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MODULARITY IN USE - EXPERIENCES FROM FIVE COMPANIES

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modular products, product families, product platforms, industrial cases

Abstract:

Modularisation of a product family may be done for various reasons, to various degrees and by using various approaches. A modular product family may be the result of a conscious redesign of an existing family or the result of a long term work where the company has grown into the modular system. The purpose of this work is to study experiences of modularity in five Swedish companies. This pilot-study describes some of the issues associated with modularity as well as identifies areas of interest for researchers of modular product design. Each of the studied companies has highlighted interesting aspects of modularisation. Generally, the importance of organisational changes was seen as a central issue; either the product structure raised the need for reorganisation or the reorganisation accentuated the need for a product restructuring. However, also major changes in technology had or will have effect on the product structure and the organisation. For example, electronics and software have given new ways to locate functionality and generate variety, which created both opportunities and challenges.

1. Introduction

1.1. Theoretical framework

The idea of modular products is far from new. However, modularity has during recent years gained actuality due to the so-called mass customisation and the need for shorter development times. The problems of time to market and product variety are often discussed in both industrially oriented and academic literature, where it is stated that modularity is one of the ways to handle these problems, e.g. [1]. A modular product potentially gives many benefits such as shorter time to market, better handling of product variety, improved quality, etc. However, the creation of the right modularity may be a difficult task when dealing with complex system.

Modularity is often associated with the terms of *product families* and *product platforms*. Product family normally refers to a set of individual products that share common technology and address related market applications [5]. On the other hand the term product platform seems to carry various meanings, spanning from descriptions that mainly focus on the artefact to descriptions that cover larger scope, e.g.:

A product platform is a set of subsystems and interfaces developed to form a common structure from which a stream of derivative products can be efficiently developed and produced [5].

A platform is the collection of assets that are shared by a set of products. These assets may be divided into four categories: components, knowledge, processes as well as people and relationships [9].

In a similar context the term *modular system* could be used for the total set of modules creating the product variety, e.g. [7]. Figure 1 illustrates the distinction between modular system and product family.

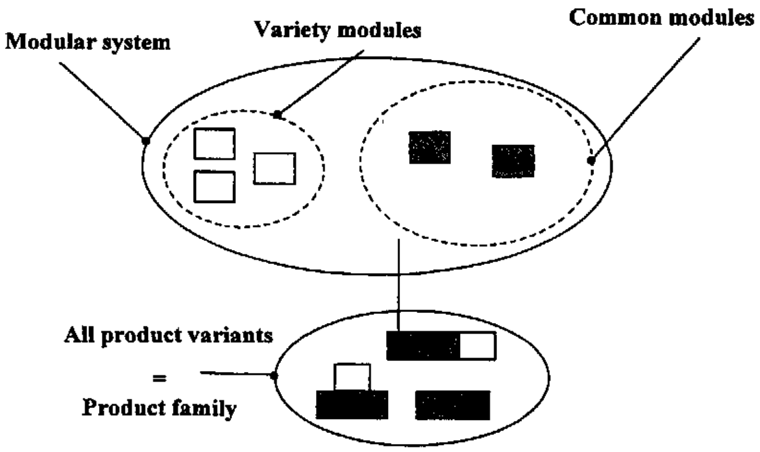

Figure 1. Illustration of modular system and product family.

The structure of the modular system may be quite different, depending on type of product and approach of the company. Typically, modular products may be grouped in three types of modular systems, namely: slot, bus and sectional modularity [11]. In the sectional system, the product variant is configured rather freely from modules that can be combined in several manners by standard interfaces. In bus modularity, the modules have standard interfaces that allow the attachment of various modules in various positions to a base module. Finally, slot modularity refers to a system where each type of module is connected in a certain position by a standard interface.

Due to achieved benefits by companies that practise modular design, much research has lately been devoted to the area. Some researchers describe how modularity may be characterised in terms of the relations between functions and components, degree of dependence between units etc., whereas others have delivered prescriptive methods, guidelines or evaluation methods for modular design [3].

1.2. Purpose and approach

Depending on type of company and business situation the modularity used may vary considerably. The modularisation may be done for various reasons, to various degrees and by using various approaches. The modular system may have been created by a conscious redesign of a product family or it could be a result of a long term strategy, where the company has grown into the modular system. Furthermore, companies will define modularity differently as well as they will stress different types of experienced benefits.

The purpose of this study is to investigate the use of modularity in manufacturing companies. The intention is to answer some of the questions associated with modularity. Moreover, the study is intended as an empirical background for further research by identifying interesting issues within the area. The study focuses on questions such as:

- What does the modularity look like?
- What benefits were achieved with the modularisation?
- How are modules used in the operations? What parts of the company have been affected by the modularisation and how did the idea of modularisation evolve?
- How much have changed from previous product family to the more modularised family? Why and how was the change initiated?
- What were the problems with the implementation?
- How are the interfaces created?
- How are interfaces handled over time? How is the modular structure maintained?

This pilot-study is based on interviews of representatives from five manufacturing companies; performed either by group or by individual interviews. The interviewees were technical personnel from both the design and the production departments; predominantly people such as project leaders, group managers etc. Both the group and the individual interviews have been carried out in a semi-structured format, where a list of interview questions ensured that all issues were touched upon. The interviews covered many aspects of modularity, in order to capture the aspects of special interest in each company. The interviews were performed during the autumn of 1998.

Because both organisations and products of the studied companies are rather different, it may be difficult to directly compare their experiences. Still, the individual experiences of the companies taken together further describe how modularity is created, implemented and used.

2. Company experiences

2.1. ABB Robotics

ABB Robotics is the world's leading developer and manufacturer of industrial robots. Most of the part fabrication is done by suppliers and consequently the own production is mainly concerned with the assembly of the parts. Sales to end customers is done by ABB Flexible Automation, other system integrators and OEM-customers. The products that ABB Robotics sells and delivers are units, which are based on a manipulator, control unit and software.

The major customers of industrial robots have been the automotive industry. During the late eighties and the early nineties ABB Robotics emphasised cost reductions. However, since the demand of robots in the automotive industry has diminished, factors such as working environment and ease of installation has increased and the relative cost for automation has decreased, ABB Robotics sees the opportunity to increase the sales to other industries. Due to the anticipated need for larger product variety, the company has started to think in terms of modularity in order to place more variants on the market.

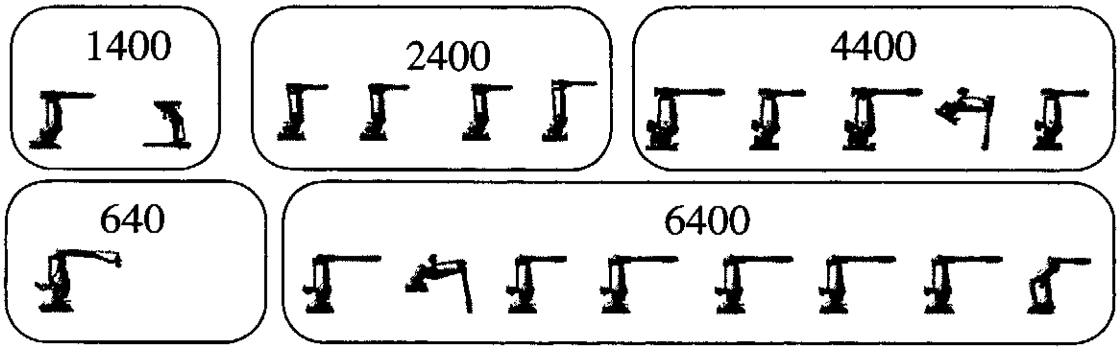

Figure 2. Some of the current product families.

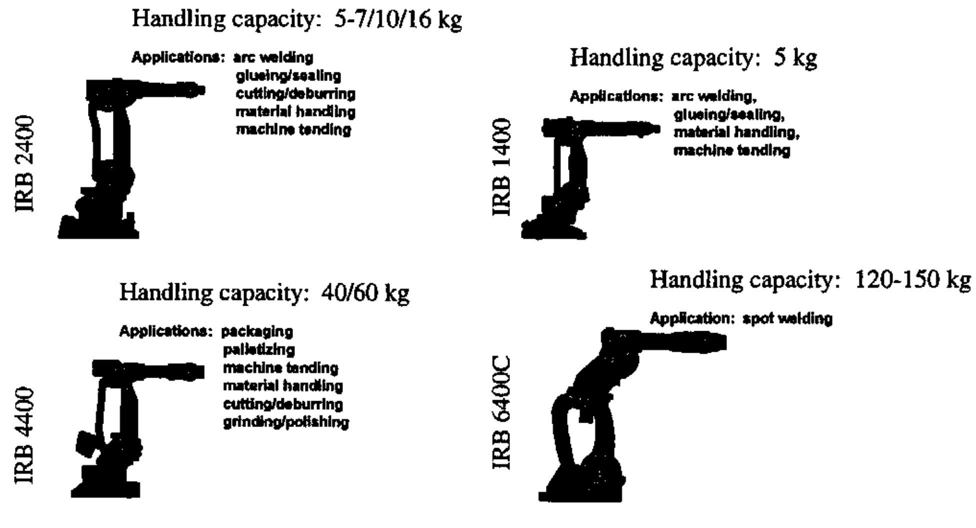

Figure 3. Examples of applications for different product variants.

The industrial robots are normally characterised by their handling capacity and reach. IRB 6400 that represents the largest robots in the product range, both in size and in sales volumes, varies considerably in both reach and handling capacity. This product family was developed with a modular approach already from the beginning in order to meet the various customer requirements. The choice of variants, in terms of reach and handling capacity, was partly based on an analysis of competitors' products. The initial family was based on four variants, shown in figure 4. These variants were also available with extra sealing for rough environments such as foundries.

2.4m- 120kg Basic	2.4m - 150 kg Extensor 1, counter weight, wiring
2.8m- 120kg Motor, counter weight	3.0m - 75kg Extensor 2

Figure 4. Some of the product variants with their variety modules for the product family IRB 6400.

Since the development of the initial platform a few new variants have been added, where some fit well with the initial system whereas others need many new parts. Still, the new variants which do not entirely fit within the system, have not changed the basic idea of the initial system. Instead all the changes are made on these new variants. A product that has many parts in common with the IRB 6400 is the palletiser (IRB640). However in the palletiser, functionality not necessary for the actual application is removed, e.g. the number of degrees of freedom is reduced. In order to accomplish the reduction of functionality, parts were not only taken away but the reduction also forced design changes in parts such as the counter weight.

Today, only very few parts are common between the different product families. Typically, the lighter wrists from smaller robots may be used for the larger robots with extended arms in order to allow the robot larger handling capacity. Of course, the considerable size difference between the robot families limits the possibilities for commonality. On the other hand, it may be noted that the robot controller is common for all the families. Some of the customer requirements, for example the requirement of minimum use of floor space, leads to difficulties in sharing components between products.

As described by figure 4, the variety of reach and handling capacity is solved by variant motors, arm extensors and counter weights. Still, the usage of arm extensors does not directly reduce the number of parts compared to if variant arms would have been used. One strong driver for the interface location in the arms, i.e. the use of extensors, is the need of after market sales and service. Because arm parts sometimes break and production downtime by the customer must be minimised, storage of spare parts and quick change must be facilitated. Another important driver, or rather experienced benefit from the thinking in terms of modules, is the possibility to separately test units.

Distribution of drive units to the motors has been considered. The benefits would be less wiring and less complex control package. Furthermore, the drive units take much floor space, which is not in the interest of the customer. However, since both the motors and the drive unit generate heat, cooling would be a problem. Another problem with the distribution of drive units is the added mass and consequently increased inertia of the robot arms.

2.2. ITT Flygt

ITT Flygt is one of the world leaders in submersible technology. The company develops, manufactures and markets a product mix of submersible pumps, mixers and hydroturbine generators. The product range, which is divided in a few product families, is depicted in figure 5.
Pumps are conventionally characterised by their pressure and flow performance. The variety is also driven by the customer's various requirements on performance as well as type of application, e.g. type of fluid and submerged or not. The air-filled submersible motor or generator, which is designed to operate both dry-installed and partly or fully submerged in the process fluid, is one of the major elements of the ITT Flygt product range.

Figure 5. The product range of ITT Flygt.

Because the product life cycle of the ITT Flygt products has been relatively long, up to 30 years, many older variants still remain in the product line. Over the years new products have been independently developed for specific customer requirements and as a consequence the product range is based on a large number of variants. As an example, the shafts exist in over 13 different diameters for a family and consequently the shaft sealings then also have to be manufactured in at least the same amount of variants. The variety escalates since the sealing may have different outer interfaces. The motors are available in roughly 15 different outer diameters and each motor may vary in terms of voltage, length, etc. The result is a large amount of variants and since the product is built from the inside out, starting with the motor, the variants are defined at the very beginning of the production process.

Historically, the organisation was product oriented, i.e. each team had the responsibility for the development of single products rather than a family of products. The development teams' focus on cost cuts for individual products rather than for product families led to a low degree of commonality. However, the company changed to a more component (sub-system, module) oriented organisation and as a consequence the problem with variety became apparent. Since the development teams have responsibility for certain parts of the products across the product line, e.g. sealings or motors, it is now easier to overview and manage variety. The organisation also includes product family or product area (B, C, M, T) responsible personnel, which together with the component areas form a matrix organisation, figure 6.

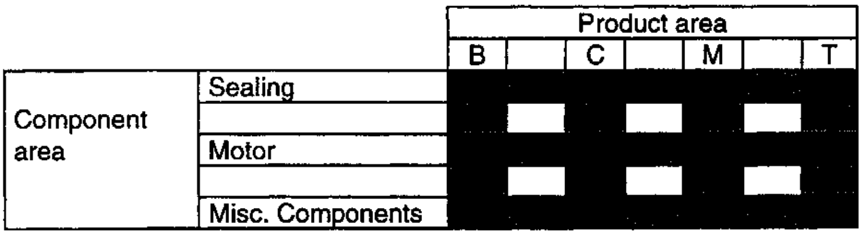

Figure 6. The matrix organisation, product area and component area.

ITT Flygt has started to reduce the number of variants by only allowing standard sizes for shafts and motors in new product developments. To make sure that the interfaces conform to the chosen standards, i.e. stability over time, an interface committee has been formed. The product committees and the component committees have to discuss with the interface committee if they want to change an interface. The interface committee has the right of decision. Figure 7 describes the position of the interface committee.

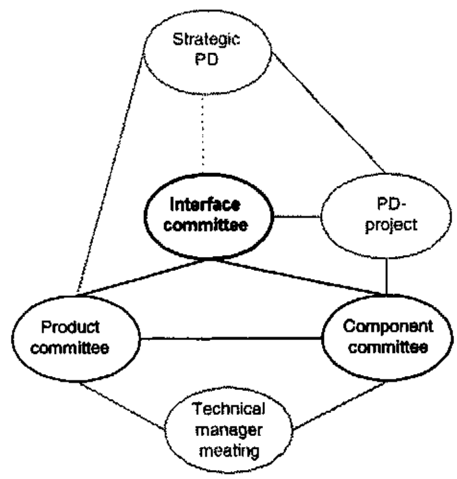

Figure 7. The interface committee's relations.

In the company, the usage of electronics to reduce the number of unique parts has been envisioned. Today, it is technically feasible to move variety from the mechanical parts to electronics. For example, the need for variant motors for variety in voltage may be handled by a transformer that adjusts the voltage. However, it is not yet economical to implement in a product.
Although ITT Flygt historically has developed a large variety of products with low degree of commonality, the company has for many years used a modular approach to configure the products based on the part numbers. The part number of a product variant could be seen as a combination of different modules that specifies the exact configuration. As an example a part number may be:

3000.000 - 030 - 131 - 220 - 300 - 400 - 500 - 600 - 700 - 800

The first digit determines the product family and the following digits determine type of impeller, size of motor, type of sealing, etc.

2.3. MHU Robotics

MHU Robotics is a small company that develops, produces and sells industrial robots for various applications, especially material handling. Part fabrication is done by suppliers and assembly is done in house from a small stock of standard components or modules. The development started as a part of the Electrolux corporation in the beginning of the seventies, where they developed and produced robots and manufacturing systems for internal use. In order to produce equipment at low cost, a modular approach were employed which allowed high degree of customisation with standard units. After a while they expanded and offered the products also for external customers. In 1980 the products were bought by Asea, where the main platforms served as rather fixed products until 1986, when the product range was sold to the present owners.

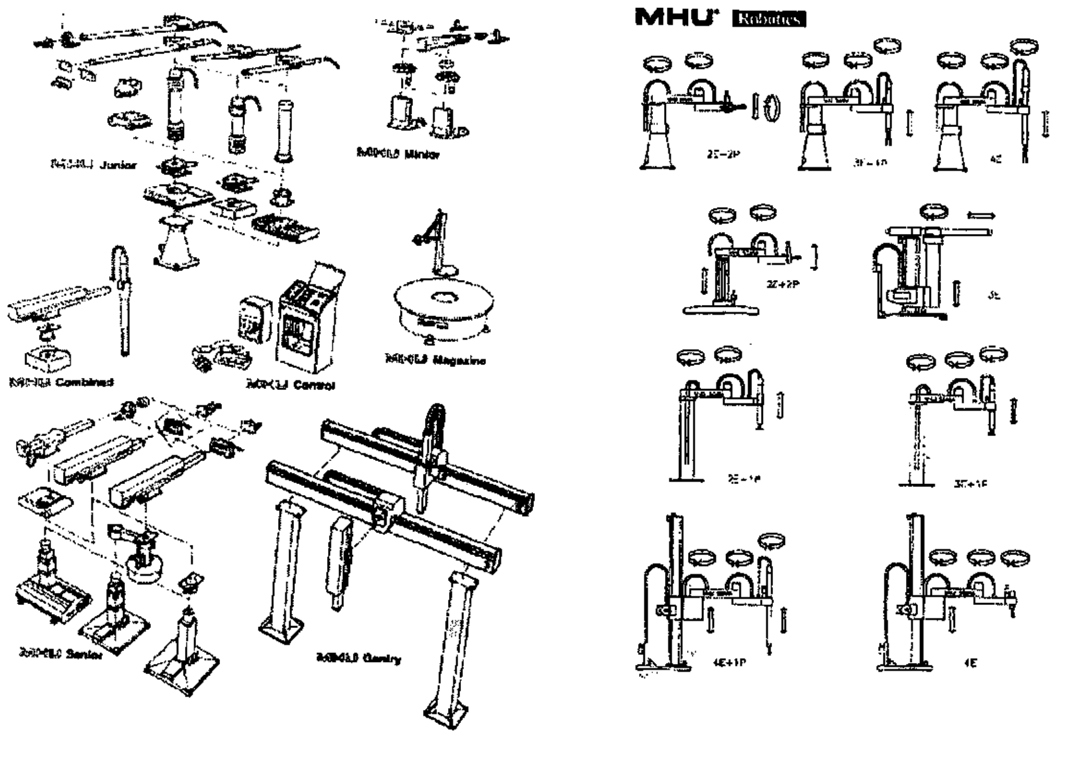

Figure 8. The product families of MHU Robotics.

Today, the products are divided into a few product families; Senior, Junior, Minor, Scara and Gantry, see figure 8, where Senior is slowly phased out. The products are often sold in the quantity of one to a customer that needs material handling equipment. Typically, the products are built from units, modules, that handles one or two degrees of freedom. The product variants are created by combining these modules. The combinations are not limited by a set number of end products, i.e. the system is very open. This flexibility is considerably improved by the interchange of modules between the different product families. For example, the linear unit from the Junior may be used in the Scara as an extra degree of freedom for the gripper. Furthermore, the vertical guide profile in some of the Scara applications may be recognised from the Gantry system. Some modules vary in the sense of drive system, electric or pneumatic, however still with many similar parts. This building block system allows the company a high degree of customisation for various applications.

As a consequence of the large possibility to combine modules, interface design is a central issue. Today very simple and standardised module interfaces are used, for example just a flat surface with a hole pattern. When the company is forced to adapt or develop new modules for a specific customer, the interfaces are kept unchanged and the new modules may then be incorporated into the modular system. The size of the company may accentuate the need for standardised interfaces that are stable over time, since there are little resources for complete rede sign. Also, the control unit is designed with modularity in mind, e.g. inputs/outputs are easily added. Furthermore, the choice to use point-to-point control instead of trajectory control significantly ease customisation.

2.4. Spectra Precision

Spectra Precision develops, produces and markets products for surveying and positioning. The systems are based on electronic distance and angle measurements as well as GPS technology. The studied products consist of a number of subsystems such as an optic tube, encoders, actuators, distance measurement system, gears, battery etc. Much of the functionality is realised electronically.

The company has practised a modular approach for many years and claims that they have grown into it rather than based it on any clear decisions. To create variety, it has been more or less a natural step to think in modules. However, still in the beginning of the nineties the customers could not fully use the modularity because the possibility for upgrading was not well developed. Since upgradability is a sales argument, in 1995 when the company decided to develop a new product platform it was important that the structure allowed upgrading in terms of performance and function. Also the transition from one platform to another was done by a modular approach, where the main modules were developed incrementally as illustrated in figure 9. First the measuring head was altered, but the interfaces to the base unit such as the shaft diameter were unchanged. The intermediate product was marketed for a shorter period until the base was altered in the second step.

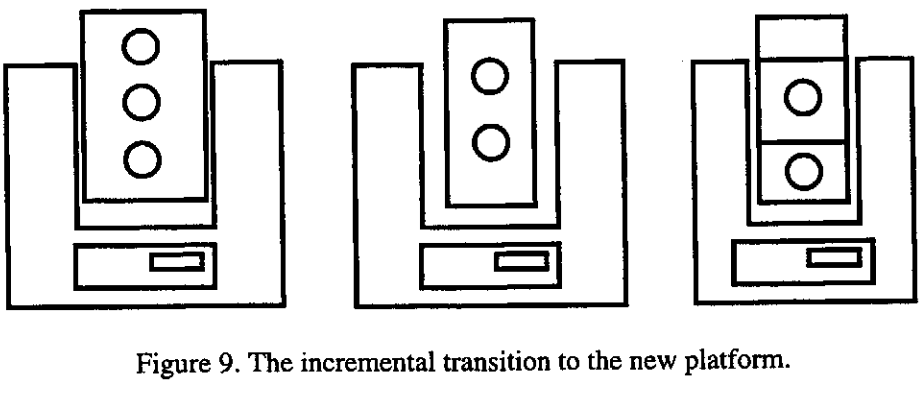

Figure 9. The incremental transition to the new platform.

The new platform, as in
Figure 10, allows the customer not only to choose functionality and performance but also to upgrade the product afterwards. This modularity is used throughout the whole company. The development department uses the modularity to focus the resources on one system at a time, i.e. incremental and independent development of modules. The production uses, e.g. the opportunity to create specific product variants late in the process. The sales department uses an order form, paper or PC-based, where the customer can configure the product by choosing modules. When the customer has configured the product, it is specified by its configuration number.

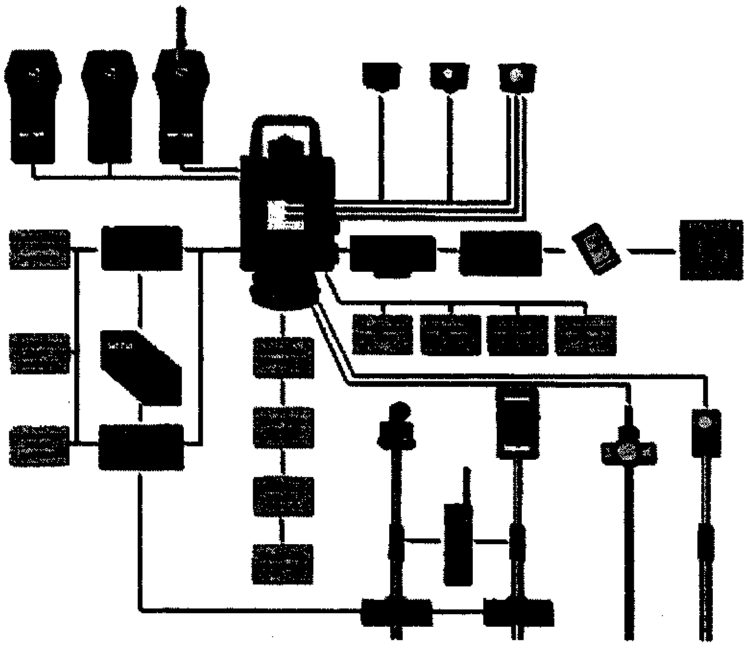

Figure 10. The new platform.

As seen in
Figure 10, some of the functionality and consequently the variety is allocated to software. Another form of variety is a result of the production process. In order to get products for the high-end market, i.e. extreme accuracy and range performance, each instrument is tested individually. The most high performing instruments are selected to form a category of products that are intended for customers with exceptional requirements.

As a part of the modular approach, distribution of functions realised by electronics and software has been used as a mean to achieve larger independence between the modules. In the old platform all modules communicated with a central computer that performed all the calculations and stored data. Thus, the communicated data was rather unprocessed. In the new platform the central computer is left out. Instead, each module has a higher capability for processing data and the modules communicate through a "switchboard". The main data storage is now located in the keyboard/interface/computer module that is detachable from the instrument to facilitate the remote work option or office use. Previously, this module was only carrying the function of keyboard/interface. The bus approach allows the company to incremental and independent refinement of modules. Moreover, as a consequence of the distribution the wiring in the product is reduced.

Spectra Precision has changed the ratio of outsourced components between the platforms. In two cases the company has taken larger control of the sub-systems. Firstly, in the old platform the radio was bought from a large supplier of radio equipment as a standard component. When the new platform was developed, the supplier of the standard radio changed the design. However, this new radio would not fit within the interfaces, which were not changed between the platforms. Thus, the company decided to develop the radio themselves. Secondly, in the old platform the measuring head was divided into three modules, where one were bought as standard equipment. However, since the bought module and one of the other modules were both based on optics these modules were integrated to one module in the new platform. This meant that the standard parts bought from suppliers would not do.

2.5. Volvo Cars

Volvo Cars occupies a strong international position as a manufacturer of large family cars and is among the leaders in the estate car field. However the product range also includes medium sized cars as well as exclusive convertible cars and coupe cars. Based on the available product models, the customer has large possibilities to customise its own car by choosing optional equipment.

The focus of this survey is on the new platform of which Volvo S80 is the first variant on the market. The initiation of the project leading up to the S80 started slightly before the idea of platform development was decided upon. The decision about platform development meant that 4-6 different car models should use the same production process. The difference to the previous approach is that many significantly different cars are planned and developed from the same base in terms of systems, production equipment, knowledge etc. Previously Volvo developed cars model by model, but also then the customer was allowed to customise their product by choosing optional equipment. However, in order to stay competitive with relatively low production volumes a platform strategy was seen as important.

Much of the platform concept was created in a pre-study where the location of the variety and the commonality were discussed. This was done by personnel that were responsible for various systems of the car. This means that in the platform there is a balance between variety and commonality, where it is important to use variety when it gives the customer added value. The process to decide upon commonality versus variety was iterative. The strategy was to strictly define the systems as common system or not for the range, rather than do small compromises for each system. In this work the cars where represented not only by the different sub-systems but also by the attributes experienced by the customer. Cars may be characterised by attributes in charts, e.g. fuel consumption versus size, which is a way to consider needed variety and position in relation to competitors.

During the platform development, the influences from production personnel on the design were stronger than ever, which meant that the chosen modular concept is rather process oriented. This is even reflected by the development organisation where the development is done in teams referred to as "module teams", which largely correspond to various steps of the assembly process. The strive to develop a customer oriented platform was later integrated with a strong process oriented vision. The process orientation has increased ergonomics and working environment for the employees. Typically, in order improve the ergonomics of the assembly process the driving unit is robot mounted as one package; a unit that also corresponds to a module team.

The modules have their origin in the process and one belief has been that a one-to-one mapping between module teams and their corresponding part in the production would be beneficial. One advantage of the modularity is the clarification of responsibilities, which ease communication. However, this ideal situation has not been possible for the electric system, which has stayed more function oriented rather than process oriented. Parts of the electric system are mounted in most steps of the assembly process, figure 11.

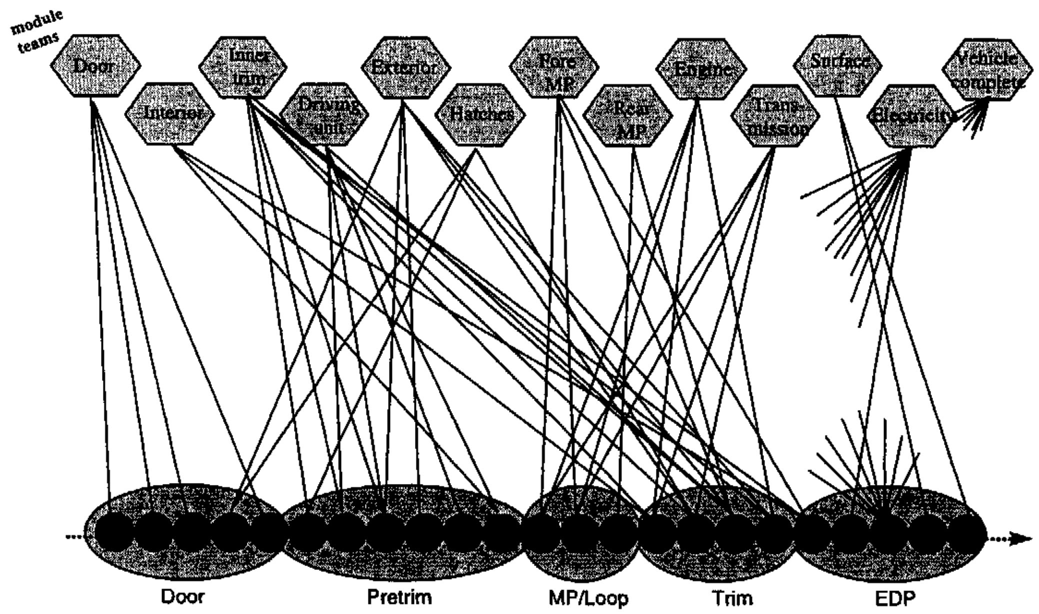

Figure 11. The mapping between development teams (module teams) and the manufacturing process, [6].

Since a car consists of many parts, the modularity may be defined at various levels. Modules come into view at three different levels where the highest level is some sort of super modules, i.e. the process oriented modules discussed above. However, the variety is not realised at this super module level. Instead, the product variety is achieved by having variant sub-modules which often are pre-assembled to super-modules when they arrive to Volvo assembly process. The sub-modules are often outsourced, however, there also exist examples where the entire super-module is assembled by a supplier. The modularisation has allowed a move of assembly time from the final assembly process to either suppliers or other groups within the company.

In the early stages the interfaces were often roughly specified so that each team could start their work. Typically, these specifications concerned initial ideas about geometry but especially solution principles. For example the interface door/doorframe was defined by its principle solution. During the development the interface have been negotiated between the involved teams. Interfaces for variation in length and width have been carefully positioned where fewest functions will be affected. For example, one possibility to accommodate length variation is in the feet area of the rear seat passenger i.e. just between the more complex front and rear end of the car.

The modularity has induced some changes in interface principles compared to previous car generations. An example is the interface for the large robot-assembled driving unit; a unit that previously was manually assembled inside the car in several parts. To be stabile during the robot operation, an extra beam had to be added, i.e. it may be claimed that modularity leads to heavier designs. On the other hand, this extra strength of the driving unit turned out to significantly affect the performance in terms of safety and unwanted noise. Furthermore, as a consequence of the higher rigidity of the driving unit, the designers of the surrounding body parts were allowed to reduce material usage.

3. Discussion and conclusions

This pilot-study is based on interviews and discussions with five manufacturing companies. In order to capture the aspects of special interest in each company, the interviews were open for a wide spectrum of issues related to modularity. If the companies would have been described by parameters such as number of employees, complexity of product, strength of competitors, etc. many of these parameters would have been rather different between the companies. Still, a common denominator is that they all use or are about to use a strategy for control of internal variety while creating choices for the customer. Furthermore, the majority of the companies have a strong position on their market.

The question of what "modularity" and "module" are, was touched upon at all companies. A common interpretation is that a module is a block of components that may be for example interchanged, separately developed, etc. In other cases the module could not really be interchanged by only one block of components but rather by a number of components that together fulfil a certain main function. It was queried whether a module could be a set of parts rather than an encapsulated block. In some case the modules corresponded well to the important knowledge bases of the company. Furthermore, the assembly process seemed to define the modules in some cases. Good modularity could possibly be characterised by the appropriateness of interface location, where low function density in the interface could be a criterion.

In this study the most common type of modularity is the slot modularity [11] or modular system [2]. Only one of the companies has a more open system that could be referred to as sectional modularity or building block system. It may also be said that the module interfaces are standardised to various degrees in the products, compare [8]. Typically, some interfaces are standardised whereas others are not. The only sectional system seem to have the most standardised interfaces.

One of the problems experienced when thinking in terms of modularity is to set the right limits for the product range. Typically, in order to reuse components, parts in the low end products may be over dimensioned. However, for a low end market segment the customers may be price sensitive and thus it will be difficult to retain a good profit margin for such a variant. In the study there have been examples of different strategies, e.g. either much of the platform has been left outside in a simpler product variant or the lower end products have been kept in the platform but with a lower margin.

The management and organisation of platform or modular development seems to be an area of great interest. The effect of organisational changes for modularity seems to be central; either the product structuring may raise the need for reorganisation or the reorganisation may accentuate the need for a product restructuring. It seems as if an organisation where groups are responsible for subsystems of the product across the full product range should be more favourable than if groups are responsible for their product variant, compare [10]. Typically, uncontrolled variety arise when project teams are focusing on their technology development, cost cuts, etc. for a specific product rather than a family of products.

All companies in this study stress the importance of interface location and design. Their approaches, however, are rather different. Firstly, there are differences in how well the modules are defined or standardised, i.e. modules defined as a building block or as a set of separate, but related, components. Secondly, some companies have defined the interface for an entire family in the beginning whereas others have an incrementally evolving product family, where they try to keep to old interfaces when developing new family members. This is related to how early the family members are planned and the parallelity in the development of the members.

Outsourcing is frequently discussed in the context of modularity. The studied companies have both negative and positive experiences. Outsourcing makes it possible to concentrate on what they think is their core competence in terms of development, assembly, etc. One drawback is that the company relies on other companies. The problem is to decide what to outsource by considering, for example, the costs, the need to control parts that are critical for the customers' perception of the product and also the employee situation.

All of the studied companies use or could possibly use electronics and software to realise variety in both function and performance. In the companies a large part of the functions is realised by electronics and software. This seem to be increasingly implemented through distribution of functionality by bus approaches, which leads to not only less wiring but also potentially to better defined modules. Well-defined communication interfaces with low dependency between modules facilitate, for example, separate development. A good correspondence between hardware and software in both product structure and organisation may be difficult to achieve, but may be important to consider, compare [4]. Related to this is the chosen control approach where the two robot companies are different; a point-to-point approach is easier to modularise then a trajectory controlled approach where all degrees of freedom act together. However, also the functionality of the two approaches is significantly different.

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