [7]. However, the embodiment was not modular, because the functions were related to systems, like drilling control system, which manifested all around the machine layout. But, component sharing and swapping modularity existed. A

DSM (design structure matrix) was applied, in order to represent the functional relations of the assemblies and to support the clustering according to their relations (http://web.mit.edu/dsm/). The idea was not to design a new embodiment, but to analyse the modularity in the existing products. The DSM indicated the integral embodiment of one of the two products. However, the project suggested that configurability could be enhanced without re-engineering the embodiment by depicting the existing relations and improving the understanding of the product.

No configurator was being applied, nor the configuration process directly altered. Instead, modularisation guidelines were being defined and the configuration knowledge was being systematised. The PDM system was suggested to be the enabling software for modular engineering.

3.3 The case 3

As a part of its business the case company had been projecting specialized machining centres over a three years period of time and had delivered a dozen product individuals. The company decided to accelerate the deliveries and improve the estimation. Thus, the management agreed to introduce systematic design re-use and change the way of projecting. More detailed analysis of the case is in reference [9].

The development project was clearly defined and managed. The organisation was a group of three new employees under the direct supervision of the engineering manager. The members of the group had separate sub-projects and goals serving the overall objective. The sub-projects were carried out in an integrated, concurrent way. Experts outside the group were consulted when needed. Several meetings of a supervising group committed managers to the project.

The management had recognised that the engineered to order deliveries could be categorised into four types. Basically, the four types had dissimilarities in the main properties. In the development of a modular product family a mixed module system was defined. The embodiment of the module system indicated characteristics of component sharing and swapping modularity. However, none of the embodiment types suited exactly to the classification proposed in [8], because the embodiment was similar to the case 2.

In the development of the module system, the functions and assemblies of the product structure were being specified and analysed. In this task, the variety in the delivered products was recognized as a useful source of product and market knowledge. Also, the potential customers and competitors were studied and experienced engineers were being interviewed. Lists were used to represent part-of structures and sales properties of the product. Design Structure and Late Point Differentiation Matrices were used in documenting the relations between different items of lists.

The module system comprised of three classes of structural elements defining the configuration context.

1. Alternative standard base units.
2. Standardised solutions corresponding to the sales properties with:
    a. alternative modules and
    b. optional modules.

3. Not pre-designed non-modules.

Engineering in delivery projects was composed of re-using standard parts, configuring and customisation tasks. In the end of the project, the engineering work had been organised according to module types too.

The module system was clear and no configurator was required. Instead, the idea was to embed the configuration knowledge into the product structure. Therefore, part of and kind-of lists, matrices as well as decision trees were used for the knowledge representation. However, problems with the long-term configuration knowledge management were evident. In the end of the project, about 3700 distinct paths, i.e. basic configurations, were possible in the graph.

3.4 Summary on the cases

The aim in all cases was to change the way of work in projecting, while the scope and context of the development project varied largely. The case 1 had most distinct scope in one engineering discipline, while the two other cases involved mechanical, electric, automation, and even software engineering. However, the case 1 was the most dependent on the other organisations (sales and engineering offices throughout the world). Also the size and position of companies varied a lot.

While the quick development approach of the smallest company (case 3) seemed to be economically beneficial, the development efforts in bigger companies appeared to have only a modest effect on the company as a whole. The implementation appeared to become the more difficult the bigger the company was. Therefore, the development projects were not scalable in implementation. In the cases 2 and 3 the people in charge could have a fulltime commitment to the development, while in the case 1 the development was done along with delivery projects. Moreover, the key to the apparent productivity in the case 3 might be the concurrent engineering approach. Also the re-organisation of design work was straightforward in the small organisation, when special attention was paid onto the processes. In the other two cases less attention was paid to the design work re-engineering in a settled, larger organisations. Even though the idea was to change the way of working, the bigger companies tended to neglect the process engineering, confusing project priorities and endangering the implementation.

Modularisation strategies were quite similar regardless to the company size (e.g. case 2 vs. case 3). All companies were aiming a module system with modules as functional elements. However, the context of configuration varied: drawings in the case 1, assemblies and systems in the two other cases. While in case 2 the aim was at fixed module system, the two other companies suggested mixed module systems. In all three cases indications of component sharing and swapping modularity existed. However, the other types of modularity [8] are not clearly perceivable. Instead, a configuration alternative or option quite often referred to many sub-assemblies in different places of the product layout. The projects were applying usual product development methods (e.g. inquiries and analyses). Only in the case 2 a review on product structuring theory took place. DSM has been used in every case, but it proved to be most effective in the smallest company. Only in one company the modularity was clearly related to the characteristics of past delivery projects.

Software support for configuration was being developed only in the first case. Any relations to success in projecting and existence of configurator were nonexistent. Instead, there was a danger of perceiving design for configuration as a design of configurator. In all cases the configuration knowledge was documented with conceptual (matrices, graphs) or textual (guidelines) means. The cases 1 and 3 indicated that engineering in projecting could be reduced by systematic design re-use. In both of the cases the idea was not to pre-design all the offered modules, but to design most of the modules only when needed in deliveries. This requires persistent attention in maintaining configuration knowledge, as in the case 1.

4 Interviews

For interviews we developed a questionnaire with ca. 140 questions. The questions themes were the definitions of products, the importance of configuration to a company, development project, product and engineering policies and procedures, the way of action (in configuration), support and demands for software as well as modularisation. The interviewed persons were business and engineering managers, designers, sales and marketing representatives and people from IT and production management. The questionnaire was send to the companies pre-hand.

Seven companies took part in one-day interviews, which were later refined by interviewers. The companies were configuring medical care equipments (A), terminal trucks (B), tractors (C), diesel power plants and engines (D), trucks and equipments for storage logistics (E) and forest tractors (F). One of the cases was about modularisation of industrial valves (G), but there existed no systematic configuration according to our definition (e.g. see [1]). Later the cases are referred with the letters in parentheses.

4.1 Business case in interviewed companies

Before applying configurable products, the case companies A and C had been producing batches of pre-engineered, fixed products. In the companies B, D and F the case had been projecting by pure customisation. Standard and customised products were being applied in the cases E and G. In most of the cases (A, B, D, G) the markets were global and companies had merged. Merging had been partially catalysing and inhibiting the modularisation in the cases C and G, respectively. It was seen as a challenge for the module system in the cases A and D. Configuring was most successful business approach in the cases C, D and F.

4.2 Development case in interviewed companies

In the case A the purpose of the development was to satisfy customer requirements better, which lead to a strategic change. Also in the cases B and F the company management made a strategic decision to apply configuration. In the cases C, D and E the configuring was seen as the only option and the decision was rather an evolution than a conscious choice. In fact configuring was seen as the enabler to survive in stiff competition and global markets. External (market) pressure initiated standardisation project in the case G.

The development process was well defined in the cases A, B and F. In other cases the process had been rather an evolution than a development project. In most cases the product engineering played a key role. However, many disciplines took part in the development of the module system and of the single modules in all of the cases. The scope of development project was larger in the cases A, C, D and F than in the cases B and E, where the companies started with only one product line.

4.3 Modularity case in interviewed companies

The modularity type was based on a fixed product family architecture in cases A, B, E and F. In the case D a mixed building block (referred as Lego) system was developed. Modules were clearly related to the functions in the cases A, C, D and F. In the case G at least six definitions for modules had been recognised in the development attempts. The case C was approaching dynamic module architecture, by allowing changes not only in modules but also in interfaces. All the cases showed component sharing and swapping modularity, even enabling re-configuration in the case A. The module system embodiment was however quite different. Bus and slot modularity emerged in the case A. The case B was based on add-on modules (accessory instruments). The sectional modularity emerged clearly in a case D. In other cases the modularity seemed to take the embodiment as functional systems like presented earlier.

None of the cases reported they had used special modularisation methods in the development process. However, different tools had played a role in some of the cases (module library in the case A, CAD in the case E and PDM in the case F). Most of the cases reported remarkable effects on engineering design activities. For instance, 40% of the engineering resources in projects were being saved and assigned to product development in the case C.

4.4 Configuration case in interviewed companies

In the cases A, C, D, E and F the configuration was based on modules. Non-modules emerged in the cases C and D, while parametric parts were being used in the case E. The cases B and G were clearly based on selecting or customising parts and part attributes. Only two companies were utilising a configurator and the other was made *ad hoc* for the case. Other companies relied on structured sales forms and manuals. However, software support was utilised (CAD in case E and PDM in case F). Companies were also starting the PDM and configurator projects. The maintenance of configuration knowledge was seen as an emerging problem in cases A and D, while the companies in cases C and F had already been dealing with the issue.

The cases A, B, C and F were manifestations of pure configuration (i.e. no *ad hoc* designed parts were allowed to emerge in deliveries). Different policies for developing modules that corresponding to project specific customer requirements emerged. Most strict in this was the case F and most flexible the case G. Partial configuration was being applied in the case D. However, different production and delivery strategies and corresponding product lines existed in the cases A, B, E and G.

5 Results

Due to the experience gained in ten diverse cases we have recognised different approaches to apply product families and configuring. Six of the presented cases start from pure customisation and projecting, while the approach of two interviewed companies is from the serial or batch production of standard products. Typically, the projecting companies did not recognise any other ways to enhance their productivity and competitiveness. The companies of the second category aimed at improving customer satisfaction and reducing work in progress both in product development and in production. Six companies competed in global markets, while three companies were operating in a few countries and one had only a domestic presence with the configurable product family. The best rate with success was in the last four cases, which experienced configuration as the strategic tool in competing with bigger, global companies. These, however, are susceptible to mergers, which had occurred in six case companies. Only one company had experienced merging as an opportunity, while two saw mergers as challenges and one had experienced as an inhibitor for product structuring.

Typically, the development of product family for configuration did either lead to a total change in business or failed in implementation. Apparently, the problems in modularisation and product structuring or configuring were not the usual reasons for failures in implementations. Only one company did not reach consensus over module system and there the major problem seemed to be the handling the multiple views / superimposition in product structures (see [1]). More likely, the problems appear in re-engineering the business processes and concentrating on product structures and information technology instead of motivating and educating the personnel.

Fastest development cases seem to have a clean sheet approach in the beginning, but most of the cases cannot start from scratch, because of the existing product assortment, standards, or even legal regulations. The development processes where sorted into three categories: clear project, many distinct attempts and evolution. The well-defined projects of four case companies seemed to pay of best, while the companies with many attempts hardly seemed to reach the harvesting phase. However, two companies with an evolutionary approach were also successful, but these cases had started already in eighties and were facing a situation where competitors were catching up the achieved lead.

The companies had also three typical approaches in the scope of development project. Four companies were making significant changes in their operation and modularised the majority of their product portfolio, four companies made minor changes in operation and modularised only a section of product portfolio, and two companies were altering either one product line or a section of engineering. The most successful cases seemed to be the cases where the scope was large. However, change in one product line seemed to be economically sustainable too.

In the beginning of the most cases there did exist a large number of overlapping products, system and part designs. The reasons for this legacy might be the customisation in projecting and the mergers; however, unneeded variety has to be unified. Four cases seemed to rely on functional modularity and a fixed module system, while three companies had mixed module systems containing also non-modules in configurations. Two companies had a system where minor changes in the product architecture and/or layout existed together with dynamic introduction of new modules, but only one appeared to be successful. Reliable option seemed to be a fixed system with modules as function carriers.

Component sharing and swapping existed in all cases and it appears to be a default property in module systems for configuration. Other modularity types also existed in the embodiment of product families, but none of them appeared to be superior. Most of the development cases did not utilise the methods and tools proposed by the academia. Rather, the product structuring and documentation methods seemed to be of an *ad hoc* nature.

Only three companies were having configurators and two of them were tailor-made in/for the company. Others relied on structured sales forms and support from CAD and PDM systems. Several projects implementing PDM and configuration systems were starting during the interviews. However, remarkable improvements in engineering productivity had been attained in projecting and a versatile product family was being offered with paper documents.

In the following table the experiences have been combined in the four different domains that were being studied. Green cells (☺) implicate success in the domain indicated in the first column of the table, while yellow cells (😐) show difficulties in the related domain. The red coloured cell (☹) indicates major problems in a domain in the related case. Thus, the "traffic lights" show the degree of complexity a company has faced in each of the domains.

Table 1. A compilation of the cases and interviews

	Int. A	Int. C	Int. F	Int. D	Case 2	Int. B	Int. E	Case 3	Case 1	Int. G
Business	☺	😐	☺	😐	☺	☹	☹	☺	😐	☹
Development	☺	☺	☺	☺	☹	😐	☺	😐	☹	☹
Modularisation	☺	☺	☺	😐	☹	☺	😐	☹	☹	☹
Configuration	☺	☺	☺	☺	☺	☹	☹	☹	😐	☹

Three interviewed companies were successful with their approach. Characteristics to them were a clear and stable business environment as well as success in product structuring and configuration processes (including the changes in business processes and methods). The company D was making also successful business with configuration, even though it had a complex business environment: susceptible to international trends. In that company the modularisation strategy was somewhat complex including sectional modularity and non-modules. The companies in cases 1 and 2 as well as the interviewed company G had problems in developing modular product architectures. However, experienced people in manual configuration managed the complexity of product architecture in the case 2.

It is worth of noticing that the interviews seem to give more positive results than the cases of participatory research. The reason for this may be that in interviews the companies do not always disclose all the problems they have, while the real problems are being faced in the consulting cases.

6 Key conclusions

Industrial cases on product family development were studied. Most problems were related to the implementation of new business processes. Many companies have underestimated the needed scope of the development project in a complex business environment. Consequently, sets of small, consecutive projects have been executed. The companies realising the effects of the development project on the business as whole have been successful. Relating the business process re-engineering to product family development seems to be an important issue.

Modularisation appears to be a major problem in more than half of the case companies. The core issue in many cases is to unify a number of overlapping products to one product family. Therefore, support to classification, composition and multiple viewpoints is needed. However, only a few of the product family modelling tools are able to do this [10]. The most advanced companies have found out that the product families and module systems should be developed as open systems in order to support iterative nature of the development and the maintenance of systems. As the means for documenting a product family seem to be left aside by most of researchers in the field, there seems to be an alarming gap between the practical needs and design methods.

Configuration seems to be a problem in half of the studied cases. Feasible solutions for documenting configuration knowledge as well as correct configuration context (i.e. what is being configured) seem to be characteristics to successful cases. The successful companies indicated that applying configurable products has a very positive effect on the business as a whole.

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