The Corporate Platform –a mean to industrialise design of customised products

Philosophiae Doctor Dissertation

by

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Abstract

In the last century there has been a vast increase in global competitiveness. The flow of products across borders is greater than ever before and the focus on price and performance increased. Companies feel this increased competition and need to develop products that meet the customer's individual needs and at the same time still be competitive on the price. It is in these situations design for product platform show their strength. It offer the companies the opportunity to sell products to different market segments and at the same time provide increased reuse of assets within the company. For products with a structure that allows configuration possibilities, there have been several methods of modularisation and product platform designed to accommodate these challenges. For products not suitable for a configuration design, there have been no models to follow. This thesis proposes the Corporate Platform model to develop a product programme. The model focuses on how to structure the product programme in order to deliver customised products and at the same time focus on reuse within the company. The model has been developed around the crash box product manufactured by Hydro Aluminium Structure. This is a component in the bumper system of cars and its purpose is to absorb all the energy in a low speed crash (16 km/h).

The Corporate Platform model is intended for the design team and their managers in the process of developing a structured product programme for all the product variants. It is primarily developed to industrialize the development process of customised product variants. The product programme involves an understanding of the market, the product and the manufacturing processes as well as the dynamic aspects related to the product's life, in order to provide insight into lean product variant design. The model focuses not only on one product variant, as a traditional product development methods does, but all the aspects of several product platforms with a range of product variants. Central relationships in product variant design are made explicit and related to strategic thinking. The model consists of three elements: Market, Product Platform and Manufacturing.

- Market covers the inputs and drivers for the product variant design and the process of segmentation of the customer's product preferences.
- Product Platform development focuses on arranging and aligning the product features to sort out the balance between distinctiveness and commonalities in the products. This is aligned with the existing products and supplemented with new product concepts, so that the decided product range can be met. All this is in close relationship with the production processes for the products.
- Manufacturing focuses on the transfer of best design and production knowledge from one product variant onto the next.

These three elements form the base from which customised product variants can be leveraged. The models also put the attention on the dynamic aspects in launching and managing new industrial processes with their associated product variants. The Corporate Platform model is a broad model covering the central aspects of establishing a product programme.

Preface & Acknowledgements

During my studies and work I always wanted to learn about and understand product development. A range of different technical subjects were explored during the studies, all leading to a growing interest in understanding technical details. This curiosity for engineering design has brought me through a Bachelor and Master's degree to this PhD.

My research career started with a small project in the NUTS project at Norwegian University of Science and Technology, Department of Engineering Design and Materials. The work inspired me so much that this PhD was initiated. The PhD underwent a major change of direction in January 2003. It had started with the intention to develop a 'language' capable of describing the product platform at a detailed level. This approach didn't lead me the right way, since it wasn't the actual challenge for the crash box product at Hydro Aluminium Structures. A more holistic approach was taken around the same design problem. The results in this thesis, I believe, are focused on the most important design challenges for the crash box product, in order to improve competitive advantage.

I owe gratitude to a number of people; I have had many good discussions with my supervisor Professor Hans Petter Hildre. Thank you for constantly lifting the discussions and taking it forward. I also want to thank Torgeir Welo for our helpful dialogue and especially for opening the door for me into Hydro Automotive Structures.

Further, I want to thank Detlef Blankenburg and Knut Aasland for our many debates and conversations and their insightful comments on the work. I also want to thank Arnar Kristjansson, Cristian Nilsson and Jens Røyrvik for our many discussions during the study. I also owe thanks to all the people I have met during the industrial cases, providing me with insight into the industrial challenges.

I am very grateful to my dear Mona who has always supported me and helped me through the tough periods. Without her help it would have been very hard to complete this project. I must also mention that our lovely son, Eivind, was born during this period. He has inspired me with much laughter and also some challenges. Finally, I want to thank my family and relatives who have always supported me in my choices and work.

Trondheim, June 2006
Tormod Jensen

1 Introduction

In our daily life we are surrounded with products in all different sizes, shapes and forms of complexity. We ride in automobiles, buses, trains or bikes to work. The door to the office is opened with a cardreader, at the desk there may be a computer. Our environment is filled with products. The customers buying these products or products for industrial use are in a strong position. They can select the product that they want to buy from a large range of variants, at what time and with a strong influence on the price. It is a "buyer's market". The manufacturing industry feels this and the pressure from globalisation. In today's global world there exist almost no barriers for trading products and the logistic is so efficient that all types of products are transported around the globe.

In order for the manufacturering industry to be competitive, the use of product platform and modular design has proven to improve competitive advantage (Muffatto 1999) (Robertson and Ulrich 1998). These methods give the advantage of both satisfying the industry's interests in standardisation and satisfying the customer's requests for new products at a faster rate and at a lower price. A modular design method is a powerful design approach to create product structures that can be configured into many product variants (Fisher et al. 1999), (Gershenson et al. 2003). The modular design approach is typically used on for example, laptop computers. The Dell laptop computer can be customised by the customer by choosing for example, processor speed, the required memory and hard drive size. In addition the keyboard is swapped according to the country in which the computer is sold. This approach gives the possibility to have high production of standard modules and allow low volume of special modules, satisfying a great variety of customer requests. Applying modular design means that the product structure must be capable of establishing interfaces between these modules that allow for adding, removing or swapping modules without causing changes to the other modules.

Product platforms have proven their efficiency in two ways; designing the products so that a complex, technology intensive structure is reused across a range of product variants (Meyer 1997) and making this shared structure scalable (Simpson et al. 2001). Both these design approaches focus on designing the product so that there are physical elements of the product that are reused. This is a typical approach that the automotive industry uses. For example the Ford Company has among others the brands Ford, Volvo and Mazda. The Ford Focus, Volvo S40 and Mazda 3 share the bottom plate, which is the component platform. The bottom plate is also made scalable by allowing it to change length so different bodies can be placed on top. The extra work in aligning the design to fit three different brands and several models gives payback in shared development- and manufacturing costs of these shared parts for many models. The extra investment in aligning the platform for many models gives better payback over time than not using it. Such a product platform is used for a certain amount time before new technology or changes in the requirements make it out of date and a new one is developed. For products where there is more constant development and refinement over time, the reuse of physical structures does not have the same strength. Sticking to a fixed platform over to long time may result in loss of competitiveness. Instead, one has to constantly transfer new knowledge into the products and stepwise upgrade the platform, in order to make them competitive. To do this it becomes more important to focus on the elements in the company that lies behind the products, which are the manufacturing processes, knowledge sharing and people & relationships. By taking this view on the design of the product and the future product variants, it is possible to increase the reuse in the development work, manufacturing, testing, etc. In the case where the manufacturing company develops products for many different industrial customers, with high product knowledge and individually defined requirements the focus on reuse between projects has been difficult to achieve. This becomes even more difficult to handle when the organisation is global and there are many projects of different types that are performed continuously in the company. In this setting the Corporate Platform model opens up the possibilities for increasing the reuse of assets to achieve increased competitiveness. The model provides a systematic way of developing a product programme that aligns the development of product and industrial processes to secure a high reuse of processes and knowledge as well as making them explicit. The Corporate model goes into the elements of Market, Product platform, Manufacturing and Product development of the complete product programme. The objective is to leverage new product platforms from the best available knowledge. This platform is knowledge intensive and will be continuously updated as a consequence of learning from earlier projects. A typical product that fits this approach is the crash box that is placed behind a car bumper. It is a product manufactured in high volumes, with common- and distinctive properties according to the customer's specification. The product's complex technology that this type of product is built around is primarily related to the production processes, but also how these support the functionality found in the products.

The motivation for this work comes from an interest in gaining a deep understanding of how product variants are best established. The early development phases are a fuzzy period of product development. For "one-a-time" products it starts to become clearer, but when it comes to including the decisions for several future product variants, a deeper insight is needed. The first choices for the product structure and manufacturing concepts define the road for further product variants. So it is in this phase one has the biggest influence on establishing the base for being competitive. The Norwegian automotive industry has for a long time been focusing on optimising the details in manufacturing processes and material quality. This seems not to be the area where further competitive advantage can rapidly grow. The focus should be on a different level, where the interaction between product variants and design projects aim for increased reuse. It is here the purpose of the Corporate Platform can have a positive effect. I hope by this research to contribute with insight on the importance of product variant design.

1.1 Background

This research project is part of a larger project called Norlight. Norlight is a scientific programme aiming at increasing competence within the light metals industry. The aim of the NorLight project is to:

"*provide the necessary competence required for increasing the Norwegian light metals industry's turnover on finished products and components*".

In order to achieve this aim, Norlight is structured into six sub-projects from Metal Forming, Surface Science to Design and Production. This PhD study is part of the Design and Production sub-project, focusing on the interaction between design and production. The product designs and the associated manufacturing aspects are investigated, in order to improve the company's efficiency in manufacturing automotive products.

1.2 The industrial challenge for Hydro Aluminium Structures

HYDRO ASA is a global oil and light metal company, with activities in all parts of the world. Within the aluminium business they are a manufacturer of aluminium as a material, semi-finished products (sheets and extruded profiles) and final products. The business unit in this study is Hydro Aluminium Structures (HAST).

HAST manufacture automotive crash management structures such as bumpers, sub-frames, and space frames. The production volume varies from low (~1,000/year) to high (300,000/year), where bumper structures are at the upper end. A bumper system is placed at the front and rear of a car. It consists of a cross beam and crash box at each connection point to the chassis and often one tow-hook nut for towing operations, Fig. 1.1.

Figure 1.1: Hydro bumper system consisting of a beam, two crash boxes and a tow nut. The crash boxes are highlighted here in blue.

The system is designed primarily for two different requirements, a Danner test for the European car models and CMVSS requirements for the North American car models. Of these requirements the Danner is the most demanding and is used for models operating on both the European and North American market. This test requires that the bumper structure absorbs the energy from a 16 km/h, 40% offset crash and leave the car's chassis structure undamaged. This type of structure must be capable of performing correctly in low and high-speed crashes (compression) and in towing operations (tension). To develop such product detailed knowledge about product functions, manufacturing and materials is needed. HAST delivers these types of structures to the majority of the European carmakers. These structures can be found in a range of low-cost to premium-brand cars. Each product is customised for the carmaker, leading to a large number of product variants. The customisation of the products is necessary in this business, and is not seen as a problem. All products must fulfil similar regulation and insurance tests.

The core assets HAST possess, is the knowledge to utilize the freedom semi-finished aluminium profiles gives and turn them into products. Detailed knowledge of the material, production processes and function are core elements to create lightweight designs with high energy absorbing capabilities. Together these technologies allow HAST to make products that consist of very few, highly formed parts in large volumes. To make these highly formed parts, they pass through several production processing steps. A typical industrial process flow is illustrated in Fig. 1.2.

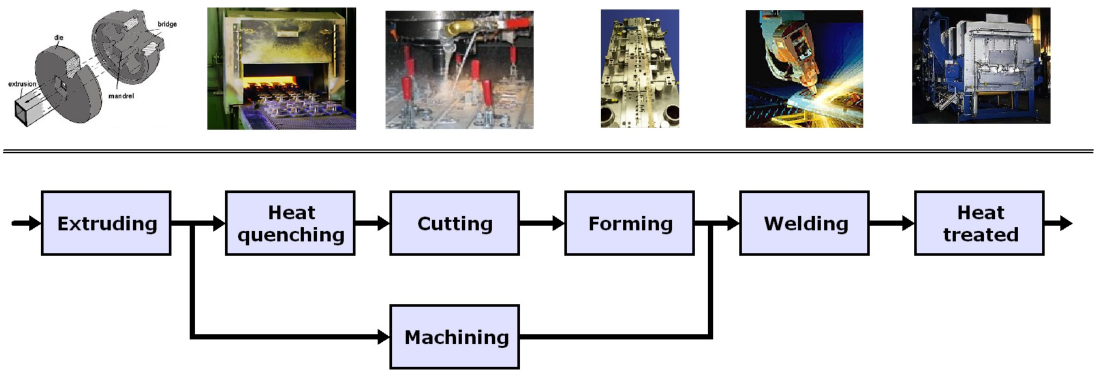


Figure 1.2: A typical short description of an industrial process. Picture reference (aluminiumtechnologie 2005)

Within this industrial process there is a flow of material over large distances and also between countries. All components in the product are based on extruded aluminium profiles and the process steps can be described as, Fig. 1.3:

- Extruding tower and base plate in country A
- The tower is cut and heat quenched before forming in a multi-step stamping tool (advanced process sequence). The processes are conducted in a large batch process, in country B
- Some components are machined by a sub-supplier
- The tower and base plate is assembled in an welding cell, in country B

- The welded products are heat treated in large batches, in country B
- The crash box is then assembled to the bumper beam (not included in the description) in country C

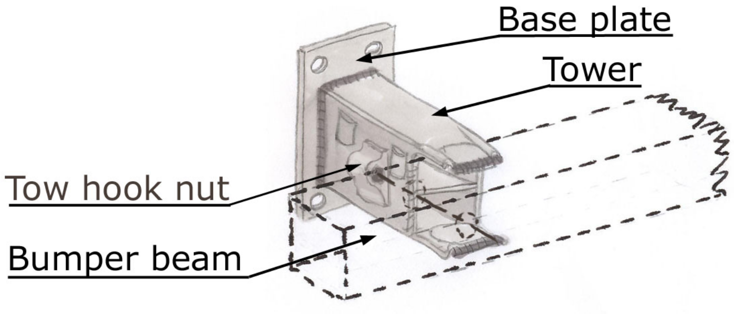


Figure 1.3: The notation used for the crash box

The challenges that HAST met with the crash box family are complex and a balance between technology, customer requirements and organisational demands. Designing and manufacturing products for the automotive industry is a challenging business. It means that one has to operate in a global business with many different product demands, but also cultural challenges. Most of HAST's customers are located in Europe, but with some also in North America. The automotive industry as a customer is very different from a customer of commercial products. While a manufacturer of commercial goods can charge extra for additional performance or functionalities, this is not as easy for a sub-supplier for the automotive industry. The customers expect that they will get the best products at a low price. To secure this they usually involve several companies to compete about the contracts, each time. This harsh competition means that the companies supplying products must place themselves in a position where the products can be constantly improved and changed, in addition the focus on low priced products must be maintained. The products and production processes have then gone through many changes during the time, as Fig. 1.4 shows.

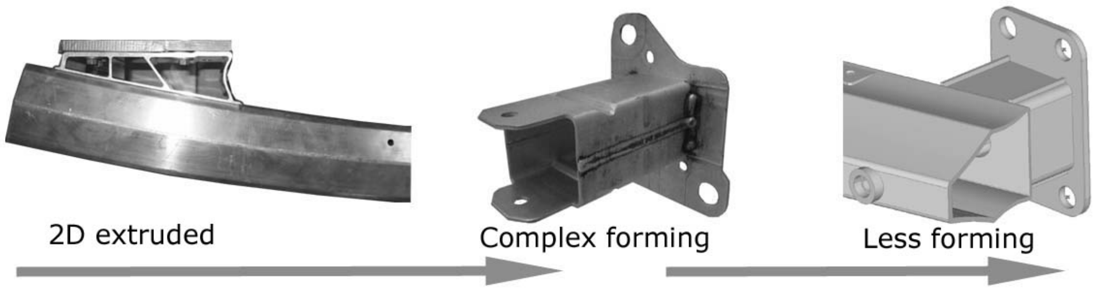


Figure 1.4: The crash box has gone through continuous change in design, functional principles, how they are manufactured and the structure of the supply system

The developments of the product also vary from being done in a co-operational manner to more as a pure supplier. With this in mind the challenges for the crash box family is related to two aspects, Fig. 1.5; the external (customer) and the internal (the organisation).

External, customer: The cost of the products is, as mentioned, very important. The challenge for HAST is that they have to commit themselves to a cost many years before the product is actually manufactured. In addition to this, the car manufacturer expects a cost reduction for the products each year the product is manufactured.

- The development of the crash box is done parallel to the car's development, and this introduces a highly dynamic development process. The requirement may change during the development and the customer expects the original time plan is kept to.
- HAST has several competitors that manufacture crash boxes from steel. They have developed new designs of high strength steel with good performance and steel solutions are well-known by the car manufacturers. The aluminium material has also a cost disadvantage over the steel solutions of approximately 3:1.
- The car manufacturers also have to deal with the end customers of the car, and they have started to demand safer cars. This gives a push to design car with high performance in crash management.

Internal, the organisation:

- HAST has had a very rapid growth of orders of crash boxes. The introduction of many new crash boxes has also lead to many different design solutions. These all needs to be simulated and tested physically in a variety of different test to prove the concepts.
- This increase in new crash box solutions has also led to an increase of different industrial processes. These industrial processes use a variety of different manufacturing technologies as well as supply processes.
- The great numbers of different product designs and industrial processes have been challenging to tune in, in order to achieve the high quality needed in these products.
- HAST is a business unit within Hydro ASA and has demands on the economical targets.

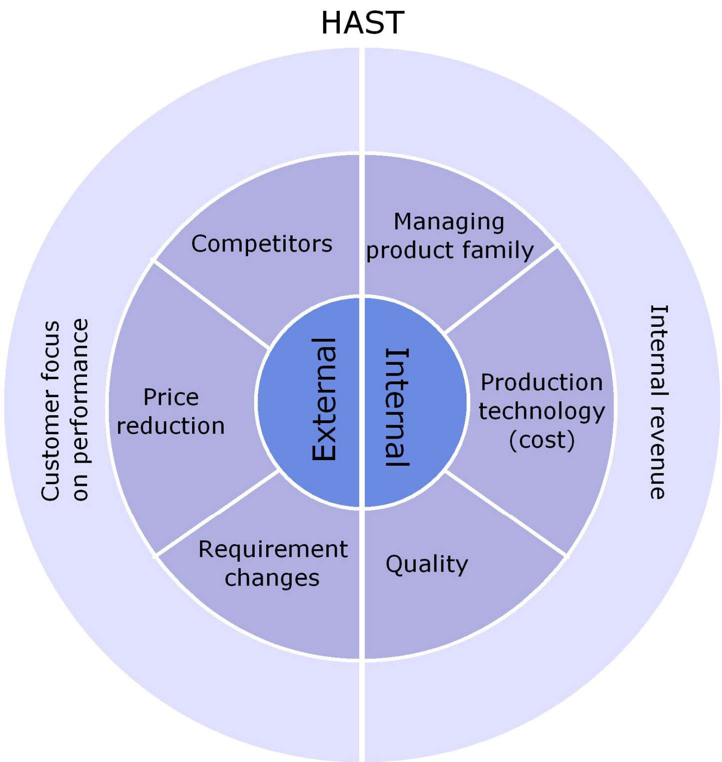


Figure 1.5: The challenges that HAST encounters with the crash box family, are related to the balance of the external (customer) and internal demands (quality, standards).

HAST's customers are constantly seeking new customised product variants and this is the driver for the whole business. It is though important to find a balance between satisfying the customer and taking care of the company. At the present time they use many different approaches to manufacture the products and ofte, dedicated production lines. The present design and manufacturing approaches have resulted in a loss of earlier competitiveness, even in an organisation with very skilled engineers. The crash box product family has grown and the earlier approaches to design and manufacturing them gives too little cost advantage compared to the improvements the competitors have made. On the other hand, HAST is in a position where there should be potential to view the product family more as one and set the direction for further growth of product variants. If HAST want a future competitive advantage, it becomes more important to find synergies between projects, so that the internal reuse of solutions and investments can be maximised. This is especially important since the focus is so fixed on cost reduction. There is therefore a need to establish a system to secure more synergies and reuse can be achieved from one project to another, in order to avoid sub optimisation of the projects.

1.3 The objective

The research aims to contribute to the knowledge of product variant design, where each product variant needs to be customised. It is research into one particular context, where one of HAST products has been studied in depth. The context can be characterised as being around a product of few parts, integrated structures and manufactured in high volumes, where component reuse is not possible. The products are therefore customised according to some general requirements and some special ones, according to the industrial customer. HAST is a tier 2 and tier 3 supplier for customers with detailed knowledge about the products. By having many customers acquiring more or less the same type of products, standardisation may be improved and this may lead to a better competitive advantage. The development and manufacturing of these products are in a global setting, with distributed design teams and several dispersed manufacturing sites.

Within the development of product variants, focus has for a long time been around the physical sides of products, as the interaction between components and the development of product platform. Both with modular approach, sharing of components or making them scalable between products has been a way to efficiently generate product variants. This is an approach that over the years has proven its potential and has been well described by several authors, among them Meyer and Lehnerd (1997), Sanderson and Uzumeri (1995) and Fisher et al. (1999). These methods are not applicable to products like a crash box that consists of few integrated parts and that has a complex production chain. The main challenge for such product is managing the complex relation between the product and the production processes. In the case of the crash boxes the product variants are to some extent manufactured from the same production line, but with no uniform design approach. By only focusing on details within one design project, it quickly becomes sub-optimal, making it a more dispersed product family. In order to develop product variants that are customised more efficiently, a more holistic view of reuse potential should be used. This leads the attention to different aspects in the design process such as the interaction between design process, manufacturing and the organisation.

The objective of this research is to provide a model systemising the design process to achieve a more efficient development of customised product variants. Such a model should be holistic in the sense that it covers the design aspects related to creating a product programme. This includes market consideration, product variants and manufacturing aspects the design team have dispositions on. It should not be a model at a business level, but for the product development organisation. The intention is to find reuse potential in making a leaner development process, understanding the consequences of product variants and making essential product variants relationship explicit. The intention is to take the development process to a different level than only focusing on reuse of product components or modules.

The knowledge related to these aspects is wider than the core competence in the company. By implementing structuring of product related knowledge and organisation relationships, the model should give increased ability to reuse design elements. A deeper understanding of the consequences of a new product- or product platform release as well as the time to remove them from the market is important in portfolio management. Establishing the model for HAST, with the use of the crash box product family should provide a deeper understanding of the crash box history as well as how the intention of product platforms can affect the product structures for future product variants.

1.4 Research questions

The main research question of this study is:

How can production-, supply chain- and technological knowledge be described as a Corporate Platform, useful for customizing products?

The research question addresses the complex relationships that appear when the design team has to consider many products as well as many product dispositions at the same time. The disposition of product characteristic in life phases as, design, manufacturing and supply chain are more important to handle for platform products than one-at-a-time products. By having a model to communicate the relationships and the consequences of design choices, a product programme can be established. Understanding these relationships gives the opportunity to improve communication with the customers and increase the reuse of product design elements. The management of the product family can also be very random and the product variants have a tendency to grow out of control and 'pollute' the leanness of the company. Handling this in a holistic way may provide increased competitive advantage for the company.

The main research question covers several subjects, some more statistical and others, time related. Product and product platforms are to be developed with a high degree of reuse. To sort this out and be able to establish all these complex relationships, the author has found it appropriate to establish sub-questions. By finding answers to these sub questions the main research question should be properly answered.

Sub questions:

RQ 1. *How are product platform- and modular design described and handled in theory?*

RQ 2. *How are product platforms described and handled in the industry?*

RQ 3. *How can a Corporate Platform be modelled?*

RQ 4. *How to handle the product assortment evolution?*

1.5 Limitations

This study is conducted in close relationships with the HAST company and targets one of their product families, the crash box. Since the focus is so closely related to this one product, the modelling framework may be influenced by this. This product also has the special characteristic of being engineering intensive, made of few parts and product variants hence developed in a successive manner. This may affect the outcome of the model and hence how it can be used on e.g. consumer products. To achieve a reuse potential it is assumed that the product platform has a certain life length as regards changes in the value chain. The benefit of such an approach is more uncertain when it is targeted at products with very high innovation speed. The Corporate Platform model consists of four main elements: the Market, Product Platform, Manufacturing and the final Product Development. The model includes a broad view on the product development and then covers many different topics, and hence there are some topics that are less exploited than others. These topics are related to how the market functions and how segmentation is best conducted and the organisation of projects, e.g. sociological effects. Within product development and especially product platforms, cost is one of the important trade-off indicators, but in this research these data have been seen as confidential and not included.

1.6 Contribution

The main contribution of the dissertation is to introduce a model framework of how companies can manage and structure their core assets needed to efficiently customise new successive non-configurable product variants. The model introduces elements from the market- and manufacturing point of view in order to balance the demand on product distinctiveness and the company's internal reuse. The model systemises the important elements to consider when aiming product platforms developing, for non-configurable products. It enters into an area within product platform design that has been little examined, since product platform has been more or less focused around configurable products. It brings the very good principle of using product platforms to also being suitable for products that cannot be based on component reuse.

1.7 Outline

This thesis is structured into four main parts, with seven chapters, Fig. 1.6. Part one sets out the research, part two finding the state-of-art within product variant design, part three provides new knowledge on product variant design with the Corporate Platform model and the last part sets out the conclusion. In connection to several of the chapters, articles have been published at conferences and all have had peer review.

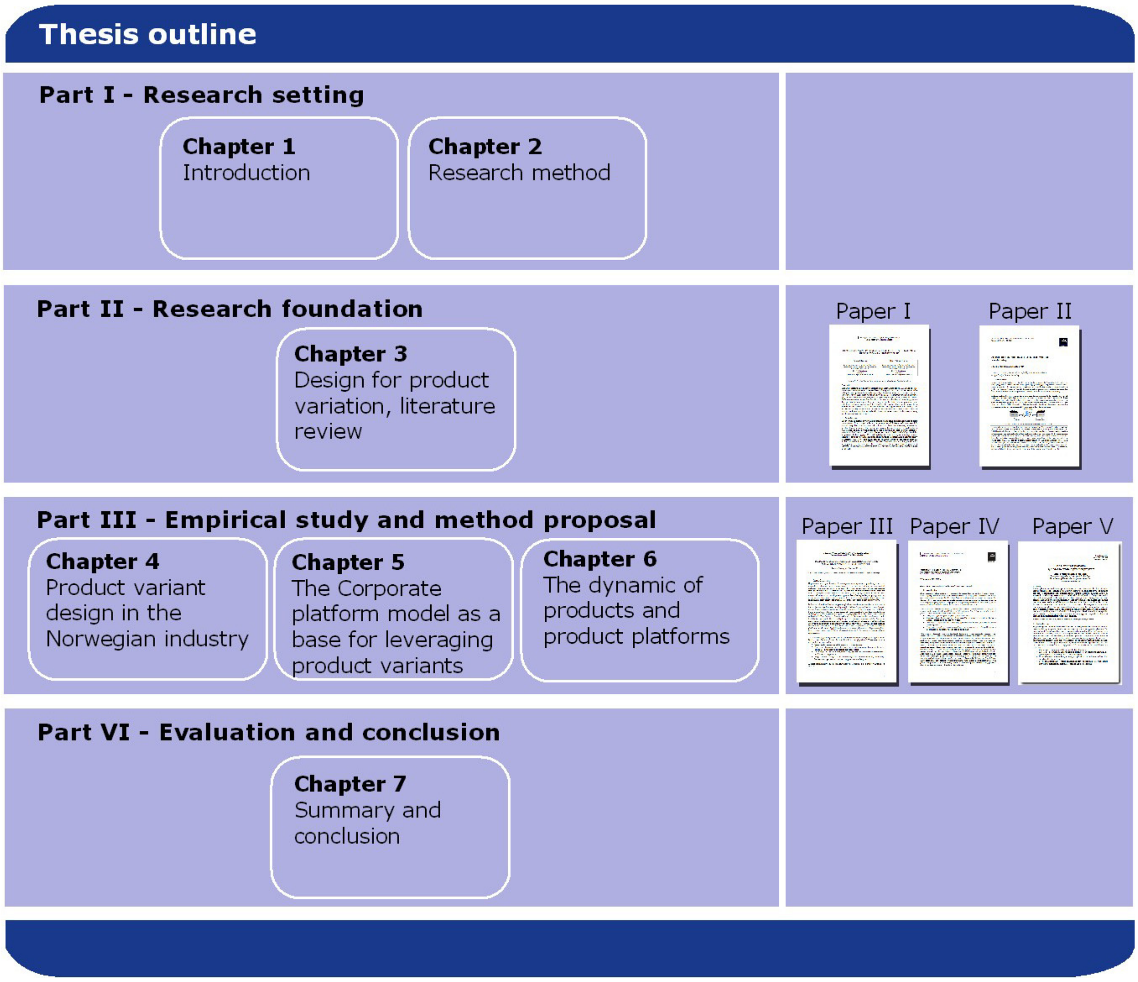


Figure 1.6: The structure of the thesis with peer review and conference papers

Part I – Research setting

Chapter 1: Introduction, setting the industrial challenge and the research questions.

Chapter 2: Research method, Research within engineering design is relatively new and several research approaches have been used to answer the research questions. These methods are described and how the empirical data is gathered and used.

Part II – Research foundation

Chapter 3: Design for product variation, within the literature several design methods for product variation have been proposed and these are presented and discussed. A paper (I) on state-of-the-art within product variant design was presented at the NordDesign 2004 conference (Jensen & Hildre 2004). A detailed evaluation method on the industrial processes' ability to handle product variation was presented at the Design 2004 conference (paper II) (Jensen & Hildre 2004).

Part III – Empirical study and method proposal

Chapter 4: Design practice in Norwegian industry, a selection of four manufacturing companies making a range of product variants have been studied. A paper (III) on how four Norwegian manufacturing companies design a product family was presented at the ICED 2005 conference (Jensen & Nilsson 2005).

Chapter 5: The Corporate Platform model as a base for leveraging product variants, when creating new product variants the product family can grow uncontrolled and loose competitiveness. The Corporate Platform model structures the development process of a product programme consisting of product platforms and product variants in order to increase the company's competitiveness. A paper (V) for the NordDesign 2006 conference has been published on the topic (Jensen and Hildre 2006 (2)).

Chapter 6: The dynamic of products and product platforms, understanding the market and how product properties affect customer choice is important. For a product based on product platform this is even more important, as the product is strongly related to the structure of the product platform. Studying the history of products and understanding how all product variants have affected the company can also provide valuable knowledge in the management of a product programme. A paper (IV) on product family from a manufacturing point of view is presented (Jensen & Hildre 2006 (1)).

Part VI – Evaluation and conclusion

Chapter 7: Summary and conclusion, results are discussed and the research is evaluated. Further research is also proposed.

1.8 Definitions

Change- Is the magnitude of the difference in a given item, as measured at two different points in time (Sanderson and Uzumeri 1997).

Differentiating attributes- Those characteristics of the product that are important for the customer and that are intended to be different across the products. They are generally expressed in the language of specifications (Ulrich and Eppinger 2004).

Form postponement- a term that is used in operational management, defined to be: the delay, until a customer order is received, of the final part of the transformation process, through which the number of different items (stock keeping units) proliferates, and for which only a short time period is available. The postponed transformation process may be a manufacturing process, assembly process, configuration process, packaging or labelling process (Skipworth and Harrison 2004).

Industrial process- is the sequence of production activities that realise the material and components into products. The word 'industrialise' refers: to organize (the production of something) as an industry (yourdictionary 2005).

Knowledge- Organized or contextualised information which can be used to produce new meanings and generate new data (christlinks.com 2006)

Modular architecture- Chunks (physical building blocks) implementing one or a few functional elements in their entirety. The interaction between chunks are well defined and are generally fundamental to the primary functions of the product (Ulrich and Eppinger 1995)

Portfolio management- The way a company selects and prioritises a group of projects to achieve its business goal, especially maximizing the long-term value of new product investment (McGrath 2004).

Product family- to be a set of models that a given manufacturer makes and considers to be related (Sanderson and Uzumeri 1997). This definition reflects on products that exist and have existed, it does not include planning of forthcoming products.

Product platform- the collection of assets that are shared by a set of products. These assets can be divided into four categories, consisting of components, processes, knowledge and people & relationships (Robertson and Ulrich 1998)

Product programme- The products put into a larger association to accomplish effects of synergy both external and internal in the company. Belonging to a product system, the value of recognition and confidence to long-term development and upgrading of products and systems (Aasland et al. 1998).

Supply chain- a set of three or more entities (organisations or individuals) directly involved in the upstream or downstream flow of products, services, finances, and / or information flow from a source to a customer (Blanchard 2004).

Variety- occurs when two or more items are significantly different from one another at the same time (Sanderson and Uzumeri 1997)

2 Research method

There are several methods of conducting science. In most of the scientific disciplines there exists a few accepted ways of conducting research, from where the researcher observes without affecting the researched or in a laboratory environment where all the parameters can be controlled. Within the engineering design discipline, which interacts both with people and technical solutions, the scientific approach is not as clearly defined. This is partly due to the discipline's maturity, which in this scienctific context is a young one. Often several different scientific approaches are used to answer a set of sub-questions. Together these different answers form the base for reaching the main question's conclusion, this research falls into that category. Several research questions are formulated and different approaches will be used to answer the questions. Below the scientific approaches are briefly presented and related to the different sub questions for this thesis.

2.1 Scientific approaches

The intention with science is to provide knowledge in understanding the world we are surrounded by. Science consists of a theoretical perspective and usually an empirical perspective to describe certain behaviours. This interaction between theory and empirical data can be made in several different ways. Routio (2005) has made an overview of the main science approaches that can be used, Fig. 2.1. There are four main directions for establishing a theory: formal science, basic research, applied research and development. The differences between these approaches are related to where the research focus is, represented in the figure by the circle. It varies from being a pure theoretical research to development where theory is more used than created.

The classical (Newtonian) paradigm into organisations and development processes research emanates from Sir Isaac Newton and his theories from 1672 (Ottosson 2003). This classical research pointed out that the researcher should not influence the research object. This is a research approach that can be conducted within formal sciences and basic research. Formal science has no link to empirical data and can be part of mathematics and logic research. Within the engineering disciplines this approach is rarely used. Most of the research conducted is to be found within basic research, either under the classical paradigm or the quantum paradigm. The quantum paradigm states that the researcher always influences the studied object through the tools used, no matter which tools are used (Ottosson 2003). Areas that it differs from the classical paradigm is that it also states that the totality is more than the sum of the pieces, irreversible processes are also treated, many equally good solutions can be found and every situation is unique.

Projects of applied research can be used together with the quantum paradigm, under a term called Action Research. Action Research was first launched in 1945 by John Collier (1945). The purpose of this research was to help to solve social problems, by taking part in the daily activities. This has been further developed and is now commonly defined as a process of joint learning (Ottosson 2003). Action Research normally sets out two goals: to solve a problem for the client and to contribute to science (Greenwood et al. 1993). This is done via an interaction between the researcher and the researched (the other) to solve a common problem. The researcher is not passive in the gathering of data, but interacts with the researched. The general understanding is that this relationship, is based on mutuality. The empirical object will, can, and should talk back, creating a discursive situation in which the empirical object becomes a subject along with the subjective researcher. This relationship is seen as an intersubjective and interactive relationship. The skill and creativity of both the researcher and the researched will play an important role.

The development projects have little contribution to theory, but are very important in industries.

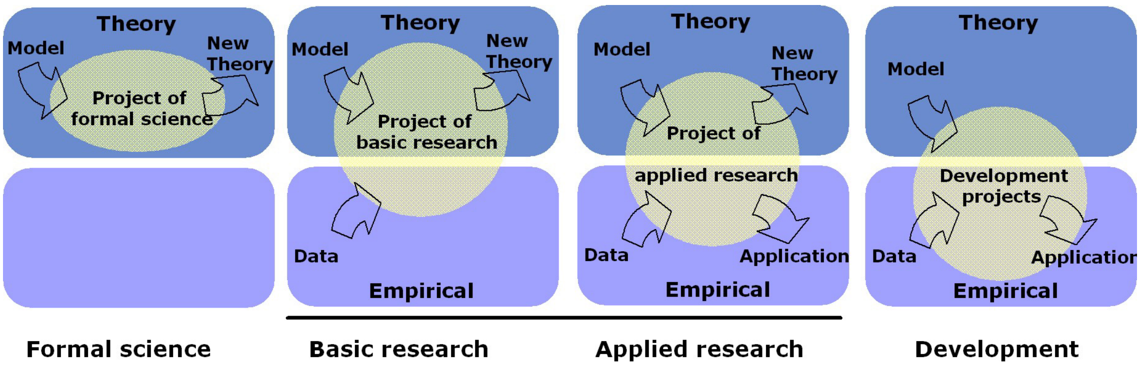
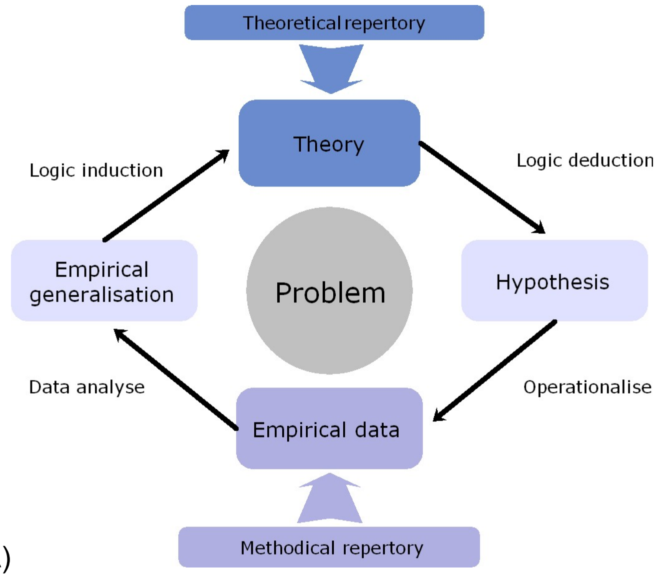


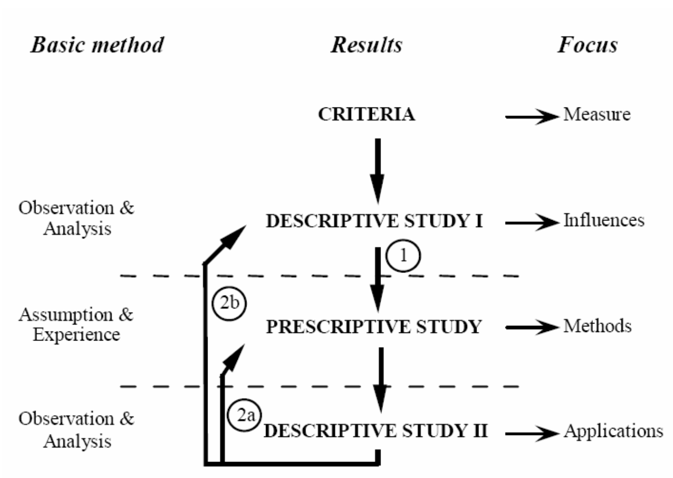
Figure 2.1: Scientific approaches to contribute to new theory and application (Routio 2004)

When a research paradigm and science approach has been set, there are still different approaches to describe behaviour. This is related to how the empirical data is used. The empirical data can be used to check hypotheses, deduction or it can be used to derive a new theory, induction, Fig. 2.2 (A), illustrates this. Empirical science involves the coupling of data and theories to explain some sort of behaviour (Schiefloe 2003). The deductive reasoning starts with a theory and specifies some hypotheses that are tested. The approach is a “top down”, working from a general to the more specific target. Deductive reasoning is narrow in nature and focuses on testing or confirming the hypotheses. Inductive reasoning is the opposite, a “bottom up” approach. Specific observations and measures are performed before being analysed for patterns and regularities. Tentative hypotheses are formulated and explored, before ending up with a general theory. The inductive reasoning is more open-ended and exploratory. Most science does however involve both inductive and deductive reasoning during a project. This complies with integrating both inductive and deductive approaches into a circle. Even in a very constrained experience, one may observe patterns in the data that lead to develop new theories.

Within the design science (Blessing et al. 1998) propose a framework, Fig. 2.2 (B); that starts with a criterion, a description study I, prescriptive study and then a descriptive study, II. Within the first step a success and measurable criterion is formulated. This sets the focus for the descriptive study, the prescriptive study as well as part of the evaluation. The descriptive study I identifies the factors that influence the formulated measurable criterion and provides a basis for the development. The prescriptive study describes a model or support tool in a systematic way based on the descriptive study I. The descriptive study II identifies whether the support can be used in the situation for which it is intended. It is also evaluated to identify whether it contributes to and provide success for the research. This is an iterative research approach, where the researcher analyses the empirical data and proposes a method or tool in a cyclic manner. This is an approach that can be very time consuming, in order to evaluate the effect of the implemented method or tool in industry. It will on the other hand give a very robust documentation of the proposed method or tool.



Methodology (A)



Methodology (B)

Figure 2.2: Approaches to the research methodology. Methodology (A) illustrates a method for developing theory or checking theories (Schiefloe 2003). Methodology (B) illustrates a common model within engineering disciplines, where there is an iterative process (Blessing et al. 1998)

Finally, my background in Action Research should be pointed out. This methodology, using interactions between the researcher and the researched colours my role as a researcher:

Education background; I have a background as a mechanical engineer (Bachelor and Master's degree) with a specialisation within product development methodology. During my education and the courses within the PhD. study I have taken courses that look deeply at direction design methodology and manufacturing issues.

Industrial experience; My knowledge of product development and manufacturing is primarily based on experience from two companies; the research centre SINTEF and Electrolux Motor AS, Sarpsborg, a manufacturer of consumer goods. I was a researcher in SINTEF for one year. The work at SINTEF was primarily with HAST for this PhD study. I have worked at Electrolux Motor AS during my study breaks and holidays for a total of 7 years. At Electrolux I had the chance to participate in a range of activities from the assembly of commercial products to the development work in the engineering department.

2.2 Case studies

Case research has consistently been one of the most powerful research methods in operation management, particular in developing new theory (Voss et al. 2002). Research within operational management and design research share many similarities, as both address physical and human elements in the organisation. Within engineering design this approach can give us good insight into the challenges, since case research has high validity with practitioners. Case studies investigate a contemporary phenomenon within a real life context, especially when the boundaries between phenomenon and context are not clearly evident (Yin 2003). Case studies give the ability to cover contextual conditions. An experiment (in a laboratory), for instance, deliberately separates phenomenon from context, so that attention can be focused upon a few variables. Case studies can also be based on any mix of quantitative and qualitative evidence. In addition, case studies need not always include direct, detailed observations as source of data. They can be used to explore those situations where the interventions being evaluated have no clear, single outcomes (Yin 2003).

2.3 Addressing the research questions

HAST has to handle the challenges of being in a market where there is strong competition between different firms for projects. They have realised that to be able to have a competitive advantage in the future they have to improve the leanness of the product portfolio. In order to learn more about product programme and how it can be implemented with the type of product HAST manufacture, the following research questions have been formulated.

The main research question:

How can production-, supply chain- and technological knowledge be described as a Corporate Platform useful for customizing products?

The main research question is complex and handles different subjects, by concluding the sub-questions the main question should be answered. In order to describe in-depth the research approach, each research question has a short introduction to the topic. A bubble model, Fig. 2.3, illustrates the main theories that are associated with this research, and these are: engineering design theory, supply chain theory and technical language theory. Within the different theories several topics associated with the question are illustrated. The topics are coloured to indicate a rough indication regarding essential or useful information. Where this thesis should contribute in the theory is also indicated.

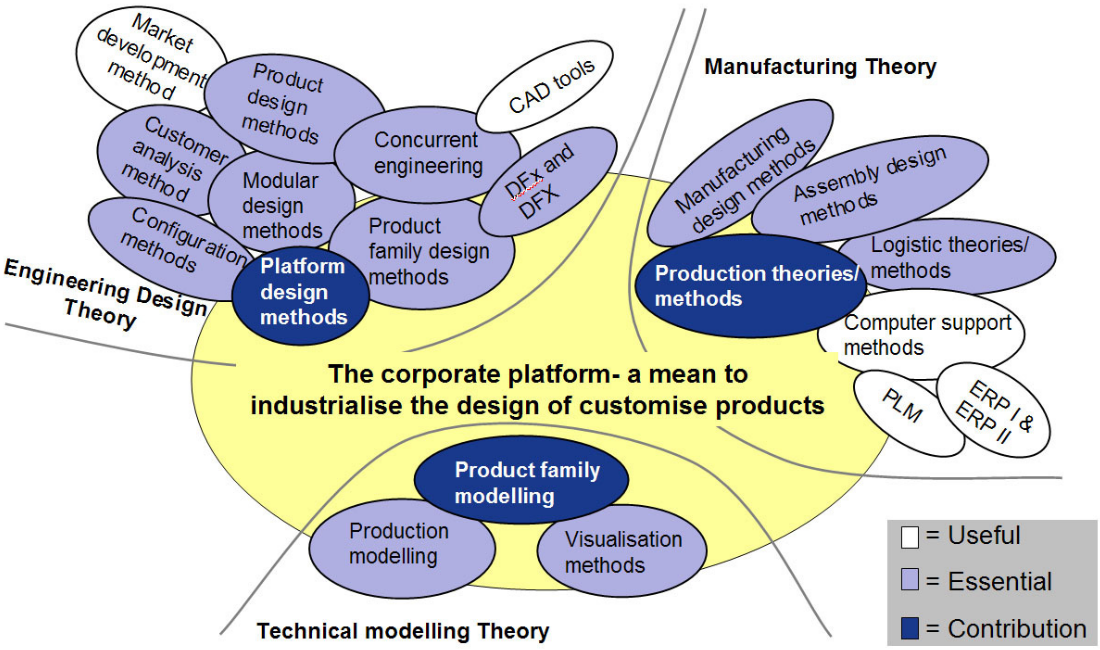


Figure 2.3. The bubble model illustrates the related theoretical topics that affect the main aim.

From this base of exist theories and methods the sub research question will have a research approach as this:

RQ 1. *How are product platform- and modular design described and handled in theory?*

This question focuses on the theoretical aspect and is a literature study. The literature study should provide theoretical knowledge about the three main theories. It should also result in a state-of-art description about design for product variants.

RQ 2. *How are product platforms described and handled in the industry?*

Established 'best practice' knowledge in a set of Norwegian companies should be performed. The companies selected should design and manufacture products and product variants and preferably include at least one additional automotive company as a project partner. The research approach should be based upon a logical induction with an interview study that compares practice with theory.

RQ 3. *How can a Corporate Platform be modelled?*

Between the company and the customers there are many relationships. The company has some fundamental characteristics and core assets that are used to develop new products and the belonging manufacturing processes. These relationships seem to be important to understand and model in order to understand the development of a product programme. Market understanding, design tradition and information management may also influence the development of products and the ability to utilize product platforms. This question needs to look into a cross discipline area and a close relationship with the industrial partner is required. The research approach should therefore be activity based, so that the interaction with the company is close too.

RQ 4. *How to handle the product assortment evolution?*

The Corporate Platform contains all the company's core assets from which new platforms can be generated. Both the products and technology that are derived from the Corporate Platform are dynamic. There is constant change in product assortment adding- and removing products. The understanding of these processes may have great influence on portfolio management and the well being of the company. This research question is closely related to life aspects of products and product platforms and how they secure a high reuse in the company's Corporate Platform. Case studies are an appropriate method research to answer this issue.

2.4 Research cases

A vital part of the research for this project has been on case studies. The case studies have given in-depth knowledge on how the company is operating, performing the design of products and the manufacturing processes as well as on product understanding.

In this research there have been used four cases to establish knowledge and find answers to the research questions. The project has been characterised as using different ways of gathering empirical data, depending on the case, Fig. 2.4.

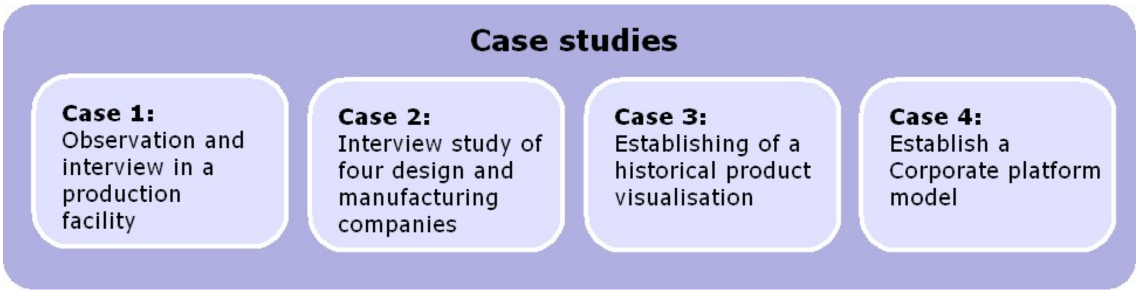


Figure 2.4: The case studies

Case 1: Observation and interview in a production facility
This study can be seen as a pre-study. The intention was to gain detailed insight into the manufacturing processes and how they could handle product variations, if future requirements were changed. A set of variables belonging to the manufactured products was altered and the effect evaluated. This research was done via observation, interviewing and collecting of data. The study in the manufacturing department was conducted over a two-day period. This case gave background information to be able to answer to research question 3 and 4.

Case 2: Interview study of four manufacturing companies
The research methodology was chosen to include both consumer-sales companies and OEM-supplier organisations, in order to highlight possible differences in the use of platforms and in the role of platform design. This case focus on topics related to research question 2.

The study is based on a series of interviews. Four companies are analysed: two OEM-suppliers, Hydro Automotive Structures and Kongsberg Automotive, and two consumer-sales companies, Ekornes and Stokke, which both produce domestic furniture. All of these companies are located in Norway, a country with high labour costs and relatively long distances to their global customers. The customers are mainly in the European Union, but also in the USA and Asia. They all have long logistic chains in order to reach the market.

Case 3: A historical product description
This case gives also vital background information for managing the product variants as well as setting the future direction. In order to find a product programme that is suited for Hydro, there is need to have an in-depth look at their existing products. Describing and establishing what the Corporate Platform is in a wider context than the traditional core competence. The case should search for elements that couple the different disciplines such as design, production and supply, in order to secure that important aspects are taken into account. The research is based on interviews (face-to-face and via the telephone), workshop meetings and documents with raw data. The case is related to the evolution aspects and information feedback into the Corporate Platform model.

Case 4: Establish a Corporate Platform model
This case has the intention to provide a model establishing the relationship between market / customer, company assets and the products. When designing new products there has been a tradition to develop a product without putting too much attention on product variants and the existing infrastructure. This model should be able to aid the designers to increase the reuse of existing infrastructure (Corporate Platform) and be more aware of design consequences when new platforms or product variants are designed. The research method used is to structure the case around existing products and new product concepts. The research is activity based, built around ongoing research in the company and theoretical studies. The case forms the base for answering research question 3.

2.5 Data collection

In this thesis the method of data inquiry has been through several approaches: in-depth interviews, action research and case studies of the company's products. During the whole study there has been continual contact between the author and the company.

2.5.1 The interviews

Qualitative interviews and informal conversations have been an important method for data inquiry, in order to understanding the company's way of designing and managing products. The research is based on 9 qualitative interviews and a range of shorter conversations. These interviews were in-depth, performed in the middle of the project together with a research partner.

The qualitative interviews were conducted according to the techniques of Kvale, S. (2001). An interview guide was used, and part of this guide was sent to the interviewees some days in advance. The conversations were aimed at being a guided conversation rather than structured queries. The intervieweese were partly selected by our contact person at the companies or by direct contact by us. The interviewees were primarily managers and senior engineers all working with product development or R & D departments. Most of the interviews were performed individually and in their working environment. All were male and either had a doctorate in engineering, or were qualified engineers or engineers that had worked their way up from apprenticeships. All of them have been working in the company for many years. Each interview lasted from between 1.5 to 3 hours. The interviews were focused around one of each company's products, in order to be able to delve deeper into the development process and the company's overall way of doing things.

All the interviews were recorded, transcribed and classified in order to perform a detailed analysis. The questions and responses were classified and grouped by topic, based on Robertson's (1998) lists of core assets (components, process, knowledge and people & relationships).

2.5.2 Activity based interaction

Activity based research is based upon long term interaction with several people in the studied company. The interaction was rich with meetings and discussions, formal as well as informal, face-to-face or through e-mail. The workshops were held at the company and often combined with small interviews and visits to the manufacturing facilities. Many of these small interviews appeared as a consequence of topics discussed in the workshops and were not planned, but have given valuable information for the research.

2.6 Verification

The NUTS- research programme is a sub-project under the Norlight umbrella of research programmes. The main aim of Norlight is to:

"*provide the necessary competence required for increasing the Norwegian light metals industry's turnover of finished products and components*".

The NUTS project focus is on the Design and Production aspects and has several industrial partners. This PhD project focuses on improving the relationships between product designs and the associated manufacturing, by using a product platform design approach. An acceptance by the NUTS partner companies and in particular Hydro, is obviously important for the work. A verification of the work is also needed in a scientific sense. Buur (1990) and Berg (2005) point out that verification can be problematic in design science. An experiment in a laboratory with all the influencing factors can be replicated and verified. In the design science, working within a dynamic world there are many uncontrollable influencing factors, all of which make a precise repetition of the work impossible. He therefore suggests the work should be verified by the scientific community and by logic verification. In this thesis all methods have been used. The methods are described as:

Logic verification

- Consistency: there are no internal conflicts between elements of the theoretical findings
- Completeness: all relevant phenomena observed can be explained or rejected by theoretical findings
- Well established and successful methods and models are in agreement with the findings
- Cases and problems can be explained by means of theoretical findings

Verification by acceptance

- The scientific community accepts the theoretical findings and statements (publications)
- Models and methods derived from the theory are acceptable to experienced practitioners
- Models and methods are taken into use in new projects

3 Design for product variation, literature review

The evolution in product development is changing from a focus on mass production to mass customisation. A product designed for mass production or products developed without future variant consideration, are so-called “one-at-a-time” products, Fig. 3.1. The design team focus on satisfying one set of requirements and optimising all manufacturing processes for each product. This is a traditional way of conducting product development, but it has its limitations when it comes to providing product variants at a lower production volume and at a lower cost. This is where product programmes with product structures utilising product platform or modular design are efficient, Fig. 3.1. A product programme consists of multiple products, designed on a, or several, product platform(s) and planned to enter the market at different times or in different market segments. A product programme is built around the likelihood that groups of customers have the same needs. These groups of needs give the opportunity to develop products customised for these needs and implement reuse of company assets. Since this involves decision making for many products at the same time, the risk profile is different. A one-at-a-time project has a risk profile that is for one product and if this fails to be successful it most likely has an impact on the other products. The risk profile will be repeated for each new product launched. For a product programme, the risk profile is related not only to the success of one product, but several. The risk for entering the market is large. Success of the product platform is critical. When it comes to deriving new product variants the product programme has a low risk profile, due to a large portion of reuse.

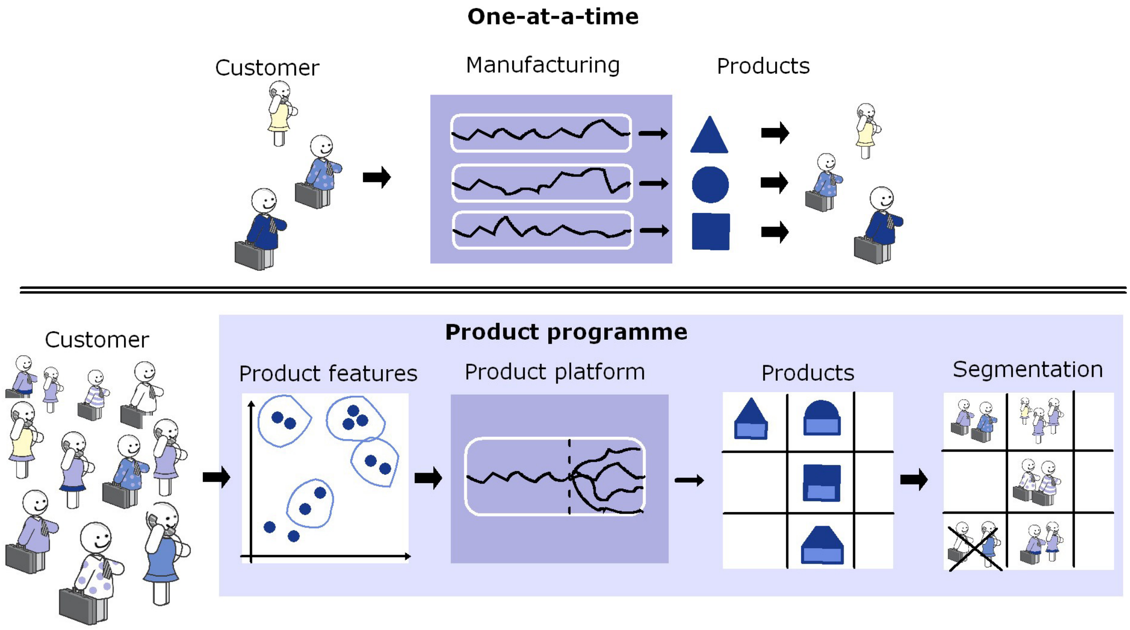


Figure 3.1: The differences between “one-at-a-time” products and product programme based products.

This change has led to the development of different methods to establish product design that fulfil the individual customer’s needs and simultaneously maintain the benefits of mass production. Very closely related to this is the simultaneous focus on establishing a lean portfolio of products.

This chapter will give examples of this and existing methods to perform portfolio management and how product variation can be created with a high degree of internal commonality in the company. The focus will mostly be on the detailed methods engineers use to synthesis or evaluate concepts to create this balance between variation and commonality.

3.1 Stories of companies that have successfully managed product portfolios and created products platforms

There have been several success stories around products based upon a product platform. In the next paragraphs some of these stories are told. The stories are mostly viewed from a technical perspective. Other views on a product portfolio may be seen from a strategist who is more focused on resource allocation and the company's vision and mission. A financial view may have looked more at the allocation of the scarce financial resources the company has and how to maximise shareholder value, while the market view is more about getting products more quickly to the market.

As the market for home and office computers increased in the 1980s, HP developed an ink jet printer with the associated component technology and manufacturing (Meyer and Lehnerd 1997). The first model, the ThinkJet printer, was reasonably priced and performed quite well. It needed special paper however and failed to sell in large numbers. The design team set themselves high goals for improving cost, printing speed, quality and printing on normal paper. After 22 months their new product cracked the dual barriers of cost and quality in the printer market. The foundation of this was an underlying platform architecture that new products could easily be derived from, providing an unparalleled level of function and price. This platform architecture consists of three sub systems mechanical elements, electronics and software. Each of these systems has clear interfaces, physical, electronics or software. Even if this platform was developed in a short time the team made excellent design decisions. The price target was also well reached. The base printer was sold for less than $400, well below their competitors. The basic architecture was used for over a decade, with only minor updates once every two or three years. Based upon the "500" series architecture two other platforms were created; the "600" platform and the "800" platform, all targeted at different market segments, Fig 3.2. Appendix VI, shows how the HP "500" platform, "600" platform and the "800" platform developed through the years.

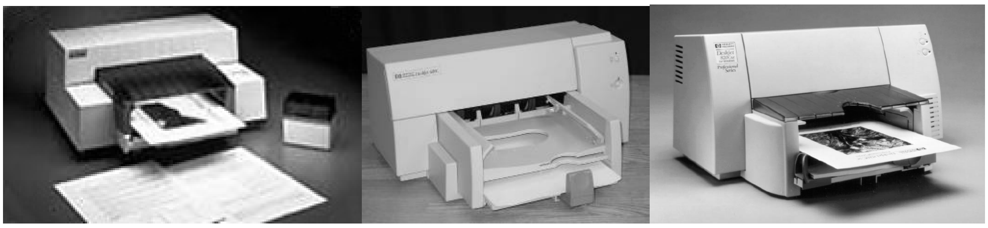


Figure 3.2: The HP 500- 600- and 800-series Deskjet printers

The automotive industry has for a long time utilised their platform structures to leverage product variants. The car models come in a variety of combinations; sedan, coupe, hatchback and cabriole, but the platform structure is often used across brands owned by the same company. In the mid 1990s Volkswagen and Ferdinand Piech aimed at implementing the world's most ambitious common platform scheme (Kable 1996), going from 16 platforms to 4 platforms, among their Volkswagen, Audi, Seat and Skoda brands. Among these four platforms the A-platform was the largest and carried 26.6% of Volkswagen volume (Israel 1998). The A-platform is found in their medium sized cars, such as the VW Golf, Audi A3, Seat Cordoba and the Skoda Octavia. This platform was one of the first successful platform structures designs used across a large range of car models and brands. This is partly due to the platform's ability to stretch and flex to accommodate different length and wheelbases. "*A platform doesn't mean that each millimetre measure is the same… It just has to go through the same systems of manufacture*" said Piech (Johnson 1997). The platform carries about 60% of the value of the car. The rest of the body and interior can be developed in 24-30 months. This made it possible to achieve the shortest development time among German luxury brands with the Audi A3. From design freeze to the start of production it took two years and cost DM 800 million, two thirds of which was for the car and one third for production equipment (Chew 1996). For the Skoda's Octavia model the development cost finished at DM 500 million, including a brand new production facility. It should also be said that this sunshine story also has its dark clouds. Piech cancelled all of Volkswagen's contracts with the sub-suppliers and made them compete for new ones. He pushed them hard on cost and as a result Volkswagen had several expensive warranty updates, due to component failure. Another issue Volkswagen has struggled with is that people have been aware of the fact that the cheaper Skoda Octavia shares so much with both the VW Golf and Audi A3 and find no reason for buying the more expensive cares. A complete illustration of Volkswagen's platforms is found in appendix 3.2.

An example of newer car platform architecture that has been very successful is the Volvo P2 platform (D3 Ford), Fig 3.3, (Lung 2003). This platform architecture seems to be able to avoid the cannibalism that appeared to affect some of the brands and models in the Volkswagen platform programme. This product platform, as have both of the others, introduced something new in addition to a plan for leveraging new product variants to different customer groups, so there is no cannibalism. The Volvo platform had one major new innovation and a stream of smaller new innovations, which have made it a success. First the car platform used a transversal engine and the concept of cab forward to increase the internal space in the car. A car with a lot of internal space was created, increasing the flexibility. The first model to appear was the 850 in a sedan and estate. These models were manufactured for some years, before there was a small update on the platform, introducing among them a four-wheel drive system. Then there was a rapid increase in the product variants offered, from convertible to SUV and extreme sport versions (S60R). Several new innovations have been presented as the first transversal straight six cylinders and V8 and at this time there are still more models to come especially under the Ford brands Ford and Lincoln (reference.com 2005), (cars.com 2005)

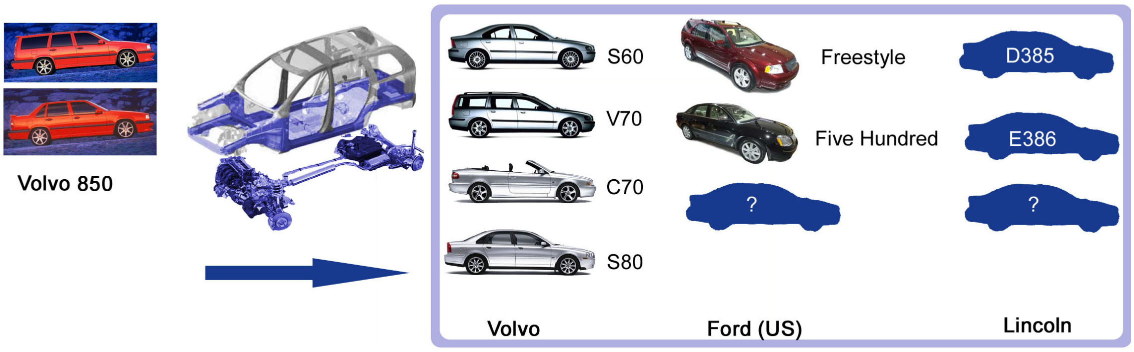


Figure 3.3: The evolution to the Volvo P2x platform in Volvo models and other brands under the Ford company. It is the underbody and drive train that are shared.

To establish a portfolio management and the products with product structures as these examples describe, is not done overnight. There has been focus for a long time on topics related to the company's strategy, management (resource allocation) and in the details of how the products are designed. Before we go into detail about the cost benefits of doing this, the cost elements that can be affected should be pointed out.

3.2 Which cost elements can design for product variation affect?

In the examples of the HP DeskJet, VW-platform and Volvo P2X platform the intention was to develop a product structure that can provide increased profit for the companies. Cost is a very essential factor in making decisions between projects and products to be developed. A number of metrics have been developed to quantify any benefits or drawbacks for the product platform. Meyer and Lehnerd (1997) suggest that the efficiency and effectiveness of platforms can be measured as follows (1 and 2):

$$\text{Platform efficiency} = \frac{\text{Derivative product engineering cost}}{\text{Platform engineering cost}} \tag{1}$$

$$\text{Platform effectiveness} = \frac{\text{Net sales of a derivative product}}{\text{Development cost of a derivative product}} \tag{2}$$

These indices base their information on projects that have been conducted and where financial information is available. When a platform project has yet to be run it must be estimated and in the early stages of development, cost is very diffuse. It is hard to find data that are reliable for cost calculation and the elements of uncertainty are high. Evaluation methods often use therefore evaluation criteria not based upon cost, but that can be indirectly linked to cost. A list of what a product programme can expect of benefits is illustrated in Table 3.1.

Table 3.1: Effects of designing for product programme (Franke et al. 2002)

Elements in cost calculation	Benefits of designing optimal product variants
Development cost	• Fewer product structure variants • Fewer product customisations • Increased standardisation • Fewer part- and identification number • Increased parametric: process re-use, partially automatic variant generation • Cost and functional optimisation of the variant steps • Fewer CAD models, drawings and part lists • Fewer tests and prototypes • Increased flexibility through postponement • …
Material cost	• Reduced number of material- and semi-finished goods • Reduced number of sub-suppliers • Reduced number of purchase operations • Reduced cost of storing • Reduced circulation of goods • …
Manufacturing cost	• Larger product batches • More suitable machines can be used • Reduced special tooling • Reduced number of devices • Reduced number of NC-programmes • Fewer work schedules • Better capacity utilization • Increased automation • Fewer for example, simplifying of assembly set ups • Increased number of modules that can be pre-assembled independent of end-product • Reduced time of flow • …
Quality cost	• Reduced number of measurements stations and tools • Increased experience and reuse • Reduced wreck and rework • Fewer customer claims • …

Cost in sale and marketing	• Early high grade sales information • Configuration together with the customer • Less product documentation • Reliable sales argument • Better price strategy (preferred product variants on reduced price, special product variants are avoided) • Packet offer (special product variants made from standard process) • Reduced shipment time • …

3.3 *Portfolio management*

Portfolio management is about project prioritization and resource allocation in the company. That is, which new product projects should receive funding and what priority should they have. It is about optimal investment mix between risk versus return, maintenance versus growth, and short-term versus long-term new product projects (Cooper et al. 2001). Portfolio management for new products is a dynamic decision making process where the list of active new products and R&D projects are constantly revised and Go/Kill decisions are taken. What happens when this is done poorly? First there is a strong reluctance to kill new product projects, Fig. 3.4. Projects seem to take on their own lives, passing through review points and added to the "active" list with little attention to the resources needed. The projects end in products that are very often developed independently of other products. This independence means that all incremental improvements, error corrections and updates have to be done separately for each of these products. Over time this can occupy the resources in an inefficient manner as the portfolio grows.

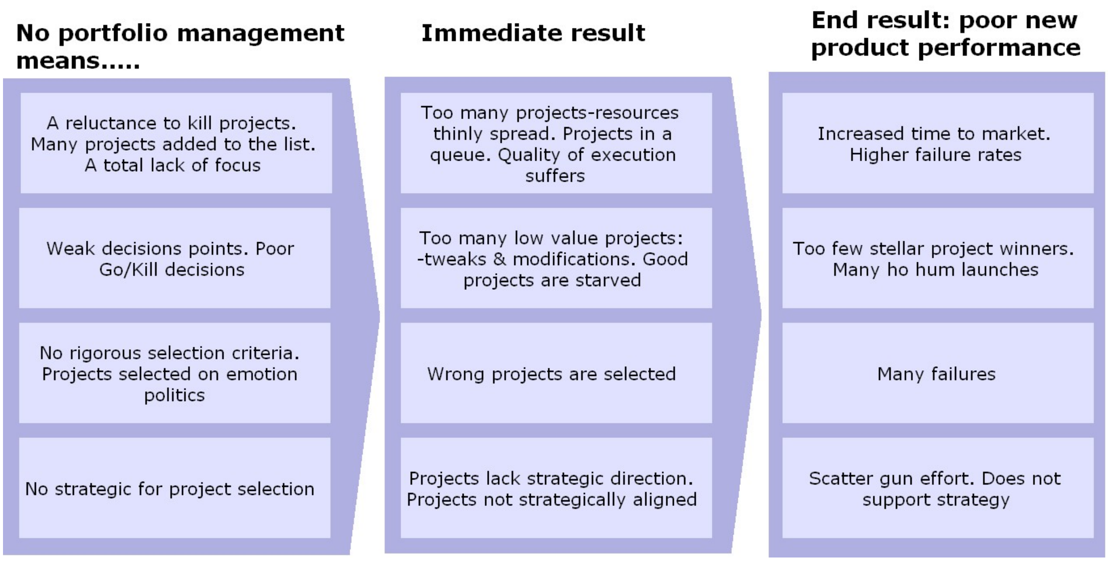


Figure 3.4: The results of no strategy for project selection and portfolio management methods (Cooper et al. 2001)

Portfolio management can be just the management of a set of products, based on market demands, but it can also be much more. If the management of the product portfolio is combined with the design of the product, it can evolve into a powerful advantage for the company. To do so the company needs to look into more than just product development. The strategies and financial elements need to be integrated into the management of the product portfolio. Portfolio management interacts closely with the product strategy the company has decided. The main business strategy direction can be set according to some central paradigms; Porter's three generic strategies; lower cost, differentiation and focus (Porter 1985), Anderson and Pine's four manufacturing paradigms; mass production, continuous improvement, invention and mass customisation (Anderson and Pine 1997) or other strategies.

Cooper et al. (2001) propose that portfolio management methods could be grouped into seven categories:

- *Financial and economical models:*, this is much like a conventional investment decisions, with payback period, break-even analysis, return on investment and discounted cash flow (net present value, internal rate of return)
- *Scoring models and checklists:*, give a project score that can be used against a standard, Go/Kill decisions or simply to rank projects against each other. These techniques can be used with limited knowledge about the finances and are therefore most useful at the earlier points, for example, at the initial idea screening and even the go-to-development decision point.
- *Probabilistic financial models:*, this model is intended to handle the elements of risk and uncertainty in development projects. Approaches often used are Monte Carlo simulation, decisions tree and options pricing theory.
- *Behavioural approaches:*, is a group of models where the modified Delphi model focuses on a group of decision makers engaged in an open discussion, followed by individual decision making. Other methods are sorting of the projects with ranking in several iterations.
- *Mathematical optimisation procedures:*, is a mathematical routine that attempts to find the optimal set of projects in order to maximize objectives.
- *Decisions support systems (DSS):*, is a mathematical model that allows the managers to make decisions, use judgment and work in areas where no one knows exactly what to do. This model relies on statistical methods, simulation and optimising models to guide in the decision process.
- *Mapping approaches:* are typical bubble diagrams that display the projects on a X-Y graph. Various parameters are plotted against each other.

From this list it is clear that portfolio management involves many topics of relevance in managing the product variant development.

3.4 Product platform strategy and product variation

Introducing product platforms and portfolio management without a product strategy is like performing product development without knowing what to develop. McGrath (2001) points out that the set-up of the strategy for a product platform and portfolio management should be done in several steps. The *product strategy* consists of three elements, as seen in Fig. 3.5; a core strategic vision, platform strategy and a product line strategy. Within the same context Kristjansson (2005) discuss the platform related to strategies and market demands.

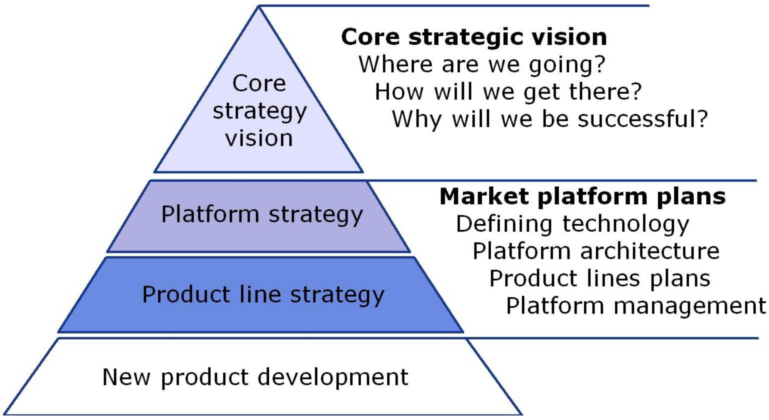


Figure 3.5: The different levels of Product strategy (McGrath 2001)

Core strategy vision: A product strategy starts with a vision, that states where a company wants to go. In the very short term this is what it is about. The subject has been commented upon by many authors and is not commented upon more here.

Platform strategy: It defines the cost structures, capabilities and differentiation of the end products. To establish a successful platform strategy, McGrath (2001) proposes some features that are important:

- The underlying elements of the platform are understood
- The platform's defining technology is clearly distinguishable from other platform elements
- The platform's unique differentiation provides a sustainable competitive advantage
- No more than one platform should serve a market

Product line strategy: This is the strategy for the specific products that are to be offered and the sequence in which products are developed and released. This topic has also been called a product programme (Aasland et al. 1998). McGrath (2001) proposes also some features here that are important:

- The product line covers all primary targeted market segments. There are many ways to segment a market, the key is to do it so that it provides a competitive advantage.
- Each product offering is sufficiently focused to avoid cannibalism and market confusion

- The product line development schedule is time phased
- Similar product families and product lines are coordinated

New product development: This is the development of each of the specific products offered for the market, based on the strategies above.

3.5 The customers' view of product properties and product choices

The dynamics of the market and how they influence the company's products are important to understand. The customer responds quite similarly to products as to the basic human needs model from Maslow (1943). The Maslow pyramid states that the human needs can be arranged into a pyramid structure, where there are some physiological needs at the bottom and some growth needs at the top. He also states that each lower need must be fulfilled before moving to a higher need. The analogy in the product-human world may be a model developed by Professor Noriaki Kano. The model is also named Kano and describes customer satisfaction. The model illustrates how the customer interprets the quality aspects of the product, Fig. 5.6 (Berger et al. 1993). The horizontal axis describes the degree of functionality of the product and the vertical axis indicates how satisfied the customer is. The three curves in the graph illustrate the customer's response to the product. Some customer requirements behave as *One-dimensional*. For example for fuel consumption of a car, the lower the fuel consumption, the more satisfied the customer. The curve *Must-be* indicates aspects where the customer is more dissatisfied when the product is less functional, but never rises above neutral no matter how functional the product is. Example of this could be to have good brakes on a car. The customer becomes dissatisfied if they perform badly. The last curve, the *attractive*, indicates areas where the customer becomes very extra satisfied, but not dissatisfied. This could for example be the car's crash performance.

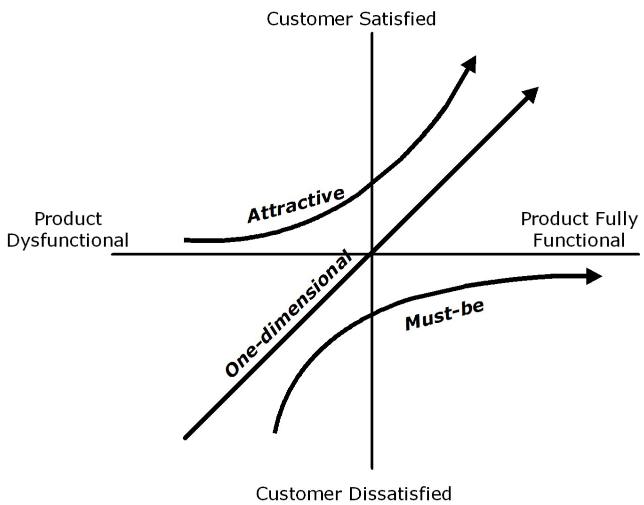


Figure 5.6: The Kano model can be used to describe how the customer perceives the product attributes as a must-be, one dimensional or attractive

Other important aspects in how the customer perceives product choices are investigated by Swartz (2005). The industry and the science community use lots of resources in finding solutions that can satisfy a larger portion of the community. Having a large portfolio of products seems to be important, but how do the individual people buying the products actually react to an increase in choices? We have many more choices today than only a few years ago. To an extent, it is only logical to think that if some choice is good, more is better. This allows people to select precisely what makes them happiest. Yet recent research strongly suggests that psychologically, this assumption is wrong. In the U.S. the gross domestic product has more than doubled in the last 30 years, while the portion of the population describing them as "very happy" declined by about 5 percent (~14 million people). Schwartz's study has categorised people into "maximizers" (those who always aim to make the best possible choice) and "satisfiers" (those who aim for "good enough", whether or not a better selection might be out there). The maximizers engage in more product comparisons, both before and after a purchase, and they use longer time to make their choice. They exert enormous effort in reading labels, checking out consumer magazines and trying new products. The satisfiers find an item that meets their needs and they stop looking. It is found that the maximizers make better objective choices, but get less satisfaction from them than the satisfiers. Losses make us hurt more than gains makes us feel good, Fig. 5.7 (A). A similar feeling of well-being initially rise as choice increases, Fig. 5.7 (B), but then levels off quickly. Meanwhile zero choice evokes virtually infinite unhappiness. As the number of choices we faces increases, the psychological benefits we derive starts to level off, and the negative effects of choice accelerate. The net sum gives an optimal sum of choices before the negative emotions increase.

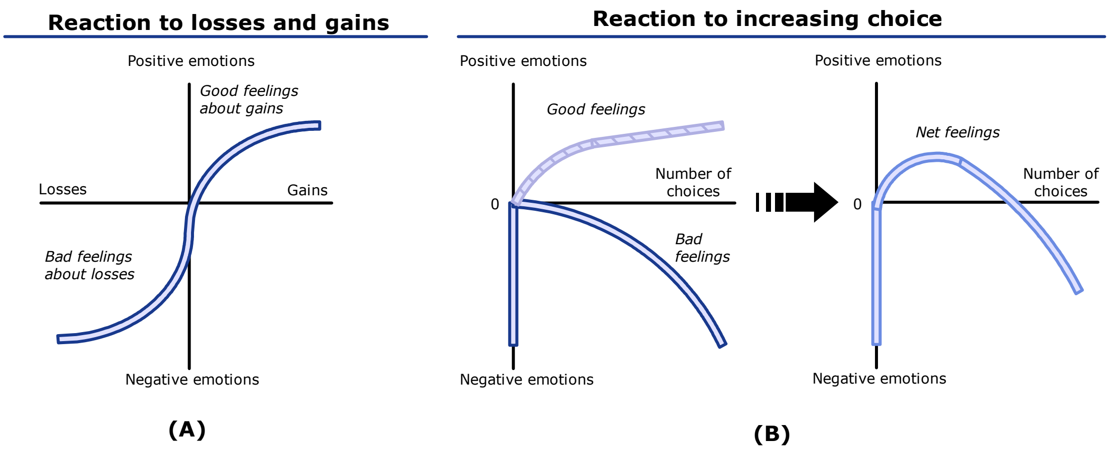


Figure 5.7: Feelings evoked by ever more choices (Schwartz 2004)

So to ensure that the customer has positive emotions towards the products, choices should be possible. It is though important as Maslow and Kano indicate that the right attributes are not forgotten, but enhanced to make the product better. One should also be very aware that an attribute that is in the attractive category can change over to a must-be. There is a dynamic in how the customer perceives the products' attributes.

3.6 The complexity of setting the focus point for the new product development

Even when a strategy is set there are many obstacles to sort out for the company. A company consists of different organisation levels that affect the design of products. It is not only the product development organisation that sets the agenda for the product development, but all the departments in the company affect the development. The company's strategy may affect the structure of the product portfolio and this is, as mentioned, closely related to the product architecture. It is therefore vital to have broad views of the organisation and the products when changing over to a platform based product portfolio. By approaching this at different levels in the organisation ideas can evolve and future directions can be drawn. The levels can be grouped (Ahm et al. 1994):

- *Corporate level:* the interaction between the product and other types of company products
- *Family levels:* the relationship between the different variants in the same product family
- *Structural level:* the relationship between the different sub-systems/components
- *Component level:* the design /specification of each individual component

Corporate level

The corporate level is at the top and is part of the company's top management. They have the opportunity to make strategies that directly influence all other levels. If we look at two companies, Hydro and SAPA. Both are dealing with aluminium and if we compare them we can see how decisions made at the corporate level affect the other levels (Hydro Aluminium 2002). Before Hydro bought VAW they produced extruded profiles and rolled products as their business. Now aluminium casting is also part of their know-how. The know-how affects what the designs will look like. So before VAW became a part of the company the design division didn't give casting and sheets an opportunity in the development of new concepts. Since all three areas have now been placed under the same umbrella, the designers are forced to work with all processes. SAPA has also extruded profiles as their business and rolled strips (SAPA 2002). Looking at their product and their main focus area it is easy to see that their designs are also based on the internal know-how.

The culture of the organisation affects to a large extent the outcome of product development. Gullati and Eppinger (1996) state that if the organisation is static the product architecture developed is likely to be the same over many product generations. Changing this architecture also becomes difficult. An approach to avoid the stiffness, the organisation could be split into project teams that generate slightly different architectures. It has though both positive and negative aspects. It may avoid the stiffness, but it might also lead to a duplication of engineering efforts or developing technology that cannot be shared, all leading to more expensive products.

Family level

At the family levels decisions about the type of different variants that should be produced and when they are launched are taken. A good family design will generate distinct products for the customer, while they can be manufactured in the same way and consist of nearly the same parts. One example is the bumper beam that Hydro produce. This part is made from an extruded profile that is formed by a stretch-forming process. They produce a series of bumpers made by this technology, with only small changes in the manufacturing. They have developed technology to produce several types of bumpers in the same tool, by just replacing parts in the tool.

Structural level
As the main structure of the family has been established the structural relationship in the product is presented. At this stage design for platform- and manufacturing methods are more visible and carried out more frequently. All the products structure processes are reviewed from reuse of components, manufacturing, assembly and packaging. At this level the know-how about the interfaces between parts / modules become central. This is both related to a removable- or fixed connection

Component level
At the last level, component, it is easier to present new ideas, but the impact of the cost reduction is less at this stage than all the previous. This will typically be to optimise the design of individual components in the products, with regards to the manufacturing and/or assembly. Within this level there exist many specialized methods, e.g. Design for Casting, Design for Welding, DFX, etc.A group of these designs for x (dfx) have been given a common name, universal consideration.

3.6.1 Universal considerations

A product development project has many targets to meet, regarding cost, quality etc. The targets may vary greatly from project to project, but there are only a limited number of general measurable quantities. From several studies seven so-called universal considerations (Ahm et al. 1994) have been established. These universal considerations affect all products developed and they are involved in the whole life cycle of the products. The importance of these factors has to be seen together with the company's strategy and will shift focus depending on if the product is a one-at-a-time, a first product in a product platform or a derivative product variant. A short description of these seven universal considerations follows:

1. *Production costs*
   Production costs can be grouped in direct costs, covering labour, materials, and overheads or indirect costs covering logistics, quality, purchase, space, cost, etc. A well-designed product has a solution that makes it low labour intensive, it doesn't waste materials. The flow of materials and information is streamlined through the entire supply chain.
2. *Quality*
   Quality is an important aspect and it may be seen from many viewpoints throughout the life phases. The primary quality goal is to satisfy the customer expectations of quality during use of the product. The other aspect is related to the internal quality. This is more related to the level of quality control, rework that is needed and the scrap percentage.

3. *Flexibility*
   Flexibility is linked to the ability the company has to adapt to the desired changes in the manufacturing output. This may be the change to update existing product, new variants or entirely new products, with the minimum of new investment on inventory.
4. *Risk*
   Risk is related to releasing new products, entering new marked, investing in new manufacturing equipment and to implementing new technology in the products or manufacturing. The level of risk is therefore much related to the situation.
5. *Lead time*
   The lead-time is the time from an order is scheduled to be produced and the time it takes to execute the order. Earlier the order was scheduled in month or weeks. A focus on this aspect and Just in Time has increased the focus on lead-time reduction.
6. *Efficiency*
   The efficiency is in the utilisation of the human and capital resources. Optimising these resources and finding the right balance is important
7. *Environmental effects*
   How the product is established has a large impact on the environmental effect. Both how the product is manufactured, the operating life and scrapping/recycling of the product is mainly determined in the design phases.

3.6.2 Universal considerations versus the design sequence

The universal considerations are among the factors that management steer the business with. Looking at two examples: The Toyota Company works very hard to satisfy the customers' experience of quality. This experience is the primary focus and all the other universal considerations have a lower priority. The other example is the Th!nk electric car. The makers of which focus very strongly on the environment and have designed the car to be as environmentally friendly as possible, but they are also introducing something new onto the market and therefore the risk factor is therefore also high.

As this type of decision is made by management, it must be a part of the designer's way of designing. Linking the universal considerations with the design process can be a tricky task, see Figure 3.6. Both axes the life phases (x-axis) and the universal considerations (y-axis) can be looked at as two ways of conducting design for x. In a way they can be considered as DFX (life phases) and Dfx (universal consideration), with a small x. If focus is on the universal considerations e.g. quality improvement, all life phases for the product have to be considered. Eliminating or forgetting one of the relevant phases, let's say production or assembly, the engineers will not meet their quality targets and the product will most likely fail that target. Each phase has to be considered thoroughly, looking at the whole product.

When it comes to the methods that are not linked to the whole life phase, but only a small section of it, they must be used with the awareness of the rest of the phases. Under the life phases many methods can be found. Some are very wide and do not go into the small details and others are very specialized and cover only a small section of one of the phases. Like design for manufacturing is a wide term, but it still covers only some of the life phases, and under this term many different DFx methods exist. Each of these methods covers the universal considerations in a different way. It is therefore important that the designer uses the right DFX(x) methods to meet the overall aim for management as well as a quality check of their own work.

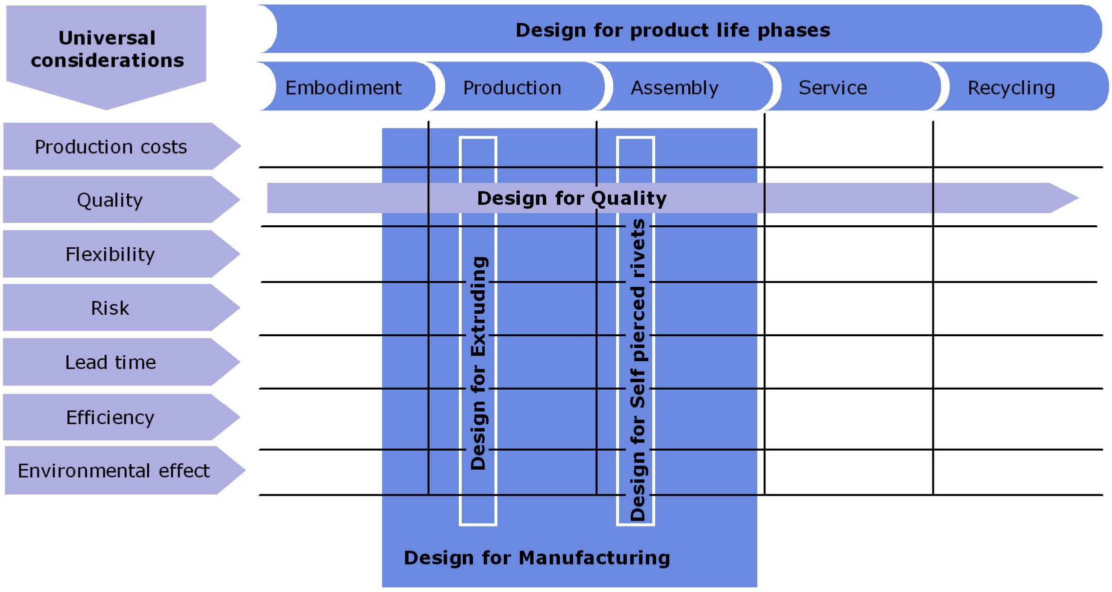


Figure 3.6: The design process linked with the universal considerations and linking how they are influenced by using different goals in the design process

3.7 *Product representation*

In order to utilise the different design for x approaches, ideas needs to be communicated between people. This communication method is closely related to the point of view needed, e.g.: early- / late in the development phase, related to manufacturing- / simulation decisions, a single- / product variant design etc. Before an in-depth description of different product representations, a review of historical engineering representation is given.

3.7.1 Historic view of engineering representation

One of the cornerstones in engineering design is graphics. Graphics is the essence in making the link between engineering-, production- and supply chain design. Ideas appear in people's mind and are made visual, in order to be transferred to other people. The communication consists therefore of an idea that is coded, sent, decoded and understood. This process very often uses a pen and paper as the medium to make graphics and notes on. The use of our language is an example of communication where there are a set of rules and practice of doing it right. If we have a look at the world, each country has its own language, the same analogies can be found in different disciplines. Disciplines have a set of rules of how the communication is done, this includes engineering design. Some very early graphics used to communicate were the hieroglyphics in Egypt around 3400 BC. The graphic language used pictograms to represent objects and phonoglyphs to represent the sound of the word describing the object. As papyrus was developed the complexity of the drawings increased. Much later, around 1450 AD, Leonardo da Vinci made some very famous drawings. He was an excellent sculptor, artist, scientist and engineer. His skills in drawing and use of colour made his work known today. Fig. 3.7 shows an example of one of his weapon systems, illustrated with a detailed drawing and additional notation. The drawing gives information about the working principle, the size (a man is included for scale) and also how it should be manufactured (wood and rope material can easily be identified).

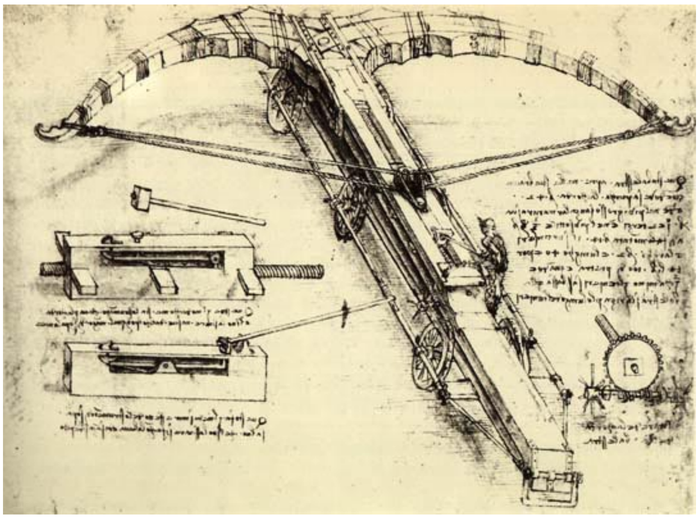


Figure 3.7: One of Leonardo da Vinci's sketches

The modern way of describing geometry was developed by Gaspard Monge (1746-1881). He was a military student in France, working with problems related to fortification and battlements. Usually these problems were solved with a long and tedious mathematical process, but he developed a graphical method that solved the problem much faster. The descriptive geometry was so successful that it was kept as a military secret for 15 years before it was taught in a technical curriculum (Earl James 1990).

Descriptive geometry is the projection of three-dimensional objects onto a two-dimensional plane, and allows geometrical manipulation to determine length, angles, shapes and other descriptive information about the objects.

3.7.2 The basic product properties

The environment surrounding us is crowded with products, from large, small, cheap, expensive and in all other combinations. The purpose of products can be said to be an object that solves a need, which we as humans have. To give an example, in 1961 John F. Kennedy decided that the US should go to the moon, and the product that can do so, is the Saturn rocket (history.nasa.gov 2006). This is perhaps one of the more complex products built, but for both complex and simple products there is a *need* that justifies the product.

The Saturn rocket or any other product is in possession of a range of properties. Some of these properties provide the needed functions for the product. In addition it will possess other properties that are more or less unwanted (Tjalve 1976). Most of all it is a function that the product helps us to fulfil. Other required characteristic may be: visual appearance, easy to assemble, reliability, etc. During the development the engineers cannot optimise one and one properties they are linked together, but Tjalve proposes that five properties are different. They can together represent the product completely, these are: structure, form, material, dimension and surface, Fig. 3.8. All other characteristics good or bad are represented from these five properties.

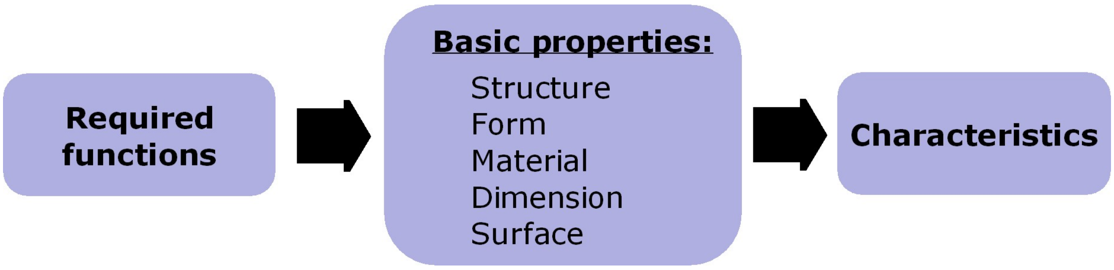


Figure 3.8: Properties in a product that represent it completely (Tjalve 1976)

3.7.2.1 The functions provided by the product

By modelling the functions required in the product, one can start the process of synthesizing the product to be designed. A model tries to represent an object (thing or system) and simplify this in a way that helps us to understand the characteristics the product will have. This way of illustrating the product may be done on different detail levels. The most abstract focus upon the overall function for the product and may not have a direct connection to the parts that the product is to be made of, while a detailed functional modelling may illustrate the components found in the product. In order to find the function, an ideal model can be made, describing the pre- and post situation. The modelling of the function can be done as input/output flows, focus on these aspects, Fig. 3.9 (Tjalve et al. 1988), (Pahl & Beitz 1996):

- The machine state, modelling of flow models (force, fluid, electricity), positioning movements
- The manufacturing process, modelling of the process and operations that create the product.
- The human interaction with the product, modelling of the human interaction with the product or the manufacturing process, how to hold, move etc. the product.
- Structure modelling, giving a description of the product from an abstract level (simple line drawings) to a detailed description giving insight on the components' interconnection and function.

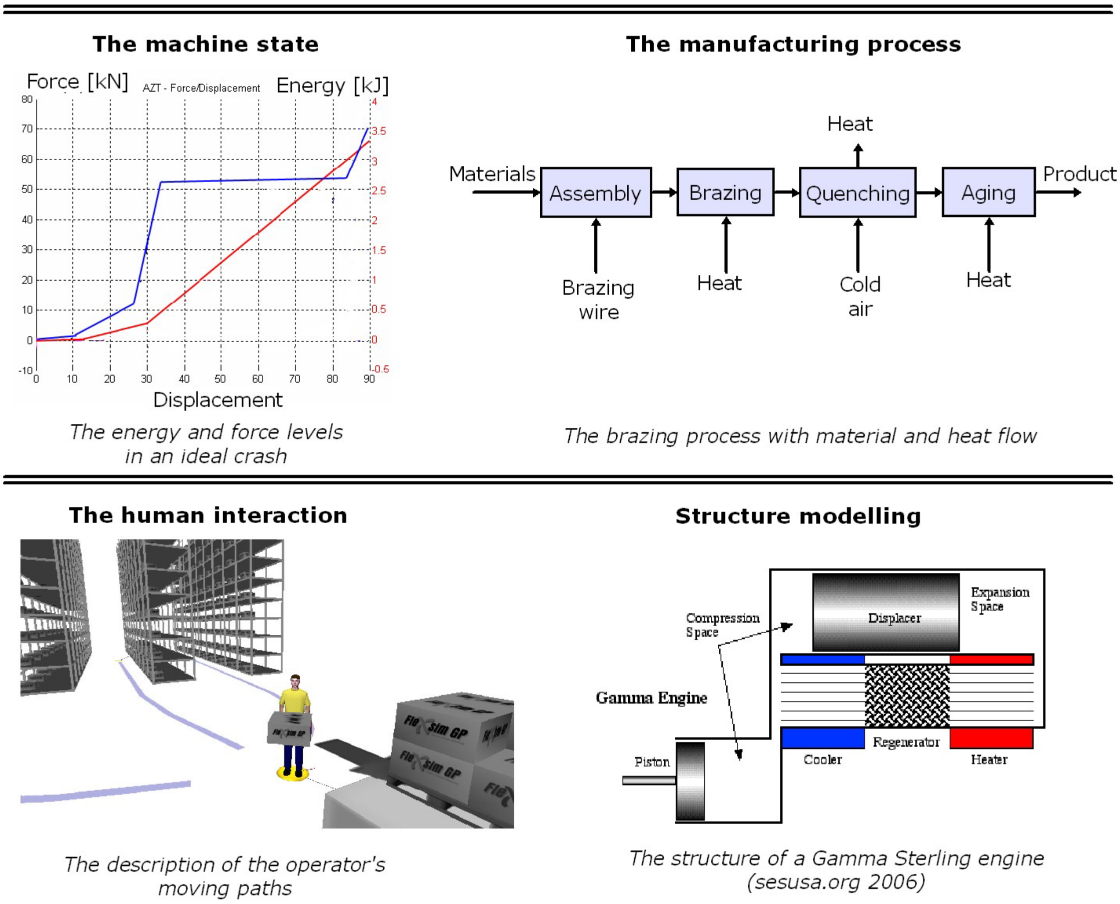


Figure 3.9: The functional modelling in four different aspects

Ulrich et al. (1990) stress the importance of functional sharing among products. Designs that exhibit function sharing are in most respects better than the non-functional-sharing product variants. It also provides a simplification of the design process by allowing the designer to think in terms of modular, decomposition factors.

3.7.2.2 The product structure / architecture

The product structure can be described at many different detail levels; from highly abstract and down to a detailed visualisation of the elements within the product. It will represent the principal structure of the product. The principal structure can be manipulated and become quantitative structures. This represents the most important relationship between the product's components. It carries at this stage no information about dimension and form.

In a product programme perspective this is the first step where components, modules and/or platform can be visualised as shared between product variants. The product structure represents the physical elements of the products and becomes the building blocks of a product programme designed to be configurable. In a configuring design there is often a mix of part and modules that can be swapped to become a different product variant. In order to establish such a design it becomes important to be aware of the building structure chosen. Ulrich (1995) proposed four structures, Fig. 3.10:

- Integral structure: the relationships between parts are strong. All components are integrated and making a change to one of them implies that all the others also have to be changed. This type of structure is useful if functionality and e.g. weight are the drivers. The part in which the part / modules are mounted can also be a platform, if it is shared among product variants.
- Slot modular structure: the parts / modules are mounted on a part with defined interfaces. The parts / modules can easily be replaced, but not swapped.
- Bus modular structure: the parts / modules have the same interfaces and can be swapped and replaced among each other. The part in which the part / modules are mounted can also be a platform, if it is shared among product variants.
- Scalable platform: the base part of the product can be scaled. This could be changing the length of a fundamental part in the product e.g. the stacking length of an electric motor.

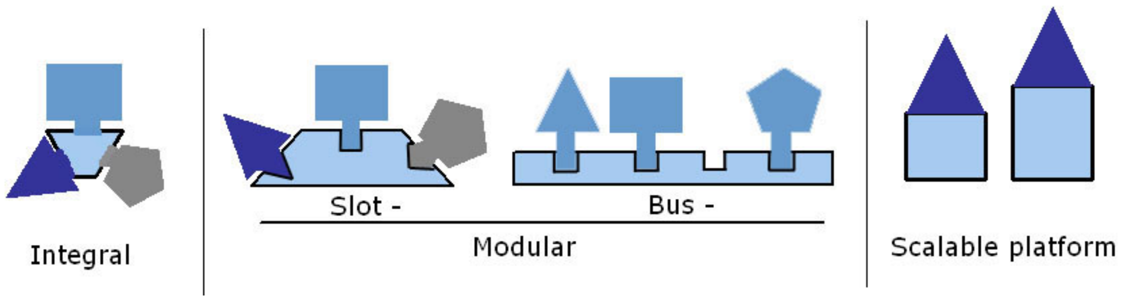


Figure 3.10: Different forms for product structures (Ulrich 1995)

3.7.2.3 The product form

The product form is shaped by each element in the product, their position in space and the overall form connecting the elements (Tjalve 1976). In the process of creating product variants these elements play an important role. They provide the form for the product's visual and functional structure. The elements within a product can be divided into three different groups, Fig. 3.11; functional partition, physical partition and visual partition. A functional partition separates the functions of the product into independent elements. The physical partition is where the product elements are separated and the last one is a separation by the visual appearance of the elements. The individual elements are then formed through decisions about the details. The details will give information about the functional surfaces of the product and give also indications about dimension, strength and manufacturability. These ways of dividing the product form can provide ideas about how to split the product into modules that provide the variation to create different structures. Oxman (1986) talks about products as systems configured from different elements to create the variations. An example where these elements are very distinct is in the air venting system in buildings. These systems are built from pipes, bends, vents, vents hats, fans, etc. that can be configured into a range of systems. The system is built around separating each function into separate components. The visual aspect of the system can be changed by the placement and type of vent hats that are used, since these are the most visual elements of this type of system (systemair.no 2006).

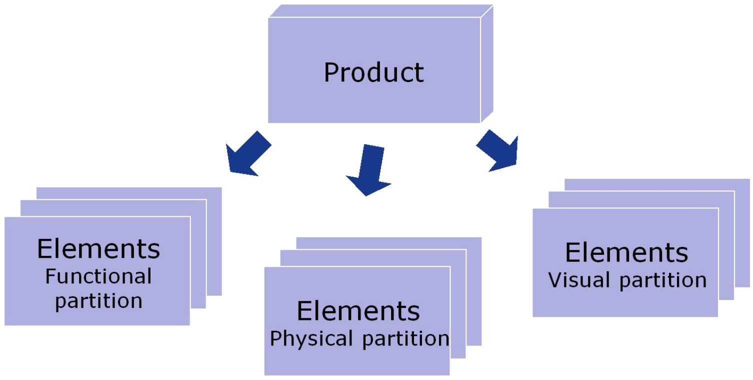


Figure 3.11: The form elements within a product (Tjalve 1976)

In the same context as functions, structure and form are discussed by Tjalve (1976), he includes also product material, dimension and surface as basic product properties. The dimension plays a role in the creation of product variants, but then more in the context of scaling as mentioned in the possibilities to modularise, chapter 3.6.2.2. The material and surfaces are rarely the only things that are changed in a product to create product variants. They are closely related to the other basic product properties and how they interact.

3.7.3 The product manufacturing and supply chain

Manufacturing and supply chain considerations have for a long time been important topics in product design. In 1788 LeBlance, a Frenchman provided the basis for the first known focus on production (Bralla 1999). He developed a system to manufacture muskets that had interchangeable parts. All muskets until LeBlance enhanced the part design had been hand made and no two muskets were ever exactly alike. Parts were not interchangeable.

In the late 1980s, the term mass customisation emerged, and emphasised the need to provide outstanding services to customers (Pine et al. 1993). This is done by providing products to the customers that meet each individual need through a combination of modular components. The goal of mass customisation is to provide customised goods (to achieve economy of scope) at low costs (to gain from economies of scale). High commonality of modules and shared parts lowers inventory levels and reduces risk of obsolete inventory, hence lowering inventory costs (van Hoek et al. 1999).

This customisation can be done in a range of different approaches. The customisation is driven by the customer's need for special solutions. Lampel and Mintzberg (1996) identified five different customisation categories:

- Pure standardisation: this leaves no room for any differentiation
- Segmented standardisation: different distribution service or channel for sales to different customer segments, internet customers versus traditional store sales
- Customised standardisation: is related to the final customisation of products where modules / parts are assembled according to the order
- Tailored customisation: this includes that customer-specific modules / parts are added in the final assembly

- Pure customisation: the customer request for customisation is met within the capabilities of the company

How this customisation is presented for the customer is also of importance. Should it be something the customer is aware of or should this information be kept hidden for the customer. Gilmore and Pine (1997) suggested four approaches for customisation:

- Collaborative: the customers are helped to articulate their needs and to identify the offerings that fulfil those needs. This is done within the offerings the company can provide (e.g. cars or kitchens)
- Adaptive: the product is designed so that the customer can alter some of the product properties. The customer wants the product to perform different ways in different occasions (e.g. mobile phone covers, different colour)
- Cosmetic: a standard product is presented differently to different customers. The offerings are packed differently, its attributes and benefits are highlighted
- Transparent: the goods or services are customised individually without an explicit request by the customer. This can be done when the customer needs are predictable and the customer does not want to state their needs repeatedly. (e.g. the goods or service provider monitors their delivery and replaces it before e.g. tank is empty, online surveillance)

All this customisation affects the right manufacturing strategy to choose. The manufacturing of products may start after a specific customer order or based on market anticipation. This depends on the type of product, production volume of each variant, the risk of manufacturing products that are not sold, the response time acceptable for the customer, etc. Customer specific manufacturing means that the customer must wait some time for the products; it must be made or configured before it can be shipped. Manufactured products based on market data are ready to be shipped or already in store. In order to create all the required product variants in a lean manner, the use of postponement is used. Postponement is an approach that helps to deliver more responsive supply chain and the delay of final manufacturing. For the supply chain it is called postponement and form postponement when it focuses on the manufacturing. The intention with postponement is to delay the final formulation of a product until orders are received, which is called the customer decoupling point (CODP) Fig. 3.12 (Skipworth and Harrison 2004). This may offer substantial reduction in the costs of operating the supply chain; by reducing the randomness in the demand for the basic elements of the product (e.g. the platform). In appendix VIII a table of different supply chain structures can be found. This type of postponement has also close relations to product modularisation and standardisation, where the product architecture plays an important role in shifting the customer order decoupling point. Is the product in a stage within the forecast-driven section it is related a higher degree of uncertainty to the sales of this goods and inventory. Have the goods reached the order-driven section, the product has a specific customer and are already sold. According to Ulrich and Eppinger (2004) two important design principles are necessary conditions for postponement:

- The differentiating elements of the product must be concentrated in one or a few chunks (e.g. the external power supply of a laptop computer)

- The product and production process must be designed so that the differentiating elements can be added to the product near or the end of the supply chain (e.g. the external power to the laptop computer is sent in a separate box)

Make-to-stock, Fig. 3.12, is an approach that aims to conduct final manufacturing before a direct order has been placed. At the other end is the make-to-order where the manufacture waits until an order has been placed. Here the company take the risk of being unable to sell some of the product stock manufactured.

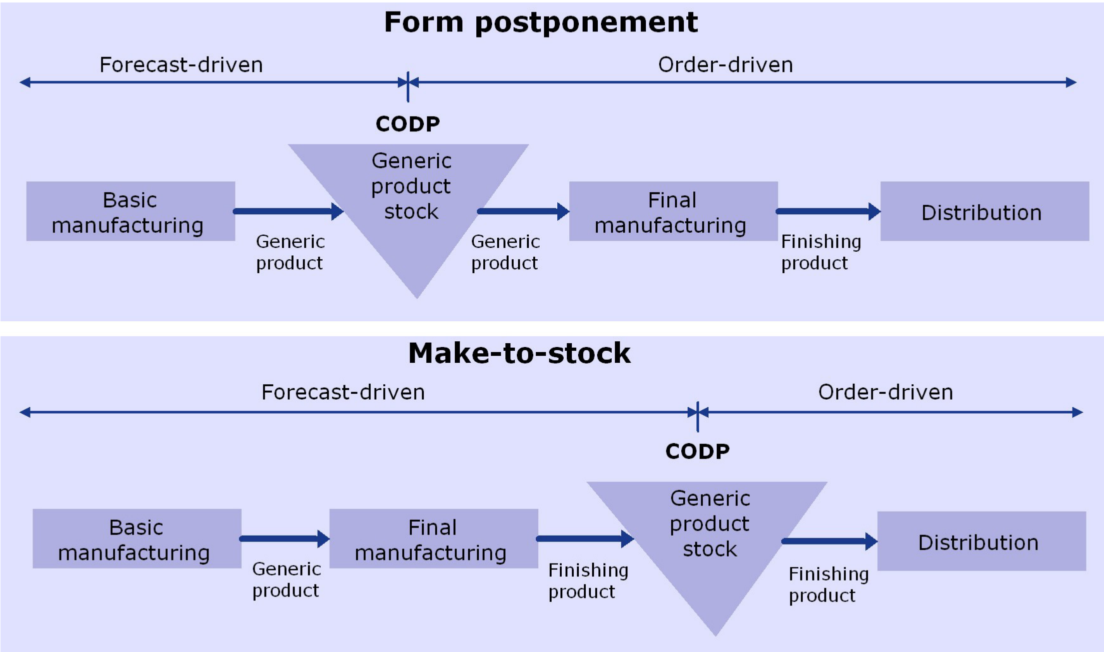


Figure 3.12: Decoupling point for form postponement and make-to-stock (Skipworth and Harrison 2004).

Ulrich and Eppinger (2004) have a focus on modules or parts that are added to differentiate the product variants, but the principles of postponement are also valid within the manufacturing sequence. Franke et al. (2002) illustrate continuity in how the product variants differentiating points can be found in the value adding chain, Fig. 3.13. The product differentiation can happen very early in the value chain and has then a square shape. This means that the inventory has to include a large range of different half finished products and with all the associated equipment. On the other hand, the most efficient layout is a T-shape. The same numbers of end-product variants are shaped from only one sequence. Inbetween these extreme illustrations, the most common way of creating product variants are found, as a step by step process.

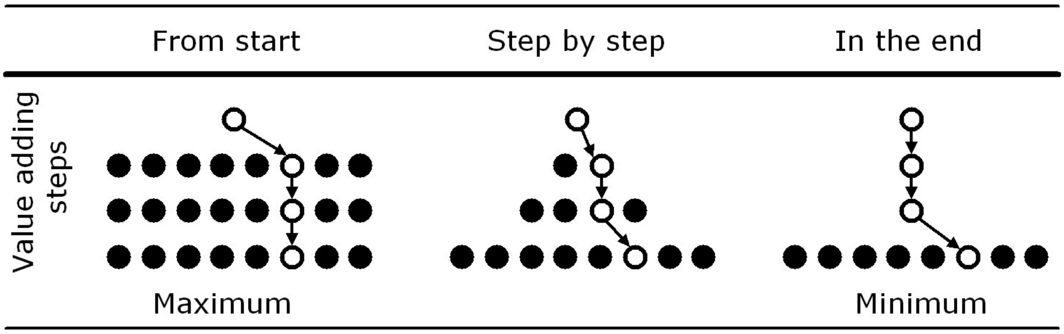


Figure 3.13: Postponement of the differentiation point. A late postponement in the value chain is recommended (Franke et al. 2002)

3.7.4 Models capable of representing product variation

To model a new and lean design assortment and be able to integrate it into a configuration system, there is a need to leave the detail level related to designing a one-at-a-time product and take a more holistic view of the product programme. First after the commonality and distinctiveness of the product variants have been mapped out, the focus can go back to the individual product variants.

To handle each product variant and the product family's relationships there is a need for methods and models capable of representing this. Franke et al. (2002) have listed the different approaches that can be found in the literature, Fig. 3.14. All of these different approaches are used in the management of product variation complexity. The approaches the models are built on are:

- *Bill of material list (BOM):* describes the material contents of a product at each stocking level in the manufacturing process (Clement et al. 1992). One BOM represents one product variant. In the product life cycle programmes several BOMs can be combined into a 150 % BOM (UGS Teamcenter, 2006). This then represents all the product variants in the family. The system can be used to configure the different product variants. The use of BOM data is based on knowing the product structures and is hence easier to build after the product architecture has been established rather than using them to find a solution.
- *Hierarchic*: is a method where a tree structure describes some product characteristics e.g. the branches consist of functional characteristics that together describe each of the product variants. All the end branches represent the total number of product variants. Software like Complexity Manager work with this method (complexitymanager, 2005)
- *Graphs*: is a complex system modelling tool. It deals with describing structural information and dealing with the transformation and generation of elements in graph morphisms (Du et al. 2003). Graphs are very closely related to matrix modelling like Design Structure Matrix (DSM). A major advantage of the matrix representation over the graph is in its compactness and ability to provide a systematic mapping among system elements that is clear and easy to read regardless of size (dsmweb.org, 2005)

- *Object oriented*: this is the base for system engineering and is based on objects represented by elements and relationships. This model includes a coupling between the customer's need, the system to meet those needs, and the components to be designed and built to satisfy the customer's needs (Oliver et al. 1997)
- *Relationships*: modelling can be systems as the Quality Function Deployment (QFD), where customer's demands are converted into quality characteristics, which again are converted into the finished product. The relationships are systematically deployed (Prasad, 1998).

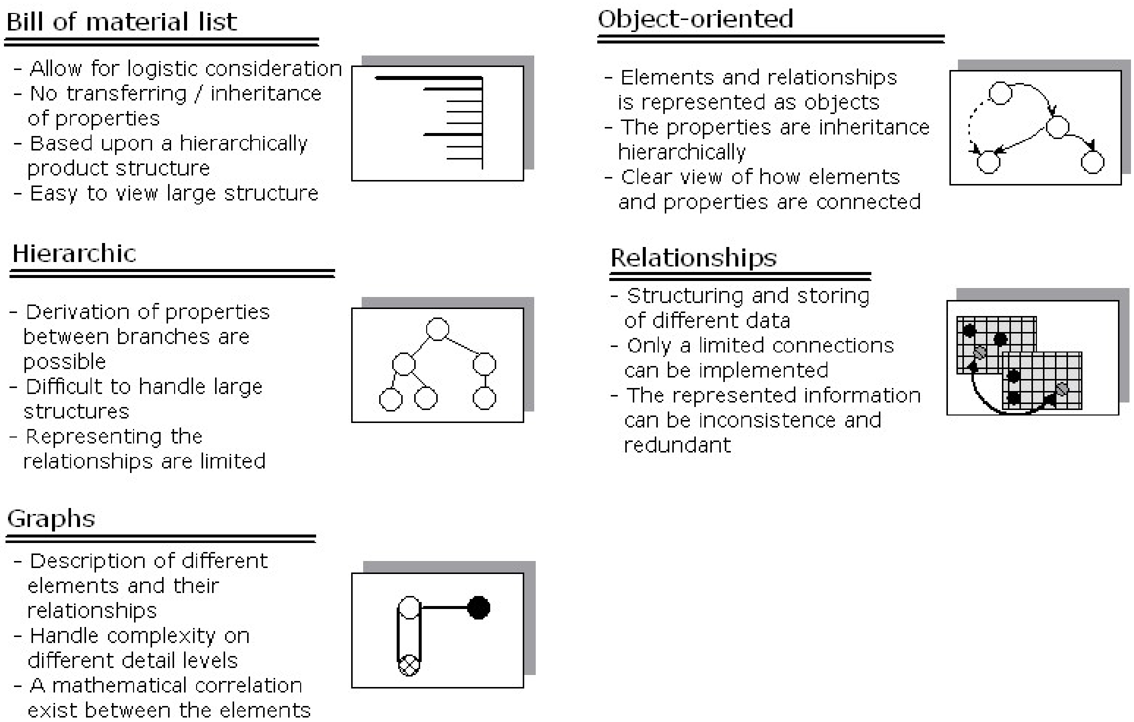


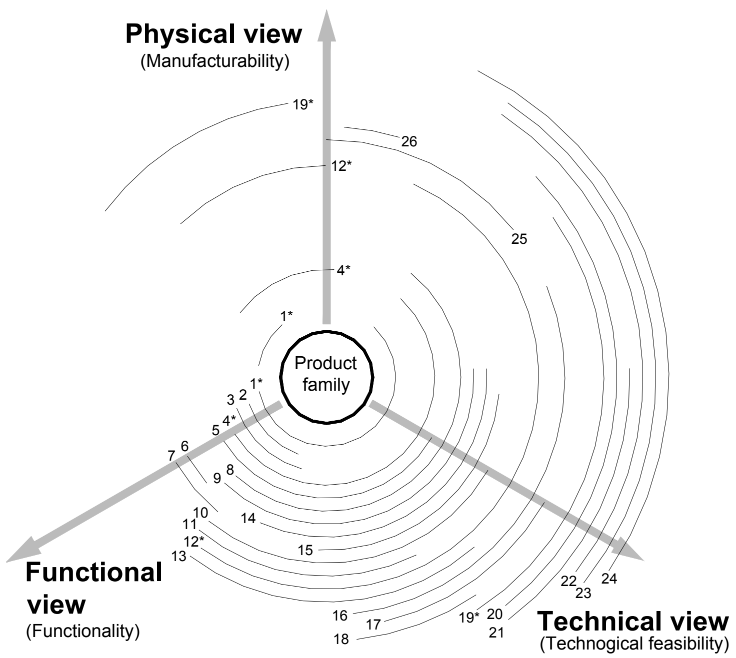
Figure 3.14: The different descriptions for representing products and their relationships (Franke et.al. 2002)

3.8 State of the art in engineering methods to develop product variants

To develop a successful product is difficult, even when only a single product is to be developed. Considering multiple products at the same time is far more complex. To prevent designers from being overwhelmed with information and demands, it may be helpful to view the challenge from multiple sides. Jiao and Tseng (1999) presented a model that considers the product family architecture from three different points of view, also used on traditional product development; a Functional view, a Technical view and a Physical view. The functional view represents the customer side, where the customer's interests are the focus. This includes addressing all customer requirements and analysing competitors. The technical view handles the implementation of the technology, solution principle and how the products are designed. The physical view looks at handling the manufacturing side where design for manufacturing and the production equipment are evaluated until the products are realised. A modified version of this model has been adopted in order to illustrate the focus the different researchers have in their methods and tools for product variant design. The modification relates to make the transaction between the views smooth. Fig. 3.15 illustrates the author's opinion on where the discussed literatures have positioned themselves. The articles are also indicated at which focus areas they have; modular and/or platform). This figure must also be seen as one layer related to the operational side, compared to the strategic level. The transition between the axes represents:

- Functional - Technical; The early phases from requirements, concept development and to the start of the detail design
- Technical - Physical; The detail design and establishing of the manufacturing aspects.
- Physical - Functional; The life phases related to sale, maintenance and recycling. These are topics that are not covered in the literature review, unless they are part of methods mainly focused on the other life phases.

As always, the articles are written by people with different backgrounds, where some aim the methodology at consumer products while others look at high performance industrial products. Creating a product programme involves two major approaches; modular design and platform design. Finding the appropriate strategic approach for the company has been discussed by Maier and Fadel (2001). It is important to establish a well-defined strategy before the design is implemented.



		Modular	Platform
1. Ho & Tang	(1998)	X	X
2. Robertson & Ulrich	(1998)	X	X
3. Krishnan et.al.	(1999)		X
4. Ericsson & Erixson	(1999)	X	
5. Mortensen et.al.	(2001)	X	X
6. Yu et.al.	(1999)	X	X
7. Otto & Wood	(1998)	X	X
8. Martin & Ishii	(2002)	X	X
9. Jiao & Tseng	(1999)	X	X
10. Gonzales-Zugasti et.al.	(2000)		X
11. Huang & Kusiak	(1998)	X	
12. Gershenson et.al.	(1999)	X	
13. Sudjianto & Otto	(2001)	X	
14. Palani Rajan et.al.	(2003)	X	X
15. Gershenson et.al.	(2003)	X	
16. Simpson et.al.	(2001)		X
17. Dahmus et.al.	(2001)	X	
18. Kokkolaras et.al.	(2000)		X
19. Gu & Sosale	(1999)	X	
20. Jiao & Tseng	(2000)	X	
21. Salvador et.al.	(2002)	X	
22. Meyer & Dalal	(2002)		X
23. Jiao & Tseng	(2004)		X
24. Jensen & Hildre	(2004)		X
25. Gupta & Krishnan	(1998)	X	X
26. Lee & Saito	(2002)		X

Figure 3.15: The author's opinion on where the articles are positioned, when (Jiao and Tseng 1999) points of views are used. Methods that are scattered in these view points are marked with *

Maier and Fadel's (2001) methods aid management and designers in determining which type of product family that is appropriate based upon earlier knowledge. In this context they propose seven different types of product families, from single and evolving single products to mixed evolving mutating product family. The methods aim at finding the manufacturing paradigm for the company, which relate the companies to four groups - mass production, mass customisation, continuous improvement or invention. All the seven types of product families are then mapped to one or more strategies regarding; single design, product platform design, scaling design and modularity design. Implementing such a strategy to design a product family is usually not the first thing a company does, they usually have a history of single products that have evolved over time. Robertson and Ulrich (1998) discuss how a company can change from doing "one at a time" product to managing product platforms. They partly provide a step-by-step description of the product platform planning, with focus both on the products (in a wide perspective) and the design team challenges. Mortensen et al. (2001) have also a method suitable for converting an existing product family over to a lean product programme, Fig. 3.16. Their method is based on describing the contents of the product in a Part_of structure. This indicates all components and modules that must be present in the product. In a separate structure the Kind_of components are described. This represents all the variations in the product family. By optimising and including restrictions on the structures, a lean product family can be designed. This method is suitable if the product variants have an architecture that is configurable and the focus is not on the manufacturing methods to the parts within the product.

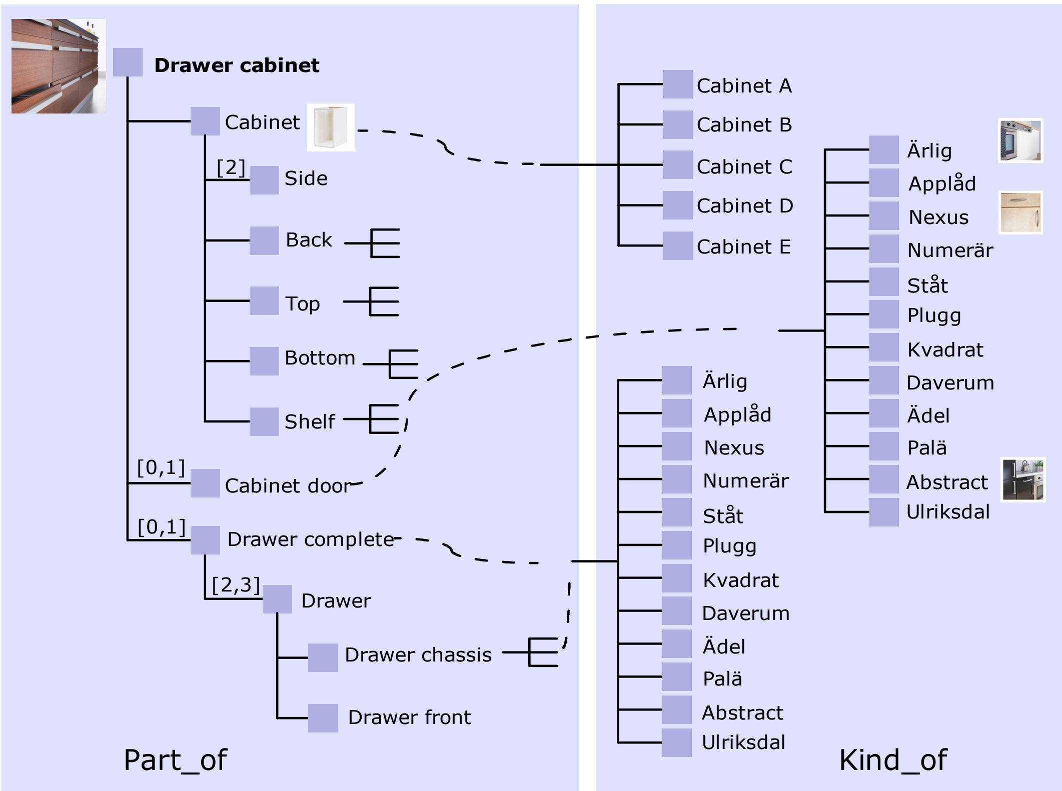


Figure 3.16: The Product family master plan viewed on a Ikea kitchen cabinets with drawers and doors

Performing benchmarking of the in-house products is often done in product development as well as reversed engineering for competitors' products, but this can also be done in a product family context. Otto and Wood (1998) proposed a method for this, but in addition the method also looks into many aspects that may be vital in designing a product family. Understanding and establishing the correct customer needs is clearly important to design a successful product. Yu et al. (1999) follows this approach and present a method to define the portfolio architecture based only on customer demand. Their method seeks to find the best architectural approach in more or less the same way as Maier and Fadel (2001), but they neglect the design and manufacturing costs. The focus is on establishing a statistical view, with distribution of customer needs over time. From the shape of the statistical distribution, different architecture for each feature in the product are proposed (Platform generation, fixed portfolio architecture, platform family or adjustable portfolio architecture). A statistical approach to guide the typology of the portfolio requires a large customer group to gather enough needs. This makes this approach perhaps more useful for consumer product rather than industrial products, where such data may be hard to get.

3.8.1 Modularity design methods

Modularity design arises from decomposition of a product into parts and subassemblies. Independency between these elements is the core elements in modular design and hence the product functions must be grouped. Pahl and Beitz (1996) propose this classification:

- Basic functions are fundamental to a system and in principle not variable. They are implemented in the basic module and are essential
- Auxiliary functions are usually also of the "essential type"
- Special functions are usually implemented in separate modules that are of the "possible" type
- Adaptive functions are necessary for adaptation of other systems. These are of "essential" or "possible" type.
- Customer specific functions are usually designed individually and adapted to the system in a non-module.

Stone et al. (2000) proposed a method to identify modules from the functional structure, by considering the dominant flow, branching flow and conversion flows. Sudjianto and Otto (2001) have extended the use of a functional structure to also model a family across different brands as well as within one brand, Fig. 3.17. The impact of brand width on brand share is discussed in Ho and Tang (1998).

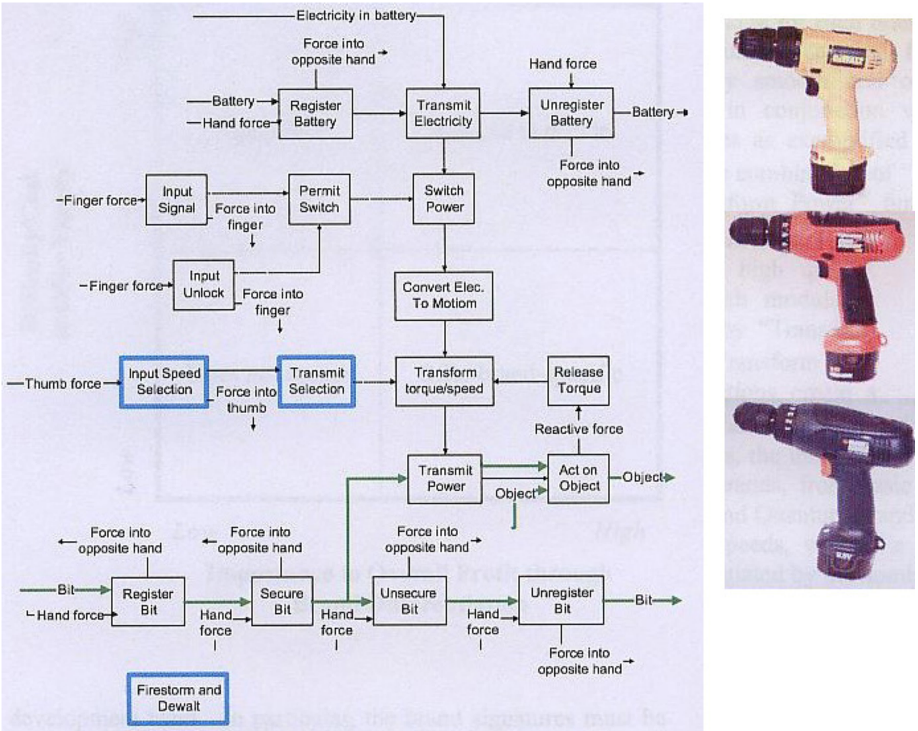


Figure 3.17: Cordless drill family functional structure for Black & Decker, Firestorm and Dewalt. All unshaded boxes are shared across all models (Sudjianto and Otto 2001).

Dahmus et al. (2001) propose a method for architecting a product family that shares interchangeable modules. Their method consists of developing a functional structure for each of the separate products and then finding the common functions structure for the family. The family function diagram consists of all the single diagrams and all the flow interactions (electrical, mechanical, gas and fluids). The flow path through sub functions defines the modules. To visualize the whole family structure they introduce a modularity matrix. The clever thing about this method is that it is easy to use and can be used across product classes. Since the method is based upon a functional decomposition of the product structure, the products in the family must have an easily dividable functions structure. The method deals only with the early phases of establishing a product programme. Functional structure modelling is a common way of establishing modules. Huang and Kusiak (1998) also use this approach in defining the modules. They use flow and force interactions illustrated in a matrix to categorize the different modules. By using matrixes possible separate and swappable modules are identified for electro, mechanical and electromechanical components. The method is suitable for early conceptual design and on structures that can form many modules. Therefore it may be most appropriate for use in electro or the combined electromechanical field.

A slightly different approach to finding the most suitable modules in the product has been made by Ericsson and Erixon (1999). They use Quality Function Deployment to ensure that the correct requirements are derived from the customer. The functions are listed in a hierarchical structure, decomposing it down to independent structures/parts. These independent technical solutions together with their modular drivers (the reason to form a module), give the possibilities to group and find appropriate modules. In their modular drivers' development and design, variance, manufacturing, quality, purchase and reuse or other reasons may be used to form the modules. Their method uses a highly holistic approach to find and establish the modules; however they do not go in-depth on how the grouped technical solutions should form the modules or how the functional flows are within the product. Salvador et al. (2002) also discuss the production side of products based on modularity. Their research looks into different modularity options on providing cost efficient solutions when the production volume is high or low. A measure for evaluating the commonality at the component level and on the process level has been proposed by Jiao and Tseng (2000). The process commonality index measures the level of commonality present in the manufacturing, by finding the component that uses the same manufacturing process and introducing the set-up time (cost) for the tools. This index then gives information about which parts or modules that should be worked on, in order to reduce the cost. This type of information may be very helpful if the set-up time is an essential cost driver for the analysed products and also to give the process commonality that is present a value. Gu and Sosale (1999) focus their attention on creating modules by looking at the strength of connections between the parts in the product. They use an algorithm and matrixes to find the most suitable modules for many different life cycle phases. Their method does however find the modules from the relationship listed in the matrix. Modules that are proposed may not be possible to form. Gershenson et al. (1999) view also the modules from multiple viewpoints as do Ericsson and Erixon. The modules are created with regard for both the functional aspect and the life –cycle process (manufacturing, service and recycling). The modules are viewed both from function and process independence or similarity. A component tree and process graphs are generated to describe the product at different detail levels. A matrix describes the similarities and dependencies for the components and processes, leading to the modules. The method opens up for designing the modules at different detail levels, since an extensive division of the modules will at some level make the structure not modular. The modularity performances are also measured by an index.

3.8.2 Platform design methods

The other major approach to establish the product programme is by using product platform structures, from which variants are leveraged. The main purpose of the product platform design is to increase the internal commonality and increase the external variety. A product platform is therefore a base that is developed to be the fundamental part of many products delivered to the market over a time or/and in different categories (high cost & high performance, mid- range and low cost & low performance). Meyer (1997) describes this in a market segmentation grid, where the platform may be horizontal, vertical or a combination, Fig. 3.18. The horizontal platform is established to serve the needs where a very clear separation between high and low range markets is needed. For the vertical platform there are two approaches; the company have developed high-end solutions that are scaled down to a lower market segment or a low-end solution that is scaled up. Scaling down gives the companies a chance to reuse design solutions established for a high-end market at a lower market as time as time goes by, but this is not risk free. If the common platform is weak it can undermine the competitiveness of the entire product line. To give an example of this, scaling down a Toyota Lexus with all the features and high-end functions down to a Toyota Corolla is not easy. The power of the platforms becomes more significant when a beachhead approach can be used. Low end, and cost efficient product platforms are developed and then leveraged across horizontal and vertical markets. This makes it possible for the companies to enter new market niches, from a superior cost position. The platforms are thus developed for a low-cost market, but have the possibilities to enter the high-cost market and achieve very good cost advantages. With the defined type of platform the work of establishing product structure may start. Ulrich and Eppinger (2004) propose a general method and the basic ideas of establishing a platform architecture that also may consist of modules. The method is based on functional flow modelling to establish the chunks and identifying of the interactions between the chunks. They also indicate the importance of the product architecture in the performance of the supply chain, but this is only briefly discussed.

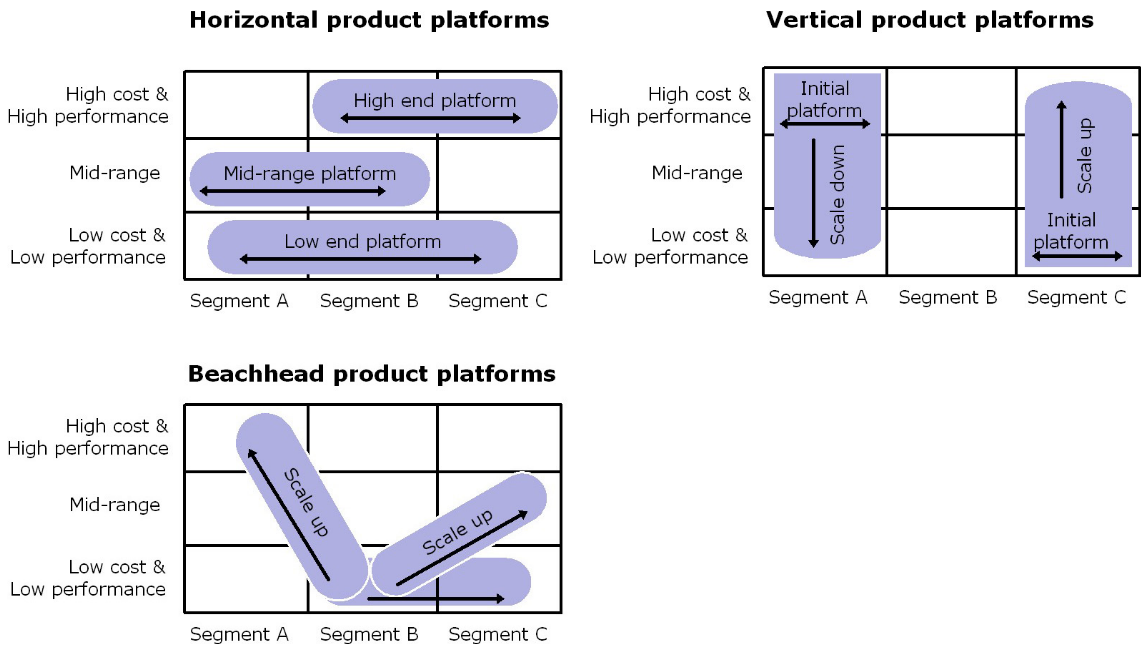


Figure 3.18: Market segmentation for platform design, (Meyer 1997)

An overall approach of a platform design process is proposed by Gonzalez-Zugasti et al. (2000). They discuss the approach to implement a product platform design in a conceptual stage. Martin and Ishii (2002) also present a comprehensive design for variability method, stretching from the conceptual phase and into a detailed description of the products variability. Their method find indexes related to the amount of redesign a component requires to meet future requirements and an index giving the coupling's strength between neighbouring components. The method use well approved technique that is combined with assumptions of the future direction. The method gives valuable information on the changeability the design has without needing too much detailed design information. What the method does not cover is discussions on using commonality in the production processes related to establishing the architecture. A different method, not so complex, is proposed by Rajan et al. (2003). Their designs for flexibility method also establish a list of potential changes and the effects of these changes. They have also adopted a traditional tool from "single" product development, the FMEA (failure mode effect analysis) and converted it to a Change Mode & Effect

Analysis (CMEA). The CMEA gives indexes on design flexibility and potential for change. This method takes also into consideration the readiness the company has to perform these changes, but this is only stated as a rough assumption. Suggestions of improvement on the design or manufacturing are not covered.

To establish a well-evaluated design a proper trade-off analysis of all the alternatives should be conducted. Simpson et al. (2001) have looked at scalable product platforms, where they compare a very comprehensive trade-off analysis. They use a scalable electromotor as a case and iterate to the optimal platform. Further they compare this to single developed electro motors under the same conditions. The advantages and disadvantages of the performance of the Product family architecture are discussed and they also include some manufacturing considerations: they conclude with emphasis on the benefits of economy of scale in using product platforms. The numbers of variables to meet the requirement are evaluated against the commonality that can be acquired in the manufacturing. Kokkoloras et al. (2002) also propose a trade of method using a cascading approach that also gives results directly comparable to the requirements. The product family is mathematically modelled and detailed input is provided so that the results may come out as weight and stiffness, in their particular case. Performing a useful analysis must therefore have good input to secure that the results are reliable. Modelling the product family mathematically may also be difficult in some cases, while very suitable in others.

All the above-mentioned methods focus merely on the section functional and technical views of establishing a product family architecture. The manufacturing that must be there in order to create the final products are only commented on or are inadequately discussed. The product used in examples and cases also consists of many components and/or sub-assemblies. This approach excludes many products that do not have a large assembly structure. Meyer and Dalal (2002) introduce the platform architecture method for non-assembled products (film and integrated circuits). Their approach aims at understanding the dynamics of process intensive platforms and evaluating the performance. They do not present a specific method of platform design for non-assembled products, but they introduce the possibility. Lee and Saitou (2002), and many others have discussed design and the products meeting with production for a long time, but not so in-depth with a product family architecture. The subject that has been discussed in Ho and Tang (1998) is the powerful effect of delayed product differentiations. The assembly sequence is a key theme to be addressed in optimising the supply chain. Product variations have a tendency to demand rapid changes in the production. Jiao and Tseng's (2004) methods measure the flexibility a process (manufacturing) platform needs has to adapt to customise products. They use the manufacturing cycle time to measure this. A slightly different approach to evaluate the design solution's space (variability) against the manufacturing process, have been proposed by Jensen and Hildre (2004), appendix V. Variance in the design is compared with the flexibility in the manufacturing processes. The needed change in the processes due to the design variation is evaluated and gives an index indicating the estimated cost of change. Gupta and Krishnan (1998) focus on establishing the optimal assembly sequence for a product family. Their method tries to maximize the commonality in the assembly sequence and minimize the number of sub-assemblies. The method may be used for modular design, platform or a combination. To utilize the method the products have to be established with constraints in order to be able to execute an algorithm. A defined architecture must therefore be present before this method can be applied. It also treats all connections in the assembly with the same complexity. Introducing the assembly sequence as an important section of designing product variants, and it plays an important role in establishing an optimal economy in the production.

3.9 Discussion of the literature study

The literature study shows that there are many approaches to develop product variants. Some of the methods take a broad view, other a narrow view. The review also revealed that there are areas in product variant design that are well analysed and other that are more sparsely covered. These topics are related to the following parts of product variant design:

- When it comes to integrate the company strategy with the development of a range of product variants, this relationship seems to be fairly loose for all methods.
- The product variant design methods have a tendency to look at product variation from a “static” point of view. The dynamic forces the market possesses are rarely discussed together with the product structure development.
- The majority of the methods consider that one type of product structure will cover the whole product family. The discussion about using several product structures to better cover the customers’ need is not well researched.
- The majority of methods are around products that are suitable for creating product variants by a configuration approach. Products that consist of few parts are not discussed in the studied literature. This may indicate that product variant design has been a design approach that has been mostly used by tier 1. (final) manufacturer or system supplier and not part suppliers.
- The design methods for product variant structures are based on approaches that are modular, platform based, scaling of product platforms or a combination.
- The majority of the methods have a focus on the details in the products, with focus on the relationship between the components in the product. Production and supply chain elements are rarely discussed in this context with the product design.
- When it comes to perform a trade-off between different concepts for the product variant structures, there are no well functioning methods. The evaluating of different variant structures has a tendency to always end up in comparing average values.

4 Product variant design in the Norwegian industry

Norway is a country where most high technology is related to the process industry rather than manufacturing finished products. Being a high cost country with large process industry activities, globalisation has a strong effect on the number of employees in this business. Competitive industry has during the last 40 years had a clear trend, a reduction in employees. This trend has escalated more recently. During the last 25 years most of economic growth has therefore been in the oil and gas industry, direct by exploitation of oil and gas and indirect as goods and services to this business (Schiefloe 2005). At the present time, production in Norway has a capital turnover distributed as shown in Fig. 4.1. The manufacturing industry has a capital turnover of 350 thousand million NOK. Of this, 200 thousand million comes from export (Lier-Hansen 2005).

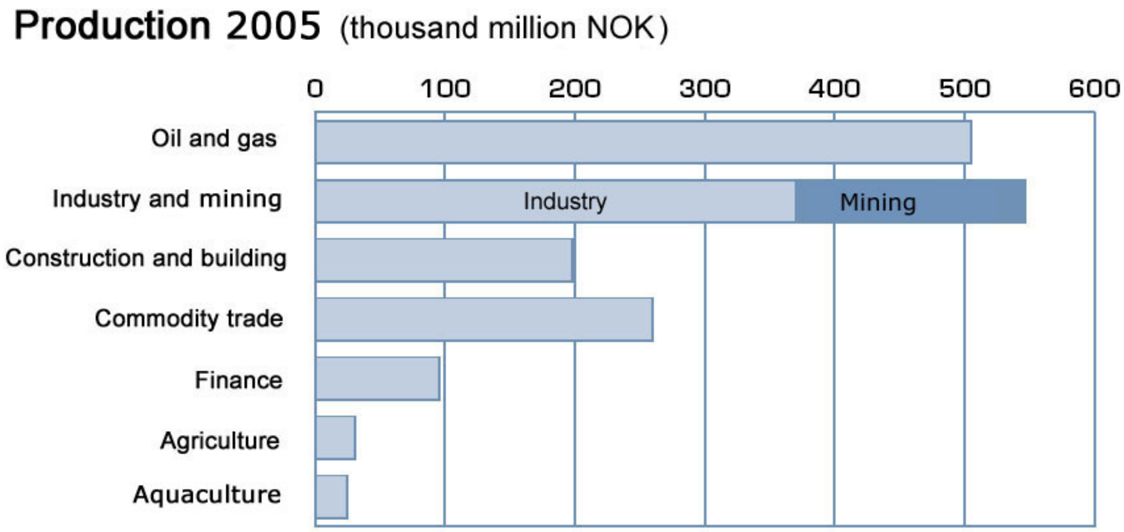


Figure 4.1: Production in Norway 2005, divided into seven categories (Lier-Hansen 2005)

If Norwegian industry is to fight this trend of employee reduction and grow in other areas than oil and gas related industry; improvements in many fields are needed. The reduction of employees has though increased the focus on how efficient company processes are, making them more competitive. Industry has also become more specialised, changing focus over to knowledge intensive types of products, all resulting in a very healthy, well-run industry for the moment (Norsk industri 2006). Many of the same changes can be found in other industrial countries, where there is a change to knowledge-based industry in order to be globally competitive. Drucker (1997) states that:

"The only competitive advantage of the developed countries is in the supply of knowledge workers… The productivity of knowledge and knowledge workers will not be the only competitive factor in the world economy. It is however, likely to become the decisive factor, at least for most industries in the developed countries."

This shift also introduces the need to go from labour intensive manufacturing to a high degree of automation in order to stay competitive. For product with many variants this change becomes of extra importance. The design of product variants must be done in a way that uses fewer hours of labour time and where the major part of the product's value chain is automated. This makes it possible to compete with products from low cost countries. To put this focus on the design and manufacturing processes, better design knowledge is needed.

One of the areas for knowledge improvements is in the product development process. Product development creates most of the premises for a successful product and how profitable it will be. It is therefore important that this process is structured, efficient and handles the knowledge in the company well. This is especially important for those companies that have a product portfolio consisting of many product variants. A study is therefore performed to see how four manufacturing companies handle the product variants.

4.1 The studied manufacturing companies

All the studied companies have a long tradition in making their products and all have many years of market experience. For the moment all of them are doing well and seem to have good profitability. This study doesn't give enough data for a statistical comparison, but does offer a few examples on how some companies perform product development on product variants.

4.1.1 OEM-suppliers to the automotive industry

HAST is one of the studied companies. As mentioned in chapter 1, one of their products is the bumper structure with crash boxes. The production volume of the crash boxes is in the range of 20,000- 500,000 units pr. year, Fig. 4.2. A bumper system is placed at the front and rear of the car, and consists of a crossbeam and crash boxes at each connection point to the chassis. Each product is customised for the customer, leading to a large number of product variants, approximately 70 new variants per year. Most of these variants are on the bumper beam. The customisation of the products is a must in this business, and is not seen as a problem.

Figure 4.2: Bumper system and position in the car

Kongsberg Automotive (KA) is also a global tier 1 supplier, which manufactures gear shift systems, seat comfort systems and commercial vehicle systems for the majority of the car and truck producers in the world. Commercial vehicles systems include, among other products, the clutch operation system, Fig. 4.3. The clutch servo reduces the pedal force needed to activate the clutch, making it more comfortable for the driver to change gears. It is the servo unit that will be presented further in this article. The servo uses air pressure to boost the hydraulic pressure from the clutch pedal. KA manufactures this product in many variants, fitting everything from small and large trucks to busses.

Figure 4.3: The clutch operating system and the clutch servo

4.1.2 Consumer-sale companies

Ekornes ASA is the largest furniture manufacturer in the Nordic countries and owns, amongst several brands, Stressless®. Stressless is one of the world's most famous furniture brands. Ekornes is located in a part of Norway with fjords and high mountains, putting an extra demand on transport. The main product range, the Stressless, Fig. 4.4, is a collection of chairs and sofas with multiple functions such as tilting back rest and adjustable head rest. The Stressless products are produced with a relatively high variety for the customer, while keeping strict control over how these variants are created. The production volume of the Stressless is around 1,100 chairs per day and 100-200 sitting units of sofas per day. The development and management of Stressless furniture will be discussed further and this is also their main product. The company designed their first reclining chairs in 1971. It was delivered in few variants and the production volume was high. Sales and profits were good, but as time passed a more modern look was needed. The chair went through some changes, without adding too many variants, until the mid 1980s. Releasing new and exciting products onto the market was seen as a way to improve sales. Highly skilled industrial designers created many new products. Unfortunately most products were created with individual industrialising terms, resulting in inefficient production. Six different manufacturing processes were handled which dispersed the product portfolio. Time spent at production on ramping up for new models and changes between them, was becoming a problem. The volume manufactured on each component fell and the cost of producing a chair rose. Ekornes was technically bankrupt in 1990, and some major changes were needed to save the company.

Figure 4.4: Stressless® chair and sofas, all seats have a tilting back rest.

Stokke is also in the furniture business, located close to Ekornes. They are a smaller company than Ekornes and focus their products towards a different customer segment. They have two product assortments, one for children (chairs and beds) and one for adults called the Movement collection. The Movement collection focuses on allowing the user to always find a new sitting position. The form and colour of these chairs appeals to a narrower customer group willing to have something special, while not compromising on the correct sitting position. Stokke launched Europe's first adjustable recliner and have continued to develop functional and modern chairs, Fig. 4.5.

Figure 4.5: A reclining chair, model peel™

To get an overview of the key values for the four companies, Table 4.1 presents the operating revenues, net profit and number of employees.

Table 4.1: Key values for the companies in 2004, * = HAST is a sub units within these numbers, ** = 2002, based upon 1€=8,47NOK

	Hydro, extrusion and automotive*	Kongsberg Automotive	Ekornes	Stokke
Operating revenues (€, million)	3258	261	267	84**
Net profit (€, million)	32.7	31	40.5	-
Number of employees	-	2265	1546	460**

4.2 Platform interpretation

The purpose of product platforms is to create variety for the customers while keeping a minimum of in-house variety. Increasing the reuse in as many assets as possible is important to improve the company's ability to perform well in the global market. Regarding product platform design, Robertson and Ulrich (1998) define assets in platform design to be more than standardisation of components, as mentioned before. They include components, processes, knowledge and people & relationships. The analysed companies carry out the reuse within these four assets in very different ways.

The companies own perception about how they design and manage their product portfolio is partly the same as found in literature, although the term "platform" is not widely used. Ekornes focuses on standardisation and establishing industrialised conditions for the products. Stokke have their attention on creating attractive and functional products that fit within their supply chain. Stokke has a well-functioning network of suppliers of competence and components. KA uses the concept of platform, as KA has positive experience from designing the servo product around a platform. The term "platform" was however not used until recently, when a new family of products was designed. This product family was designed with a variation strategy from the beginning. HAST has a strong focus on optimal use of their production lines. Products such as the bumper beam are therefore designed to fill the production lines. HAST also has a new product family, crash box, which is included in the bumper system. For this product, HAST is in the process of designing a product platform architecture.

4.2.1 Components assets

Ekornes is a company that has first hand experience with both loose and strict control over the product variants. In 1992 they restructured their product portfolio and a standardisation process was started. In 1993 this process had removed 75 % of the components, meaning higher volumes for each component. The focus then went from removing components to optimising them for manufacturing and focusing the variants to different customer groups. The product platform was based upon component standardisation and postponed differentiation in how the variants were created. A central technical aspect of the platform is how the design of undercarriages, steel frames and foam within the seat is tuned to fit the automated production line. The chairs are created in three different sizes, where the width is the variable parameter. This parameter can easily be varied without having too many adjustments to the production line, since all the interfaces between the components are kept constant. The main differentiation of the product portfolio happens when the final foam and leather/textile is assembled, but even here Ekornes is strict about standardisation, as the development manager says:

A new colour is a variant and we must also at this point think standardisation. The standardisation must not slip at the last segment. If we can remove more variants than we replace, that is desirable.

Ekornes is in a position to have full control over their product portfolio. They can decide when a new product is to be released or taken out of the market. The customers are not interested in an excessively fast turnover of new variants, so only a limited number of variants are changed each year. This, combined with the high level of component standardisation has reduced the production cost so much that the high employee salary in Norway has little influence on the final product cost. Ekornes has also arranged so that most of the manufacturing is in-house. Because of the high volume of products Ekornes produces, it can arrange an efficient logistic chain to the customers.

Stokke has a different strategy for running their business. Stokke does not have a product portfolio based on reuse of high volume production. The products are produced in low volumes and target a niche in the furniture market. They have strong focus on creating chairs that allow multiple sitting positions. By having special competence around the critical parts that allow the chair's movement, Stokke can use external consultants in the design process, which give the chairs a unique form and identity. The use of external consultants helps Stokke to push forward the chair design front. One very vital part of their way of doing business is a lean supply chain and manufacturing on-demand. Transport is by road, and although delivery can take several weeks, the supply chain is considered sufficiently fast by the customers.

Kongsberg Automotive is also a company that has a long tradition of making their products, such as the clutch servo. The design of the servo first appeared in the 1970s and has evolved since then. The product is built around a scalable platform, with approximately 200 variants, partly illustrated in Fig. 4.6. The high number of variants is needed to satisfy the different customers and their truck models. The customisation is mostly related to the response the truck driver wants to feel, the servo force needed on the clutch and the servo's interconnection points (fluid-, pressurized air connections and mounting connections) to the gear box. The product is built around a large cast component, fig. 4.3, which is customized with minor changes to meet the customer requirements. This is also the most costly component in the product, since it requires an expensive die-cast tool. Adapting the most complex component each time might seem unwise to an outsider, but the main technology in the product is actually related to some interfaces within the product. Although these interfaces connect relatively inexpensive components, they have very strong links to the overall functionality and quality of the product. The products have long lifetime, approximately 7-8 years before a mid-life update and then another 6-7 years after that. In addition KA must often supply spare parts for up to 10-20 more years.

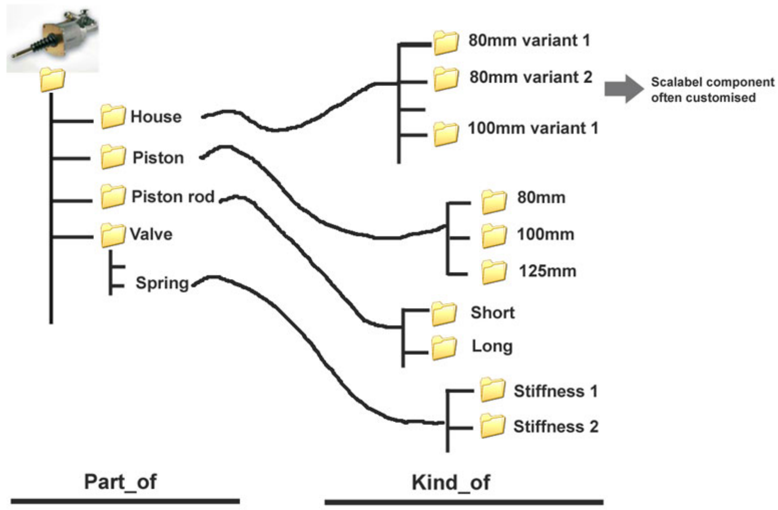


Figure 4.6: Part of the product architecture to the servo, illustrated with the Product Family Master Plan (Mortensen et al. 2001)

Hydro Aluminium Structures has a different approach to the use of their product platform than the other companies. Their products have a very high degree of customization, more so than all the other companies in this study. The customisation is also of the character that it is not easy to accommodate in the final assembly step. So the customization is performed early in the design process, with close contact with the customer. As the customers develop each new car, for example over a 4-year period, there is a lot of parallel design of components and therefore the customers often change the functional and packaging requirements several times after the design work has started. As early as 1969 Hydro started to manufacture the bumper beam and have now managed to gain a large market share for their product. The HAST product platform could be characterized as being several technological concepts that are adapted to the customer, but can be manufactured with minimal investment in tooling for the production line. HAST's portfolio of bumper systems is very large, both regarding the total number of product variants and their production volume. The variants vary with regard to, for example, if the product is aimed at a European or a North American car, the required energy absorption capabilities and the chosen manufacturing processes. The production volume ranges from 1,000 to 800,000 units for each product variant. This type of portfolio makes it possible to design the products to suit one of the production lines, and to ensure that the all lines are filled with appropriate products.

The other part of the bumper system, the pair of crash boxes, is a component that appeared in the mid 1990s, as the focus on crash behaviour increased. HAST started the product development of the crash box from scratch. The first generation of crash boxes had good performance, but the industrial processes chosen has proven to be too expensive. The next generation of crash boxes will have a better match between the product architecture, flexibility of design, industrial premises and cost. The portfolio is redesigned to accommodate more of the platform capabilities that have been achieved in bumper design.

4.2.2 Process assets

Ekornes has a component-standardized product architecture that is highly suitable for the production process. Production is designed around a postponed differentiation of variants and is highly automated. A new factory has been built to optimize the material flow and establish the best premises for automated production. For example, most of the work on wood and metal structures is done with robots, making an earlier expensive structure much cheaper. They also focus on having as many of the activities related to the product under their control and close to the main factory. Thus, the internal logistics are reduced and the external supply chain is simplified. The supply chain uses both sea and road transport to and from the factory.

Stokke is at the opposite end to Ekornes, with their production based much more on manual production. Stokke uses many specialized suppliers that do similar work for other furniture companies. The suppliers can thus have continuity in their work.

KA focuses on manufacturing the main part of the servo in–house (cast house and piston) and out sources the other components. The cast servo house has several surfaces used during manufacturing and for test set-up. These are kept constant through the product variants, making the manufacturing sequence and testing less sensitive to new variants. As the largest servo was designed, additional fixture surfaces for the manufacturing were established. This can be seen as a generation update of the platform, since the production technology also has improved over time. From the beginning, several of the cast house versions have also been designed with multiple connection possibilities for hydraulic fluid and pressure air and they are machined open according to the variant produced. KA aims to reduce the stock of semi-finished products as well as cast dies to a minimum.

At **HAST** the manufacturing process is a vital part of the product platform. It starts with the material used. Since Hydro also is a primary manufacturer of aluminium, a melting factory for a special alloy is located close to the production site of both the semi-finished products and the final formed components. The bumper beam component is made of stretch-formed extruded aluminium. This is an advanced method of forming semi-finished products into the final product shape. Through many years, HAST has managed to standardise several elements in the design and production of these components and related tools. Several lines have been designed, each with a different number of forming steps. The designers can choose a production sequence in the design phase, which matches the required production volume. HAST invests heavily in production equipment and can handle high volumes, provided the lines are up and running most of the time. For the crash box, a good match between the design architecture and the manufacturing process (like for the bumper beam) has for the moment not been established. Another challenge HAST has concerns the assembly of the system, which often is done close to the car manufacturer's plant. The components must thus be designed and manufactured in a way that makes it possible to assemble them after transportation and still be within the required tolerances and product performance boundaries.

4.2.3 Knowledge and product information

The marketing division at Ekornes plays an important role in maintaining the product portfolio. The product development manager can get full access to sales statistics for each product variant, statistics about each of the 2500 Stressless shops world wide, and information on the type of marketing campaigns that have been done at each shop. Product variants with falling turnover are investigated. Action is taken with additional marketing to extend the product life or to replace it with a more modern variant. New variants are specifically designed to target the same customer group as their predecessors, without affecting the sales of the other variants. The product development manager expresses the market orientation of the product design as

”We have a product development division that has an industrial anchoring, but also has a connection to the market that makes us able to create modern and timely products that can be industrialized on a rational way.”

When it comes to stored product information, electronically or on paper, there is a large difference between the furniture- and the automotive industry. In the furniture industry the products are not so technically complex, so most of the documentation is sales related. They rely very much on the previous experience people possess and perform only some simple tests to verify the product. Ekornes has in the group’s objectives and values, a product strategy emphasizing the need to designing with product platform. The technical product information in both Ekornes and Stokke comes from CAD systems and outside of that, little information related to product platform is stored. A product developer at Stokke said

“To find an appropriate level of documentation, we have to balance the time spent on documenting against the risk of having too little documentation.”

In the automotive industry product knowledge goes much more in depth than in the furniture industry, meaning there is a greater need for technical documentation. Furthermore, the automotive customers have requirements as to how products should be documented and quality guaranteed.

At **KA** the product platform of the servo is based upon an old concept. Through the years they have gained knowledge from their own tests and customer’s feedback, refining the technology within the product. A lot of development and tests, both simplified tests and from years of road tests make the foundation for the technology. Even minor changes to the design can trigger the need for new testing. Testing is time consuming and very expensive, so keeping it at a minimum is much more important for the platform cost than strictly focusing on component reuse. The database with test results has become very large and to extract the correct information for reuse in new projects is sometimes found to be difficult. For the earlier product versions the test information may not be stored with sufficient product data to be fully reused as documentation for new variants, since testing has become more demanding over the years. The customer usually requires that the product goes through a long test run test that last years before it enters the market. Changes during this period are usually not allowed. KA has also tried several methods to ensure that the platform is used in the best way possible, in addition to the existing quality systems. One method tried during the 1990s was to write down why changes were made, on a detailed level. This should then simplify the design work next time, but it became quite time consuming and it was found difficult to retrieve the wanted information from the database later on due to difficulties in organizing the information in a good search-friendly manner. Nowadays the most important information from the development projects are stored in a “Book of experience”, which is a few pages with relevant information which the project leader for a new project reads prior to starting up similar projects. To stay in front of servo design, KA’s products are constantly benchmarked against those of competitors.

HAST products are designed to have excellent performance in both low and high speed crashes, yet still have a very low price. The complexity in design is to control every aspect of the aluminium’s temperature- and forming history far down into the micro scale, throughout the whole process. Simulation is therefore carried out during the manufacturing forming steps, assembly (welding) and on the product level, so that the final crash behaviour and the product cost are optimal. The high number of projects per year makes it important to make some parts of the design process. For example, for the design of a new bumper beam variant, several starting models (CAD models), from previous projects are used in the early design phases. They give valuable information about crash performance, mass of material used, manufacturing steps needed and cost. Several systems assist the communication between departments and disciplines. One of them is a detailed description of all the production lines which is aimed for use by designers. These descriptions go in depth around the manufacturing possibilities and limits. The manufacturing process departments maintain this system. To further improve the reuse of experience and knowledge, a “design portal” is under development. This is a place for the designers to get ideas and use previous experiences to avoid pitfalls, etc. Behind this portal there is large amount of highly detailed data from many projects, for example related to simulations, physical tests, and production experiences and so on. This design portal is seen as a tool to secure correct reuse of product and process experience. HAST’s primary reason for such detailed documentation is that they are a large product development organization, spread around in different countries and want to avoid making the same mistake several times.

For the crash box component there is less experience. A concept that can function as a design platform has not been established and the structuring of design knowledge has only just begun. Even if these two components (beam and crash box) use many of the same basic technologies, they are implemented differently and this causes challenges. The crash box interaction with the manufacturing is very different, due to how the assembly is carried out and the design of the very complex stamping tools.

4.2.4 People and relationships

Ekornes and the Stressless product is a good example in how to see that industrializing the product is one of the key areas in product platform design. For a period the industrial designers had a lot of influence and they did not understand the mechanisms that provide efficient production. But after this time, the organization structure was changed to match the product platform developed. The product development was organized as a factory within the factory, with all phases of the production represented. Skilled employees from production were transferred to the development organization. The use of external consultants was abandoned and the internal designers focused on matching the design to the production line and ensuring that all the people within the product development factory knew the company's industrial premises. As the platform was introduced there was a change in the decision structure. All new product variants must be accepted by the product development manager as the first step. Then a product council decides which variants to display at a furniture exhibition and with the response from customers, a new collection is chosen. The council consists of people from marketing, production, product development and executive directors. Other than the Executive Director of the company, there are no representatives from the financial department. The composition of the organization and council is done to ensure that new product variants fit within their industrialized processes and secure the future.

At **Stokke** the product development group is small (9 people) so the internal communication of knowledge and experience flows easily. Since they use consultants to design the form of the chairs, they have established a very efficient contact network of people who are expert in different engineering and manufacturing fields. People from the product development team also train the sales people so they have in-depth knowledge about the products.

KA has from their early day had frequent contact with their customers. As the product is tested and verified by the customer, a change is only made if strongly needed. Any change would increase risk, which can only be reduced by new testing. This is mutually understood by both parties. The platform technology and associated processes are developed primarily in cooperation between R&D and the model factory ("Center of Excellence") in Hvittingfoss. The technology and associated processes are then emulated in the KA factories outside Norway.

In **HAST** the product platform is strongly linked to the management of the knowledge and experience people possess. HAST is an organisation that has a lot of engineers and contains special competence on material (aluminum) property and manufacturing processes. Each new project is always manned with people from different disciplines. If projects run into design difficulties, people from other design teams are brought into the project to help, but in spite of this sometimes the designers still miss the best flow of information across the design teams. To find new projects, the market department traces the market and contacts the potential customers who they know well. HAST is usually involved in new projects in their early stages. A vehicle is developed over several years (cars around 4 years) and throughout this time the car design is very dynamic. The packaging and functional requirements change constantly as the development of the car progresses. Hydro must be able to customize their product platform to the initial requirements and to the changes that appear. They must be able to quickly change the design without altering the industrial premises. This process demands close contact between people but also intensive exchange of product data. HAST's customers usually conduct their own tests, both virtually and in physical models. HAST links their product models directly into the customers' systems. Table 4.2 summarises the findings of how the concepts of platform can be applied to the studied companies.

Table 4.2: Summarises the main characteristic of the companies' platforms. The grey areas represent the main areas for reuse, within the companies. * The reuse focus is far less for the crash box product than their main product, the bumper beam.

	Ekornes	Stokke	HAST	KA
Components	High standardisation High tool re-use	Low standardisation	Low components and tool re-use	Medium re-use of components and tools
Process	Routine design process Vertical supply chain integration (in house) Factory adapted to platform	More flexible and informal design process High focus on supply chain	High re-use of design concepts / technology High re-use of manufacturing principles and infrastructure	High re-use of design concept / technology High re-use of manufacturing
Knowledge & information	"Culture" for industrialisation	Informal channels of knowledge communication Innovation intensive	Highly specialised know-how around material and product performance* A lot of design data is stored*	High re-use of product history experience
People & relationships	Strong link between product development and retailers	Strong network of suppliers	Dynamic and intensive communication with customers	Strong internal relationships also between global units

4.3 Discussion

All companies in this study use the concept of product platform differently. The term platform was not found to be widely used, but more often, the concept of asset re-use. Ekornes has adapted the principles of product platform, in order to achieve a very high commonality of part sharing in their products. The way Ekornes use product platform and organize their product portfolio is closely related to differentiating the product portfolio and removing components from the portfolio as found in articles from Meyer (1997) and Mortensen et al. (2001). They have the opportunities to utilize product optimization in depth, due to the full control over the product portfolio. They can release or remove products from the market as found most beneficial. In addition the technology in their products is far less complex than that found in the studied automotive companies. Stokke has a product portfolio of chairs with strong focus on a movement function, all target different market niches. This results in low production volume and less component reuse potential than Ekornes, but they manage to reuse key movement elements in the chairs. They also develop other types of products (not furniture) that they have gained substantial reuse of the supply chain structure for the chair distribution.

The automotive industries are in a different position than the consumer-sales companies. Their control over the products and release of new variants is strongly related to the release of new car and truck models. They also have a different approach in how the product platform is used compared to the consumer-sales companies. Here the product variants are developed after eachother with some successive reuse. The product platform is therefore used as a way to reduce the complexity, by increasing reuse in the design process and reuse of production principles which is more than component reuse. It should also be said that the awareness of where the reuse is and where the potential are is little exploited. Looking at relevant literature for utilising the product platform this way, Meyer and Dalal (2002) and Jiao & Tseng (2004) discuss the use of platforms in industries that manufacture non-assembled products, such as film and semiconductors. Their focus is mostly on establishing product and process efficient indexes. The authors Jensen and Hildre 2004, discuss the design's variability and the associated manufacturing flexibility for process intensive products, but still the amount of product platform research done for this type of industries is far less than for consumer-sales related companies.

One of the major differences of the products and platform used in the consumer-sales companies compared to the automotive is illustrated in Fig. 4.7. The consumer-sales companies have very strong focus on reusing the most technological components in the products. While the automotive companies have to some extent, focus on transferring knowledge from one product to another and keeping the manufacturing more fixed.

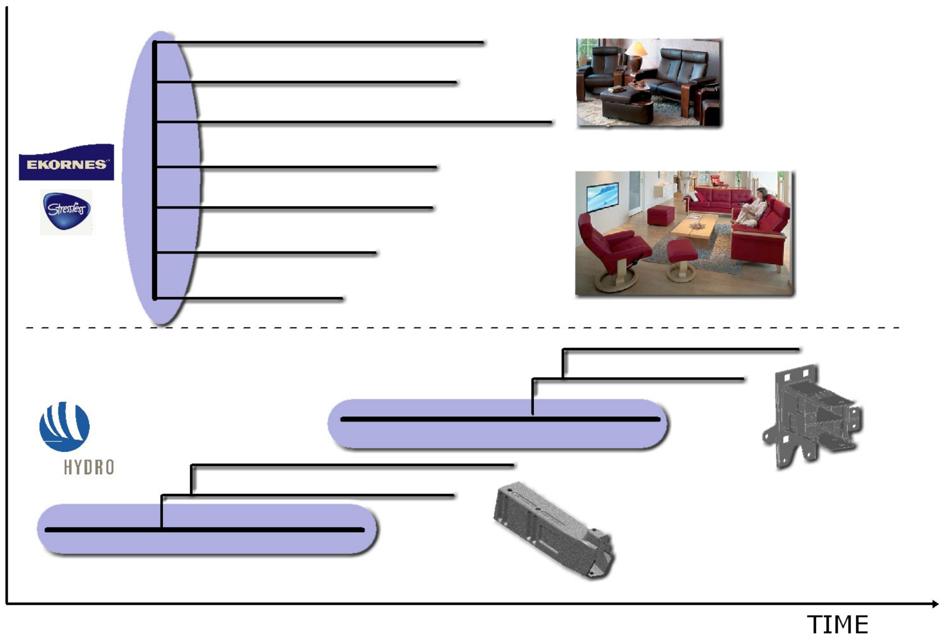


Figure 4.7: An illustration of the different product variant development in consumer-sales- and automotive companies, shown with Ekornes and HAST

The focus the companies have in the way the products are developed is very different. Riitahutha and Andreasen (1998) created a figure (shown in Fig. 4.8) relating the product architecture to three elements, increase variety, increase commonality and reduce complexity. In this study the consumer-sales companies seem to be mostly positioned between increase variety and increase commonality The OEM-suppliers technologically advanced products are more related to a reduction of design complexity and hence are capable of quick redesigns. There are always some requirements that will change with time and the product architecture should be capable of such a change. The invested capital in design, knowledge and production equipment is large and a long lifespan for the platform is preferred.

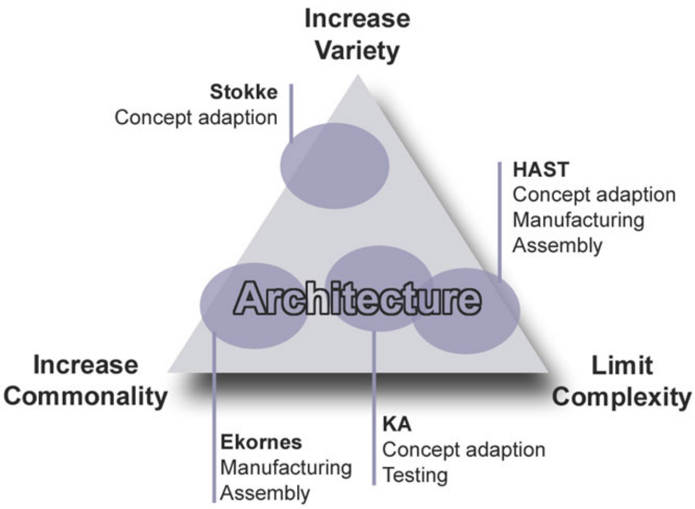


Figure 4.8: Dimensions in product platform development and the main focus areas for the companies in this study (Riitahutha and Andreasen 1998)

When it comes to communicating the platform's commonalities and distinctiveness, Ekornes has a strong culture driving standardisation in all parts of the organisation. The product complexity and turnover speed of new variants at Ekornes is thus limited, so the need for a large information flow is not as great. The product development management has the ability to control when new variants are released and the old removed. In all the other analysed companies, the drive for standardisation is not as strong as at Ekornes, but both at KA and HAST it is increasing.

HAST who have many projects each year, cannot channel all information through a few key people. They need to spread the knowledge and ability to decide on reuse issues to several people. HAST has many design teams and each design team work more or less towards the same customers, again and again. This can be seen in the type of design solutions that are selected, for the crash box. The sharing of information between these design teams is therefore limited. Sharing of information is related to some personal networks and when projects run into trouble, and then they are assigned extra people from another team. This can also be seen for the stored information. It is difficult to navigate around, and there is no classification of "reusable" and "not reusable" information. There is a need for a common Corporate Platform, to avoid sub optimising the products. A more holistic plan for how to develop and manage products and manufacturing processes is essential for the crash box development. The product may satisfy the customer, but the internal company requirements at HAST could be better satisfied through a clearer understanding of what that is important and where to extract the profits.

5 The Corporate Platform as a base for leveraging product variants

In this chapter a model will be proposed that deals with creating a balance between the customer's request for an appropriate product variant and the standardisation a company needs. The model will provide information about the complex relationships that exist in developing a product platform from a Corporate Platform base.

The customer in today's world has a huge variety of product to choose between. The shops are filled with all types of consumer goods such as electronic products, sport equipment, toys etc. The car showrooms are filled with car models covering a wide spectrum from small economical cars, family cars and luxurious sport utility vehicles (SUVs) and they all offer a degree of customisation. Still the customer has never been more aware of what is the latest and best product. The customer is fed product information from advertising, tests in magazines, user experience and comments from the internet. This makes the competition even more difficult and products descend very rapidly from best in the market to average.

The customers' influence on the product variants points in two directions; choosing from predefined product variants and being part of the customisation of the making of the product. The selection from predefined products is most common in consumer goods (e.g. shoes, electronic equipment etc.). There are to some degrees customisation in some consumer products such as a sofa (seats, colour and style) and car (engine, colour and extra equipment), but these choices are limited and within a predefined set of variables. Within these types of products the manufacturer can manage the product portfolio with a strong link to manufacturing standardisation. Products can be phased out and in according to a holistic market plan, controlled by the company. The other direction, where the customer is part of the making of the product this is more difficult. Here the customer requires being a part of the design process in order to adjust the product to fit within a larger system. An 'off the shelf' product would not fit well enough, but still it is important for the company that manufacture these products to take advantage of a commonality opportunity that may exist. The companies in this position usually have many customers with individual requests, but the concepts that have been sold to them may not vary too much. A set of "basic concepts" can then be adjusted and leveraged into new product variants.

This is also the position HAST is in, with its crash box product. With the crash box, HAST has been very successful in satisfying the individual customer's requests, but they have not been able to standardise the solutions and production processes needed to lower costs. Each project has been run more or less as a one-at-a-time project. New thinking in the structuring of the product development process is therefore needed for HAST crash box development, in order to be competitive.

5.1 The Corporate Platform model

One thing is to develop "one-at-a-time" products; a different thing is to manage a product portfolio. To develop such a controlled product portfolio, it is necessary to implement product development methods such as product platform and modular designs. These are methods that have been developed first of all to change the product so that an increased reuse of components can be achieved. Both with a focus on improving the internal commonality (cost reduction) and maintaining the flexibility of design solutions towards the customer.

These two approaches are different in how they provide increased reuse in the product variants and how tightly the organisation is coupled to the products. Modular design has proven its success in products where there is a need to create many product variants and also to have a high reuse of components and modules. The modular design approach is in its nature split into many elements, and hence the connection internally in the product is somewhat decoupled. This means that the development of each module can be done "independently" of each other. This decoupling can also often be found in the organisation of the product development, each module is often related to a team, making it easier to enhance the reuse. For the product platform approach it is different.

The product platform is intended to form a base from which the product is leveraged. It differs from one-at-a-time projects in that it is coupled with the other products in the family and that there is a deliberate reuse of assets. In its simplest context it is a technological and important structure of the product that is reused in all product variants, but it can also include much more. It can be used strategically to improve the reuse within areas as processes, knowledge and people and relationships (Robertson and Ulrich 1998), Fig. 5.1. In this context where more than a technological part of the product is reused, the product platform intention can embrace over more types of product. Making it suitable also for products that cannot directly reuse the technological important structure of the products, i.e. there has to be some sort of engineering on the product each time.

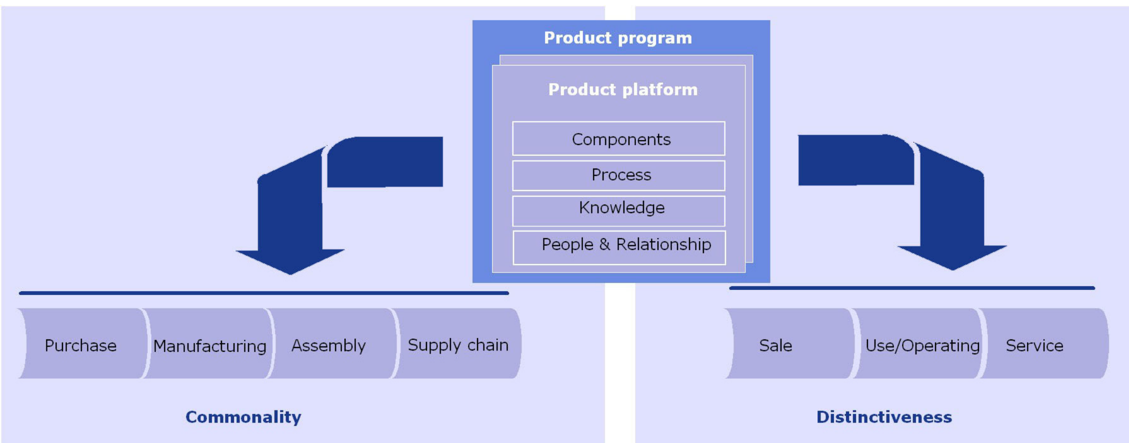


Figure 5.1: The elements in the product platform and the focus for reuse in meeting with the life cycle.

When the product platform is also viewed from the other assets such as process, knowledge and people & relationship, it becomes possible to include more than one product platform (component) in the product family. All of the additional assets are on levels deeper than the product itself. By using a structured way of aligning the product structure and these other levels improved reuse in the organisation can be achieved. This is achieved through a balancing of the commonalities and distinctiveness between platforms and the product variants. Changing the organisation over to a product platform approach means that one has to establish the platform. This is not just a small and simple project, but one that the company needs to invest in. It should be developed so that future product projects can harvest from this extra investment and improve the cost profile of developing products in the future.

To develop a product programme based on product platforms means that one has to have a very active control over what types of projects that are run and what they focus on. The product platform consists of, as mentioned, of a base and an element of the product adaptation to each product variant. In the daily product development one should only work with product engineering of the customisation. This should make it possible for development projects to deliver product variants at the right time and on budget. A development project should therefore be a low risk process. The derivative products should be made with only minor engineering work. Therefore the development projects should use only known technology and manufacturing processes within the borders of the product platform. To make changes on the product platform base one should be aware of the consequences it has on the future products, but it should not be too static either. If there is disruption in the product requirement or a large change in technology, the base of the platform should be reviewed. This classifies therefore these types of change projects as research projects. A research projects have more uncertain outcome than a development project, both regarding the time used and risk of success. It is therefore important that such development is not mixed with the daily product development. This leads to many elements to consider in product platform design, in order to couple the different product development projects.

With the Corporate Platform models, a formal description of the product assortment encounter the marketing and manufacturing, different customer requests are made explicit. In the same setting the production possibilities and limitations for the product variants are described. The Corporate Platform model consists of three major elements, Market, Product platform and Manufacturing. These elements form the base for conducting the product development that deals with the final customisation. All these major elements are described on two levels, one at a detailed level and the other at a more holistic level. Within each of these elements there are several processes that are made explicit, and between them a flow of information. To visualise all the complex relationships that exist between the dynamic customer interaction and the more static corporate knowledge, this Corporate Platform model describes the major interactions. By understanding the interaction and what processes to go through, the different elements can be mapped out. This should result in a more controlled product development, where there are clearer separations between research and development projects. As mentioned, if a product development can be done with less research this gives benefit in lower risk and cost. The elements in the Corporate Platform model will be thoroughly described in the coming chapters with an example and below is an overview presented, Ffig. 5.2:

- *Market*; the market element is where the interaction with the customer appears. The customers have a request of getting a product that fulfils a certain set of functions. In the sales process the company need to know what type of properties in the product that should not be changed and where customisation can be offered. There should be clear and defined lines when products to be developed include more than a final customisation. The different types of products are visualised with a market segmentation chart. The products are structured according to some vital product performances. In the process of establishing the market segmentation the engineers need to make prediction of how to best align the product portfolio. The customer and trends analysis provides data on the differentiations that the market segmentation should be built upon (Dibb and Simkin 2001) (Dibb and Wesley 2002). All these anticipated demands on variation must be analysed, and a selection of functions should be targeted to fulfil. All this information is fundamental for developing the product platforms.
- *Product platform*; involves the establishing of new product structures, reorganising of the existing products and the associated production processes. This element combines the market information with manufacturing knowledge to form one or several product structures, for the product programme. A few basic features can normally characterise the products and the ranges they must vary within. These features are then worked with to give a first idea about the size and complexity of the product variation that needs to be considered. Closely related to these features are also the associated production processes. Both the synthesising process of finding appropriate products and production go through iterations. This synthesising process is more like finding the best alignment of all the elements in the Corporate Platform. The result is one or several product structures that can be used for detailed engineering to become the customised products. The reason for splitting up the product platform into a product and production section is related to where the customisation of the products starts. By separating them one can handle products that need to have a final engineered customisation. A specific product line can have several solutions of product structures that fit within the lines. The opposite situation can also happen where one product structure can be realised through several different production lines.
- *Manufacturing*; is the knowledge base that exists within the company. The knowledge is something people possess and improve through experience and learning. It is shared as an information flow on different media such as conversation and written information. The written and stored information is one of the sources of information sharing. In large and global organisations the sharing of information between people is not always easy, so written information must to a large extent be used. Structuring the stored information can be done in many ways, depending on the use. In the Corporate platform model, a way of structuring the design information to enhancing the reuse is proposed.

Product development; are the final product variants. The product structures and production processes are used to engineer the specific product variants. This is engineering with low risk and hence should be done more often than changes to the product platforms.

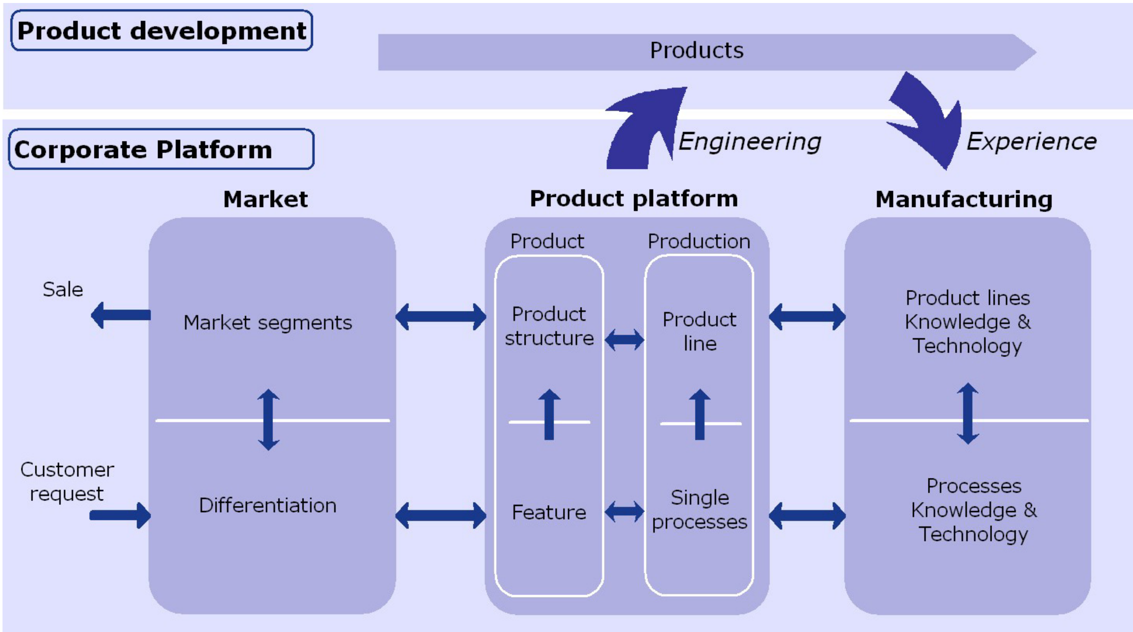


Figure 5.2: Corporate Platform model, with all elements and the relationship to the product variants

To incorporate this model in the company and make it work over time, it must become a foundation for the product development organisation. This includes that the company manager set the strategy for the product development on the agenda. By focusing on the product development in a wider context than only the ongoing project, a better optimization is possible for the company. Focusing on one project at a time results in sub-optimisation. The product that comes out of these projects may well satisfy the customer's requirements, but how well do they satisfy the company's needs? In companies that constantly provide new product variants it becomes therefore important to take a more holistic view of the product development and ensure that the best solutions are used and that there are synergies between the projects.

In the product development organisation the people have to know and understand the benefits as well as the consequences of developing products from product platforms. It is these people that will interact with the elements of the model, Fig. 5.3. They will use information from it, create solutions and feed new information back to the company. The Corporate Platform model provides in this situation, guiding for the product development. It is also beneficial that the company managers establish supporting activities for the market and manufacturing, by improving the information flow relevant for the product development.

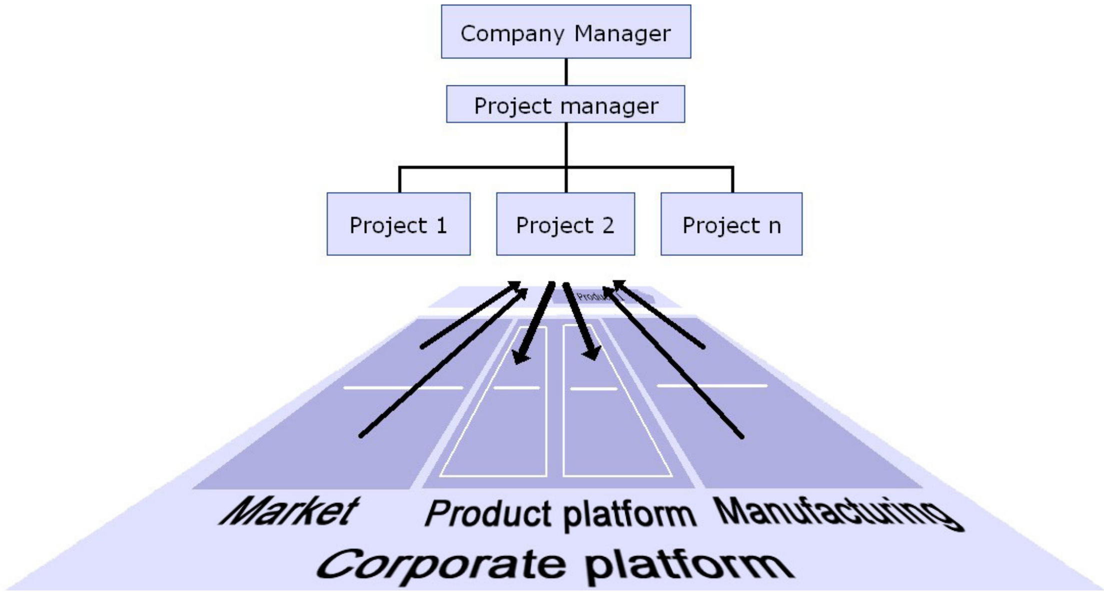


Figure 5.3: The user of the Corporate Platform model is the project manager and all the development and research projects for the products incorporated in the product platforms. The project teams get information from the model and create solutions

The Corporate Platform model enhances important product variant relationships, makes them explicit and relates them to the company strategy. The model suits companies that make products that need a customisation process that involves more than pure configuration work. Since the model makes the relationship between the product variants explicit, the reuse of product, production and supply chain can be easily improved. The reuse benefits are found in the total structure of the product programme and the reuse of industrial processes.

5.2 The crash box case: Market relationships

This section of the Corporate Platform will cover the input needed to form the product programme, while there will be a section in the end of this chapter on special consideration in the sales process of products from a product programme.

The development establishing or change over to a product programme is highly dependent on gathering and understanding the needs that the product must fulfil. This gathering of data from a range of customers or stakeholders is related to identifying the product's differentiating elements and what they have in common. The stakeholders in the crash box case are; customers buying the car, the OEM customers (Original Equipment Manufacturer), the government regulation and the company itself.

5.2.1 Product differentiation

The driver for the shaping of the product programme is the stakeholder's needs. These needs must be understood and translated into product characteristics that can form the base for developing products. This is just according to traditional product development, but in addition several projects have to be used to shape this foundation, not only a single project / product. The entire set of all stakeholders needs in the total market covers a wide range, possible wider than HAST can or want to deliver, Fig. 5.4. HAST's extruded aluminium crash boxes covers only a part of the product characteristics that all customers seek. They manufacture only Al solutions, but also do engineering on steel. It is therefore important that HAST is aware of the characteristics range they offer and that this is according to the overall strategy. This must be matched with the required range of product characteristics with as few product structures / production lines as possible. This will then guide the focus and direction of new projects.

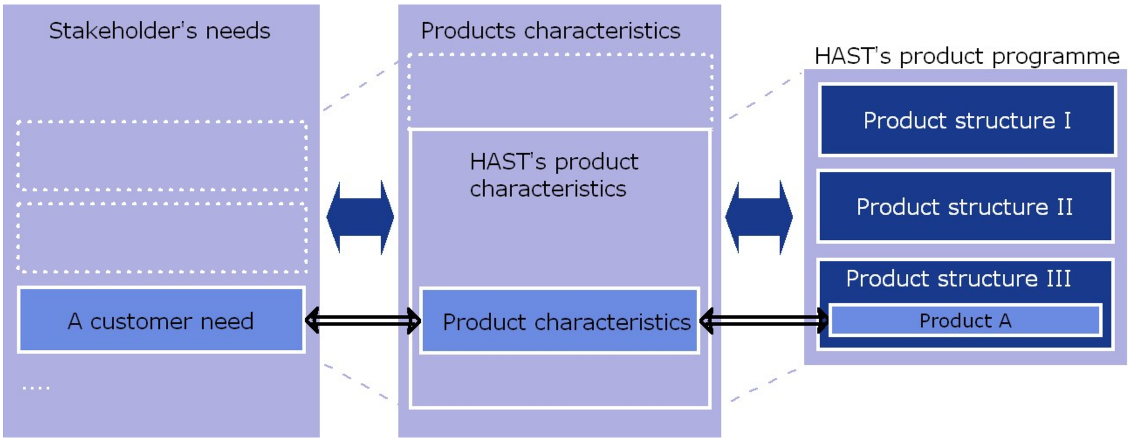


Figure 5.4: The relationship between customer's need and the product programme. The product programme can contain from one to several product platforms. One development projects is also indicated as a small part of the whole product programme

In a product programme one seeks to develop an assortment of product variants that will satisfy the customers so that they buy the products. The shaping of the assortment clearly affects the chance of a sale, but also how it is established and what combination of options are offered. Adding a third higher quality/priced options will in many cases result in improved sale of this and the cheapest option losing most (Simonson 1999). In the crash box case the differentiating characteristics HAST need to consider are related to:

- Product performance characteristics
- Stakeholders' needs and changes to them
- Product properties driving customisation

The product characteristics that are present in the product cover a wide range. Some are very important for the customer as key performance while others are of less importance. When establishing the product platform it is essential to know which characteristics that are important for the customer at the present time and most likely to be in the future. A well-known model in the product development the Kano model (Berger et al. 1993) (Chapter 3.5) which can be used to sort out the different types of characteristics in the product and how to focus on them. To give an example of this on the crash box, Fig. 5.5 lists some of the characteristics that the customer (OEM manufacturer) have a perception to. The attractive characteristic “crash performance on special tests” covers also the characteristic that the customers that buy the car focus on.

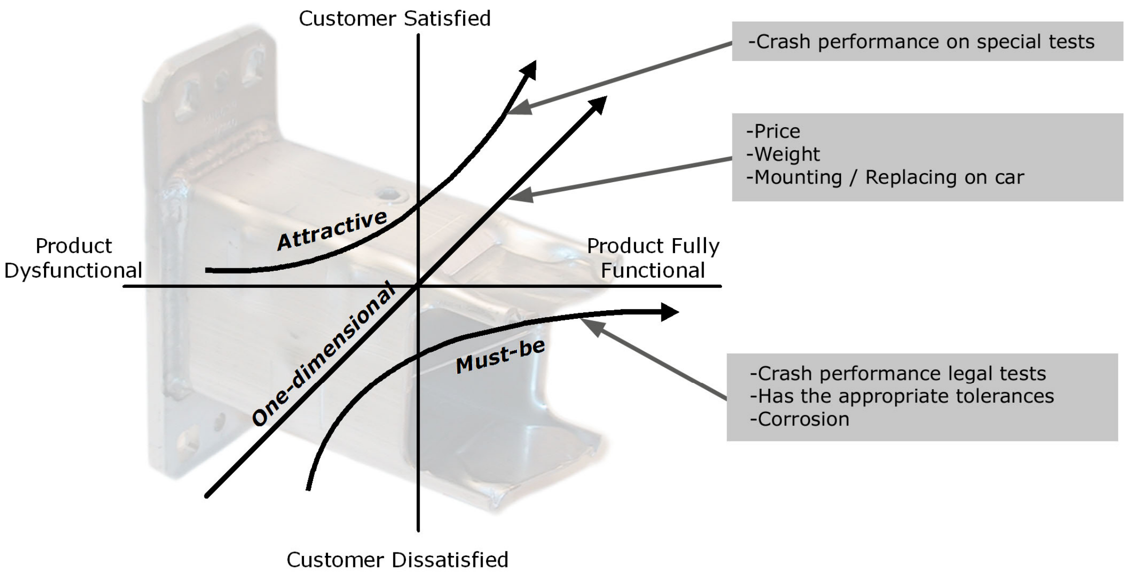


Figure 5.5: Some of the characteristics that affect the customer’s perception of the crash box and what type they represent in the Kano model

Since this is a vital crash component, this is of course an important topic. It is so important that the crash performance is measured in many tests, both required legal tests, car specific tests and tests that independent organisations perform. This is why crash performance is both in the must-be- and the attractive group. The crash management is an area in the automotive industry that has changed dramatically over the years. In recent years advertising of new car models emphasise the scores achieved in crash tests. This has then become an important sales property. There are also some car brands that focus more than others on this topic, but common for all is that the minimum required performance is constantly increasing (NCAP). In the beginning it was only car’s front, rear and sides that were tested (euroncap.com 2006). Now the speeds used in these test are higher and tests of pedestrian impact and child safety have also been added. These shows that that the cars’ crash performance have increased over time, and the tests are constantly changing, in order to separate crash performance. It is therefore very important to consider this in the product programme.

Stakeholders’ needs and changes to them. In the case of the crash box product there are several stakeholders, all with different needs and change rates. Governments rarely change their regulations but customers buying the car change rapidly and often only act on feelings, e.g. from what other car brands can offer on crash performance in tests. The OEM manufacturers are of course rapid in analysing their customers and establishing new demands as customers of HAST. To be in front in the product development, HAST should make their market analysis and anticipation explicit, so they can be used efficiently in the product development. This becomes especially important when converting from one-at-a-time projects over to a product programme. An in depth analysis of possible future scenarios should be performed. The product programme is established to be future oriented and not focused around the first upcoming project. An example of the elements that a product programme for the crash box should consider for future directions is illustrated in Table 5.1. These driving changes are related to the stakeholder; customers buying the car and the OEM customers. The stakeholder government's regulation has in this case been ruled out, since there seem not to have been any changes here for a long time.

Table 5.1: Indication and scenarios of the future directions for a crash box product programme should consider.

Stakeholders	Need changes /directions	Affect the design / characteristics of
Customers buying the car	Better safety for the drivers and passengers	The force level must be changed in step levels as the structure is deformed. The crash box is one of these steps. Additional load path in the chassis may be needed to fulfil this need. In the crash box this is related to the cross section or shear force in the tower component
	Better safety for pedestrians	The first force levels must be adapted to a soft impact. This affects the structure in front of the bumper and may occupy space today used for a higher force level deformation.
	Customers want to buy a car that activates the other car's safety structure if a collision should happen	The bumper structure must be positioned so that the load paths in both cars are activated. A secondary load path may be needed or variability in the height for the load paths
OEM customers	Reducing weight	Differentiate the designs, where some solutions are weight (performance) optimal, while other are cost optimal
	Reducing cost	Introduce product programme. Differentiation of high performance system and average performance system
	Increased performance of a regular bumper system	Introduce systems that are fully welded / or joined by a other method (not bolts to bumper)
	Handle higher crash speed (16 ->~20 km/h)	The tower length and cross sections are physically related to the amount of energy that can be absorbed and must be changed if the speed or weight of car is increased.
	Function well in low speed as well as high speed crashes	The connection between bumper beam and tower, tower and base plate and the tower geometry and the tower form is critical
	Using several load paths, upper and lower	Two bumper beams and two sets of crash boxes, one for an upper and lower load path

Product properties driving customisation. The crash box is supplied to OEM customers and must fulfil a range of different properties, depending on:

- Which country the product is to be sold in. There are different regulations that must be fulfilled. In the crash box case there are different mandatory crash tests in Europe and North America.
- The OEM customers have in some cases their own specified crash tests that must be fulfilled, in addition to the regulatory tests.
- The crash box requirements vary between the different OEM customers. Some have very strict design requirements, while others not.
- The crash box properties vary depending on if placed in the front or rear of the car
- The crash box must vary in properties depending on car model and size. The crash performance must be tuned to the respective car size and design request, e.g. the type of mounting to the car chassis and bumper beam. This tuning must

also be done in relationship with the available packaging space, e.g. the length from crash box base plate to the front of the bumper beam may be fixed.

- The crash box often has requirements on additional functionality as having a towing hook nut in the crash boxes. The placing of this is driven very much by the styling of the car and it presents a large design challenge, due to the strong stretch forces required to be withstood.

To understand the complexity of the crash box variations that HAST can be required to deliver, a short description of some of the physical relationships should be pointed out. The energy a crash box can absorb is related to the deformation force and the distance it is continued over, equation 3. The force is related to several factors such as the cross section, the material and the shape of the deformable components, equation 4. (Hanssen et al. 2000).

$$E = f(F, s) \qquad (3)$$
$$F = f(c, \sigma, b, t) \qquad (4)$$

E = Energy
F = Force
s = Stroke efficiency, the deformed distance
c = Constant, depending on single, multi cell profile, triggers and folding pattern
σ = Material property
b = Dimension of tower cross section
t = Wall thickness of tower

Fig. 5.6 shows the most essential crash box dimensions that HAST indicates should be handled within the product programme.

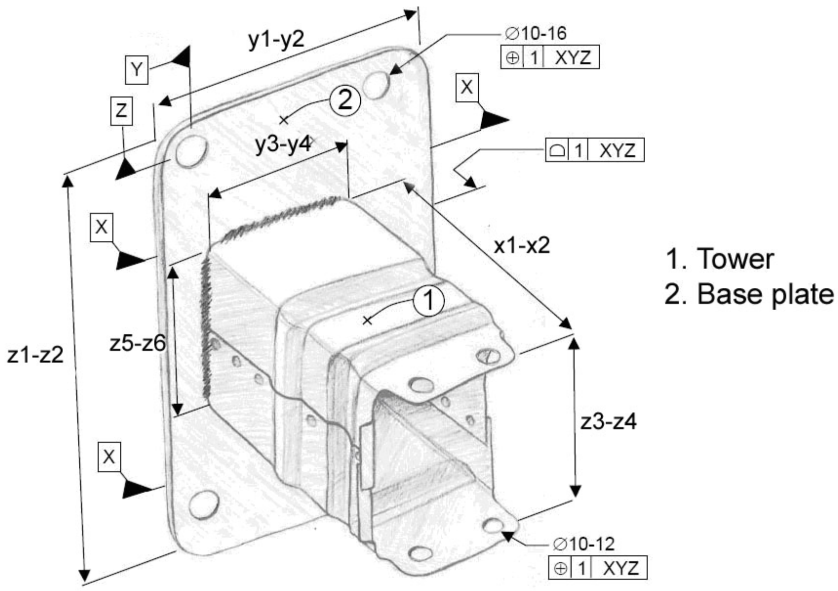


Figure 5.6: The crash box illustrated with dimension ranges that are needed to satisfy the different customer needs

All together this product has many features controlled by the customers and not by HAST, but since they deliver the product to many OEM customers and several car models there are many similarities.

5.2.2 Market segments

The automotive industry has for long time used market segmentation as a way of positioning their products. The market segmentation is based on the assumption that customers demonstrate heterogeneous preferences and buying behaviour (Dibb and Wesley 2002) (Dibb and Simkin 2001). This assumption about customers being heterogeneous is also a vital part of product platform design and makes it a good combination. It provides therefore a way for the business to fine-tune their offerings and develop competitive advantage. This could result in increased market share as well as improvements in the sales processes, by being able to communicate better with the customer about product possibilities. Performing market segmentation means that one or a few properties in the product are chosen to become segmentation parameters. How to select these segmentation parameters is related to the company strategy and the attractiveness factors in the products. It is beyond the scope of this thesis to do in depth research on this market segmentation, but authors as Weigan (1977) and Shapiro and Bonoma (1984) discuss market segmentation in an industrial context. The crash boxes HAST have in today's product family have no established separation between their customers, regarding topics such as crash performance, price, etc. All the design solutions as well as the industrial processes to make the crash boxes are used across all market segments.

For mature businesses it is rare not to find products where a step-up function exists in its products. Businesses in the same category as HAST should have interest in distinguishing its products. Too little focus on product features may change the customer's view on the products and it becomes more of a commodity rather than something special. Research has also shown that the number of quality levels that buyers consider affects the likelihood that a relatively more expensive, higher margin option will be selected (Simonson 1999). If it only is developed in the direction of being a commodity, the only thing for the business to compete on is cost. This alone, may in many cases be difficult to do business on. Searching and exploring new and old market niches is therefore important. By doing this there is also a risk for satisfying the customer's needs by new products, designed outside the product platforms. This may destroy the commonality the platforms can offer, by share too little technology.

To illustrate that the crash box can be aligned with market segmentation, a few examples can be presented. The following companies have segmented their products:

- Volkswagen Group has a portfolio of brands covering the whole spectrum from low cost to premium cars. They have two groups of brands both positioned in the market to avoid internal cannibalism and at the same time attract different customers; Volkswagen (Volkswagen Passenger Cars, Škoda, Bentley and Bugatti) and Audi (Audi, SEAT and Lamborghini). Between these brands a sharing of components and technology is widely used (Volkswagen.com 2006).
- Hand tools, the Black and Decker Company sell cordless drills that are sold under DeWalt and Black and Decker brands. The Dewalt is for the professional

and a premium brand, while the Black and Decker sells to the home users, but there are synergies between these products (BlackandDecker.com 2006), (Sudjanto and Kevin 2001).

- Car brakes, the Baer Company offer different callipers and disks according to the performance needed. They offer three types of callipers that are combined with different disks to create the product variants. These combinations are then sold as an upgrade to standard brakes, in market segments as light upgrade (Serious Street) and up to the best possible (Extreme plus) and this in eight steps (baer.com 2006). This indicates also that this safety feature, the brakes, on a standard car are not optimised, but a compromise between performance and price.

With these examples in mind it should be possible to convert the crash box system into market segments, even as a safety product. As the example above illustrates this is done with complex systems as well as simpler product, and safety products. By segmenting the crash box solutions and cultivating important properties in these segments, a product programme can be created. It is though important that the product within the product programme is different, so that the customer is in no doubt of this. This introduces a change in customer choices. They must to a higher degree select design concepts within the groups, with the associated functionality. For the crash box this is strongly linked to the flexibility of the production lines. In order to ensure that the customer does accept the proposed solution, is to provide some type of "upgrades" on other features. To give an example that it is possible to guide the OEM customer's choices within a strict set of design and manufacturing criteria have been proven by the steel industry and their high strength bumper beam. The use of this material means that primarily 2D forming must be used and little extra functionality can be built into the product. This does not allow the OEM customer to have the same degree of freedom as earlier, but still they are attracted to this type of product. This might be related to the fact that the product performs very well on key performance characteristics.

In today's crash box portfolio HAST already has some solutions with different crash performance and other functionality differentiating properties. HAST should make use of these differentiate possibilities and make them more distinct. The market segmentation should be used to make the most important characteristics explicit and easy to communicate. It is important that the customer knows what he is getting, i.e. high performance- or low cost solution and that it is something that is demanded. Other differentiation possibilities could also be considered. The establishing of market segmentation can be formed by using:

- The Kano model to find the differentiation characteristics (Berger et al. 1993). In the crash box case the most important customer perceived characteristic is crash performance. This is related to how the energy is absorbed (steady with little fluctuation) and in which load paths in the car's chassis that can be used.
- Products such as the crash box exhibit a life where one product variant provides knowledge used in the development of the next one. This makes it suitable for being a horizontal platform as discussed by (Meyer 1997). Therefore the market segments should aim at making the platforms horizontal but also to some degree beached (vertical and horizontal), Fig. 3.19. This gives opportunities for an even

higher degree of commonality. How many and which type of platforms used is also closely related to the strategy the company wants to use on their products.

The market segmentation is formed through an alignment of the customer preferences and how the company design and manufacturer their products. This is an iterative process and only established when both the product structures and the production lines also are decided. Fig. 5.7 shows a proposal for how to transform today's crash box portfolio over to a product programme that emphasize the product's distinctiveness characteristics and Table 5.2 describes the segmented product structures. The development of the product structures and the production lines will be described in the coming chapters. The existing crash box portfolio is also visualised in a special way that will be thoroughly described in chapter 6. Briefly it can be said that it presents the product variants on a timeline and the groups of different backgrounds colour represent different industrial processes. The colour represented by an industrial process is coherent with the industrial processes used in the proposed product programme.

The market segmentation grid proposed differentiates the product platforms (with variants) into premium and standard segments as well as with different load paths. This segmentation differentiates the product based on the most important product attributes. This is also an attribute that can be related to the cost of the crash boxes. Since crash performance is an important product attribute and HAST manufacture products that can satisfy this, they should perhaps not enter the basic end of this market. This is also related to the fact that HAST at this point delivers only aluminium solutions. At the present time the material cost has a very large disadvantage compared to steel- or multi-material solutions, and should there be a product here it must be very different from the rest. Therefore a basic solution is not included

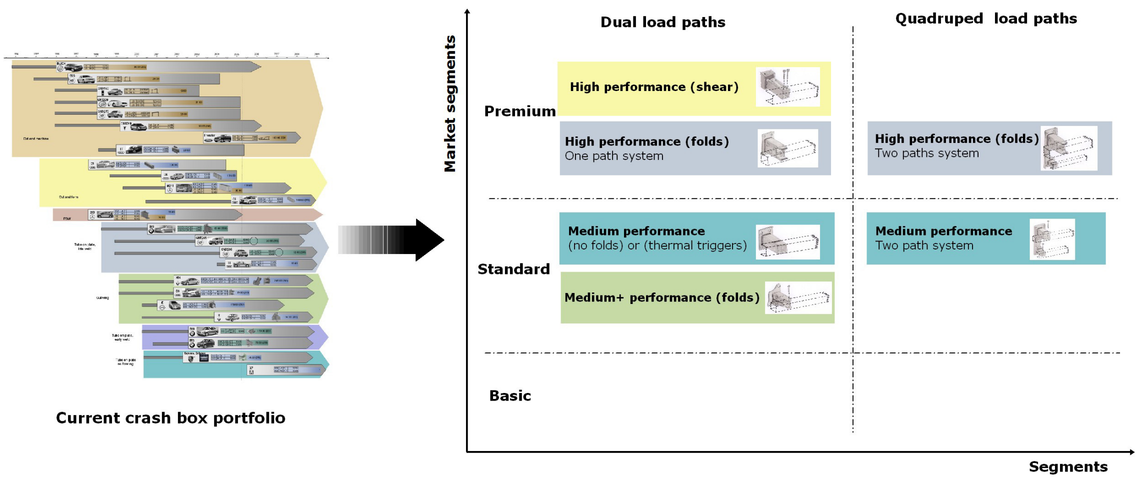


Figure 5.7: The proposed layout and overall distinctive plan of the product portfolio for HAST crash boxes. Segmented in a premium or standard and dual- or quadruped load path segments. A premium crash box combines high crash performance and flexible packaging design. A standard design optimises crash performance and packaging in a reasonable priced design.

To find the right portfolio is a difficult task. It should be a balance between economic,, market and technical considerations. This is only achieved through several iteration and constantly working with the alignment of all the elements in the Corporate Platform. In this market segment proposal there is no sharing of components among the segments and the different product structures within the segments. The commonality is intended to be found in the industrial processes and the structuring of the knowledge in manufacturing them. This will be described more in the next chapter.

Table 5.2: A comparison of the products within the differentiating product groups.

Products		Comments
Premium	High performance	The best energy absorbing principles that HAST have is based on shear technology. This gives opportunities to optimise the force. It demands on the other end a special mounting bracket on the chassis, a bolted interface to the bumper and it must be made in a 6xxx alloy. Using this combined with a second load path would result in a time-consuming assembly process with many bolts.
	High performance, dual load path system	A very good energy absorbing principle. By forming triggers deformation pattern can be controlled, and the formed parts can be calibrated. To give additional performance the crash boxes and the bumper are welded together. By having a welding cell that makes all the joints in the same operation, sufficient tolerances should be obtained.
	High performance quadruple load paths system	This is the same system as the above, but also with a secondary load path.
Standard	Medium performance, dual load path system	A solution that is very cost efficient and with very good packaging adaptability. The crash performance can be changed by adding thermal triggers. This solution can be manufactured in a bolted- or welded solution for the bumper beam interface.
	Medium performance quadruple load paths system	This is the same system as the above, but also with a secondary load path.
Basic	A new type?	A new solution needs to be developed to enter this range, Perhaps steel or a multi-material design, based on self piercing rivets?

5.3 The crash box case: Product platforms

The product platform section of the Corporate Platform deals with the development of the product programme with defining the product and production lines. This section is divided into two main parts;

- *Product*, deals with defining the product designs that can further be customised into the final product variants.
    - *Feature*, the characteristics and options chosen to be part of the product programme
    - *Product structures*, the existing or new product concepts used for customisation and that are aligned to satisfy the features and production
- *Production*, deals with defining the production processes to the product.
    - *Single processes*, represent the production technology at a detailed level

- *Production line*, is the combination of single processes that form the production line(s). This is aligned with the product structures to give the flexibility needed in the product programme.

The separation of the product and production is due to several reasons; the product structure developed may be produced by different production methods and the change rate in the production processes should be slower than the products derived.

5.3.1 Product

The structured development of the products starts with condensing the market information. At this point one should be very open regarding what type of product concept the process should end up with. Becoming too focused on only one type of solution at this early stage can substantially narrow down possible design solutions. To open up the solution space one should start modelling with features. Modelling with features gives an opportunity to handle all the products within the product portfolio at the same time. Later in the process groups of features can be segmented and developed into distinct product platforms with a range of product variants. This also includes adapting existing products to the product programme.

5.3.1.1 Product features

The customer request of product functionality combined with trend scenarios form the base for product features. Usually only a few product features are capable of describing the whole range of crash boxes. To these features all the customers' needs are set as options. A set of options describes the product variants and together they describe all the individual characteristics of each product variant. By combining this matrix with a restriction matrix the product programme starts to be formed. This gives the opportunity to model with the features of product variants before a concept is made.

In the case of the crash box these features are illustrated in Table 5.3. By making all the possible combinations of the options in this matrix, all possible product variants can be listed. In establishing of the options list also options excluded should be listed as considered. Even a small feature matrix results in a large number of option combinations. Of the option combinations made, there may be some that are not allowed, physically impossible or not wanted. Such restrictions are implemented by a new restriction matrix, Table 5.4. The combination of these matrixes can be handled in the Complexity Manager software (Complexity Manager 2005). The sequence the features are arranged in after also plays a role in the graphical layout. The features may have a relationship to independent manufacturing sequences, and if this is the case the sequence becomes important. The sequence of the production operations can be optimised, so that the product variants are created at the end of the value chain. Fig. 3.12 in chapter 3 illustrates this as well as the purpose with postponement. For the crash box product this is even more complicated, since the products featured are created in more or less the same operation. The matrixes; Table 5.3, 5.4 and the tree structure, Fig. 5.8, give in this case an illustration of combinations and feature combinations that make all product variants unique. A full size tree structure for the product programme is shown in Appendix IX.

In this example several assumptions are taken, regarding:

- The crash box features are a representative selection, but may not be complete
- The numbers of options on the features are a selection. A complete description requires, for some features, many more options, due to the fact that features often are stepless, e.g. Tower length.
- The restrictions generated are based on the customer's future needs as well as physical relationships e.g. Al 6xxx alloys have lower flow stress than 7xxx alloys and this affects the energy absorption. The restrictions should be based on the customer's needs and physical relationships, but these topics are so strongly linked to the product design, design restrictions are used to make the tree structure readable.

Table 5.3: Matrix of the features in the front and rear crash box that are derived from the stakeholders' needs. The proposed variants are described in steps, but often are continue variables within a range. In this illustration they are only shown as a set of discrete values. Gray boxes indicate options chosen not to be included in the product programme.

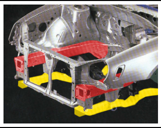
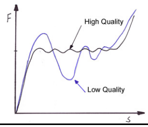
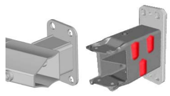
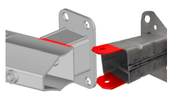
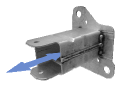
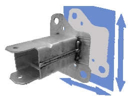
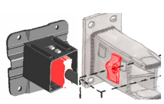
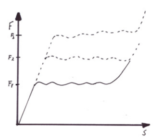
	Features	Options						Comments
1	Load path	One load path	A primary and secondary load path					Upper load path is the primary. Lower load path is the secondary
2	Energy absorption quality	Medium	High	Very high	Low			Even curve gives high energy absorption quality
3	Deformation triggers	No trigger	Thermal trigger	Folds				Folds are mechanically formed, Thermal trig. are local altering of material properties
4	Material	6xxx	7xxx					Different Al alloys
5	Crash box – bumper interface	Bolts	Welded	Self pierced, Laser welded				Assembly at HAST (weld) or assembly close to customer (bolts)
6	Tower length	Short	Long					This variant option is an example and is more continuous- than distinct values
7	Crash box-Chassis connection	Base plate	No base plate					The base plate option can have a range of options, size, holes etc.
8	Tow Hook	On box	In box	In beam	No			The position of the tow hook is strongly linked to the car's styling, due to the placing of the cover in the bumper facia
9	Force level [kN]	50 kN	60 kN	80 kN	90 kN	40 kN		A front crash box (80-90kN) has a higher force level than a rear crash box (50-60kN). It can also vary between car brand and model

Table 5.4: Matrix for restrictions in the combination of crash box variants

	Variant	Not allowed with	If	Comments
1	A primary and secondary load path	Very high		Customer trend
2	Very high	On box + Base plate + Welded		Physical and design restriction
3	High	50kN + 60kN		Related to product differentiation
4	Medium	No base plate		Physical and design restriction
5	High	In box + 6xxx		Physical
6	7xxx	Thermal trigger		Physical
7	Very high	7xxx + Thermal trigger + Folds		Physical
8	High	No trigger	A primary and secondary load path	Related to product differentiation
9	Medium	50kN + 60kN	A primary and secondary load path	Related to product differentiation
10	6xxx	90kN	A primary and secondary load path	Physical
11	High	No trigger	One load path	Physical
12	Medium	Folds	A primary and secondary load path	Related to product differentiation
13	Folds	Welded	One load path	Related to product differentiation and physical
14	Medium	90kN	6xxx	Physical

These two matrixes combined give a tree structure describing all the possible product variants. This gives a total of 352 product variants. If no restrictions were implemented the total number of product variants would be 4608, but one should bear in mind that this is a theoretical number since several of the features have stepless options. This includes both the front and rear crash boxes as well as systems that perform differently in crash performance.

The tree structure gives opportunities to create the first structure of the product programme as well as providing a visualisation of it. The outcome of the tree structure is strongly linked to the restriction matrix. By making changes to the restriction matrix and altering the sequence in the features matrix, branches in the tree structure will indicate groups of features that can be covered by product concepts. These feature-based concepts may be new or existing. It is though important that the choices regarding the use of existing products as well as the new concepts are capable of fulfilling the range of features that are wanted.

To give an example of one specific set of features, representing one existing product variant, illustrated with a blue line in Fig. 5.8. It is a one path solution, high energy absorbing quality, it is bolted to the bumper, the crash box is long and has a high deformation force. This indicates that this feature set is for a front crash box.

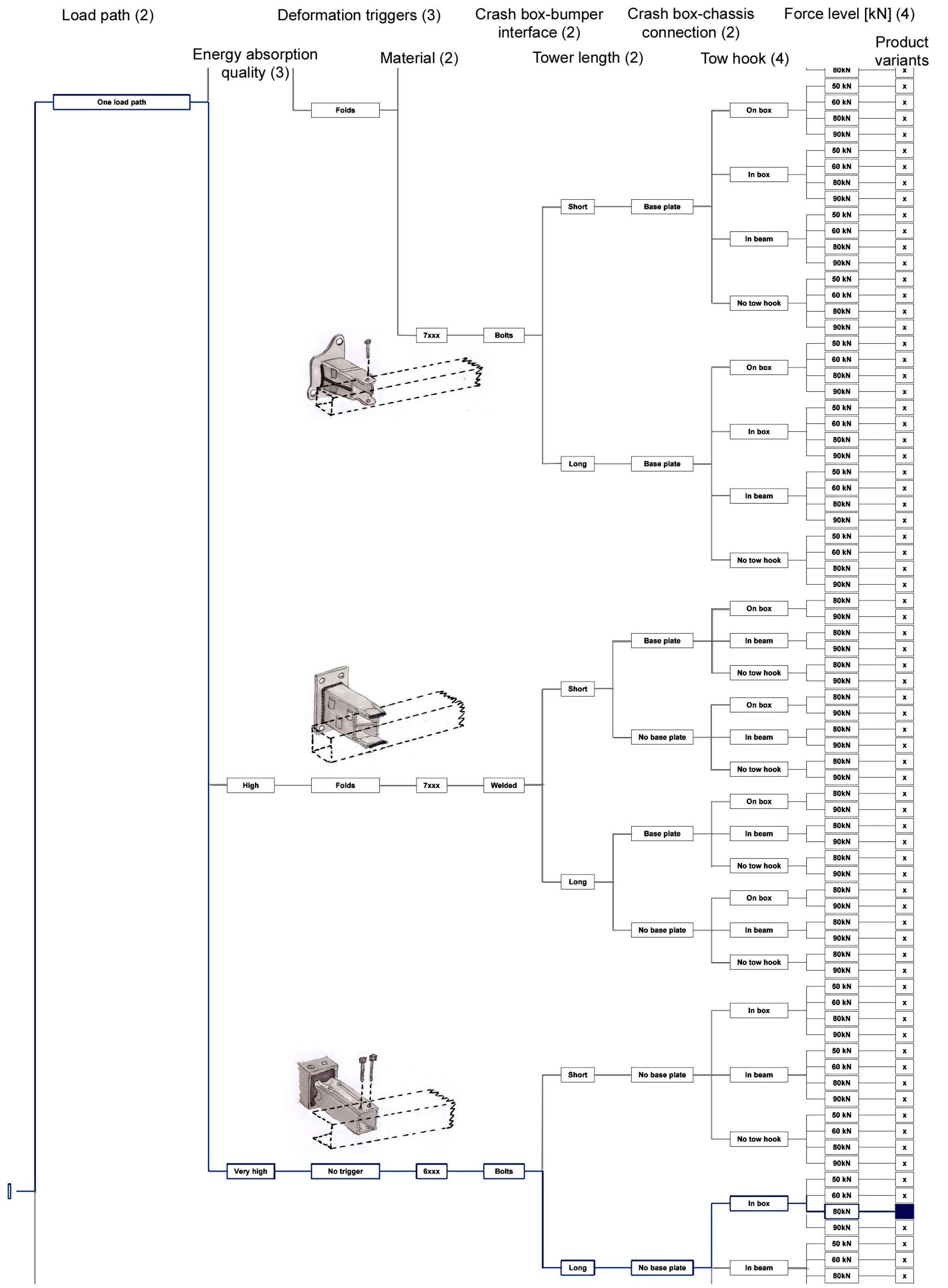


Figure 5.8: An illustration of part of the tree structure for the product programme. The bold line illustrates the feature combinations for one product variant. The whole tree can be found in Appendix IX

Such a tree structure makes explicit all the features and options in the product programme. The use of such a visualisation method makes it possible to discuss the variety needed in different product design as well as the flexibility needed in the production to accomplish the variety. Establishing a tree structure that suits the product programme (customer's needs and HAST's needs) is an iterative process. It is much like establishing a product specification. Creating a detailed specification is difficult in the first run, but it can be continuously refined. The same is true for the product programme.

5.3.1.2 Product structure

The product structure involves the development of the product concepts that form the base for the physical products. The intention with the product structure is to establish product concepts that fulfil the feature, define option combinations and the degree of production standardisation required, forming a product platform. In this process all product variants must be discussed at the same time and in the same setting, to avoid duplications and sub-optimisation. Existing products can and should be part of the product structure, analysed according to their ability to fit in the defined feature tree.

The product structure development and alignment process has inputs from feature combinations, strategies for market segmentation and manufacturing competence in the company. Together these elements guide the development of product concepts that optimise the product portfolio of the company. The guiding input in the design process contains::

- The product feature tree structure which gives information on feature combinations that is most likely in the customer's interest. The range and combination of these features may be so dispersed that one single product structure solution cannot be found. The tree structure must then be aligned so that groups of feature combinations most likely can form as few product concepts and production lines possible.
- The market segments which give indications on how HAST wants to position the products in the market. Products with the intention of being best must be able to have product features and performance that are clearly better than a regular crash box. It is the purpose of the market segments to give such differentiation information into the development process.
- The product line which plays the opposite role of both the feature and market segments, by aiming for as few industrial processes as possible. The fewer production lines the better economy of scale. The lines have thus to be flexible enough to handle the options and variants defined by the selected range in the feature tree. This might lead to the need for several product structures with different production lines. These different product structures are then the product platforms that must be capable of leverage several product variants.

The process of developing product platform concepts for the established feature combinations follows the traditional product development methods (Ulrich and Eppinger 1995), (Pahl and Beitz 2001). Suitable methods in this process are in particular, the morphology diagram (Pahl and Beitz 2001), principle and quantitative structures (Tjalve 1976). In the development process of the product platform concept it is important to be creative. In order to be creative one should not focus on too many things at the same time. The alignment of the feature tree with product structures is based on:

- Mapping in the existing products that should be part of the product programme. They must be analysed in what types of feature and options they can and should cover.
- New product structures should be developed to fill in the features and options not covered by the existing products.

The feature tree should, with both the existing product structure and new product structure, have solutions for all feature and option combinations defined. In this alignment process one should exclude product solutions that can act as duplications and give them defined areas to cover.

This approach gives all stakeholders needs a better match compared to the situation when development projects are run one-at-a-time. The difference in developing a product programme compared to the traditional product development is the increased complexity of inputs and demands on the design results. There might not be only one product platform combination that gives the optimum result, but the development or adaptation of these predefined product concepts relates to how successful the product programme can be. There is though one very important aspect regarding this design process, the extra input introduces several discussions on topics that might never have otherwise arisen. These extra discussions add valuable information to the outcome of the designed products.

The alignment process for the crash box product structures and the feature tree can be matched with eight product structures. Fig. 5.9 shows an overview of all the branches of features and options, while Table 5.5 gives a description of the different product structures. All the product structures can be found in the feature tree. Of these product structures four are based on existing solutions and four on new structures. These eight product structures generate 15 major branches in the feature tree. This increase comes from changes in some features with limited affects on the design, e.g. material. These new product structures are based on existing solutions that are modified to make them more distinct. From the original product family of crash boxes, several product variants are removed. Each of these eight product structures is aligned closely with the production processes, which will be described in Chapter 5.3.2. Fig. 5.9 and Appendix IX shows the feature tree visualising the product structures and 15 major branches of product variants. There might be better solutions, but these solutions provide one solution.

To find the optimal product structures to form the product platforms is a difficult task. In Chapter 3 several methods for developing product platforms and modular structures were commented upon. As stated in Chapter 3, most of these methods work best on products that are assembled from many components, but these are the best available for realising the features into products.

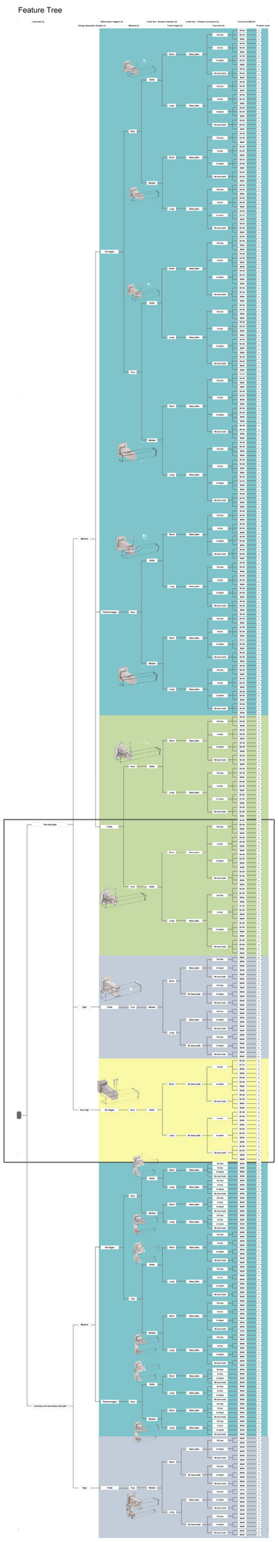
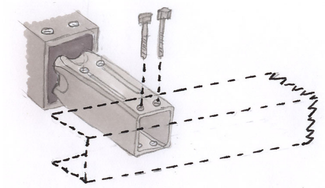


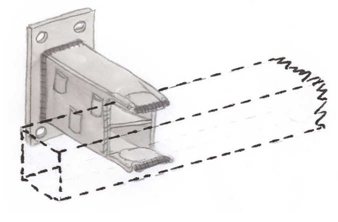
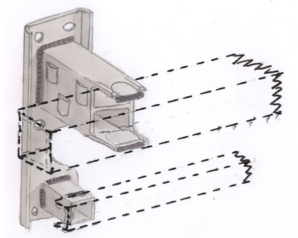
Figure 5.9: The complete feature tree. It proposes a product programme where the customer features are aligned with the market segments and industrial processes. The colour represents the industrial process and represents therefore the different product platforms. The square box is presented more in detail in Figure 5.8

Table 5.5: The product structures description for the product programme

High performance

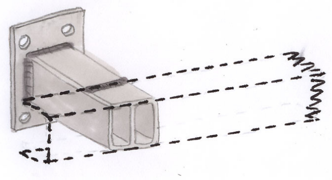


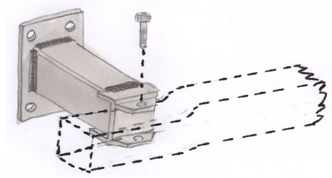
The product structure is based on a bolted assembly to the chassis and bumper. The bumper beam is of an open profile in the attachment to the crash box.

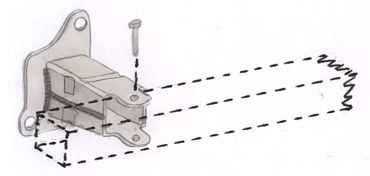
High performance, dual load path system	High performance quadruple load paths system
	

The product structure is based on complete welded systems. All the welds are made in the same fixture, since the product structures have gliding planes to ensure the required tolerances. The welding cell should be flexible enough to weld both dual and quadrupled load paths systems. The lower load path consists of an open profile beam.

Medium performance, dual load path system

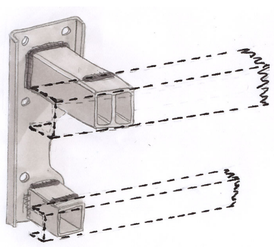


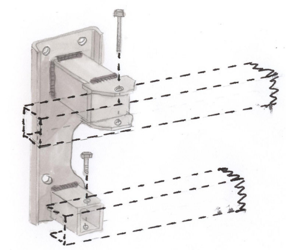




The product structure is either a completely welded- or a bolted system. The tower can be of one or multi chamber profile, in a 6xxx or 7xxx alloy and with options for thermal triggers (no forming required). Gliding planes for tolerance control are also included in the design.	This product structure is very different from the other, since it is made out of one piece. It is welded to close the tower profile, but only bolted to the bumper beam. It might be of 6xx or 7xxx alloy

Medium performance quadruple load paths system





These product structures are similar to the medium performance dual load paths system, but have an additional load path. The welding cell should be flexible enough to weld both dual and quadrupled load paths systems. The lower load path consists of an open profile beam welded or bolted.

5.3.2 Product platform production

Behind the distinctiveness plan and market segmentation the products have to have some commonality that can provide a boost for the company's economy. In the case of HAST's crash boxes the commonality cannot be focused around components' reuse, but must be found in the industrial processes.

5.3.2.1 Single processes

The single processes represent the production technology at a detailed level, Fig. 5.10. For the product to achieve the required properties many single processes are stacked together to form the product line. In the corporate model Fig. 5.2 the single processes are closely connected to three elements:

- The features which represent wanted behaviours in the products that the single processes should fulfil.
- The process knowledge & technology is the provider of knowledge needed to develop the single processes. This information must present the single processes so that it easily can be reused, e.g. when smaller or larger changes in the production are needed.
- The production line represents a set of single processes for each product platform developed, i.e. the industrial process. The single processes within each product line must be capable of handling the required product variants within each product platform.

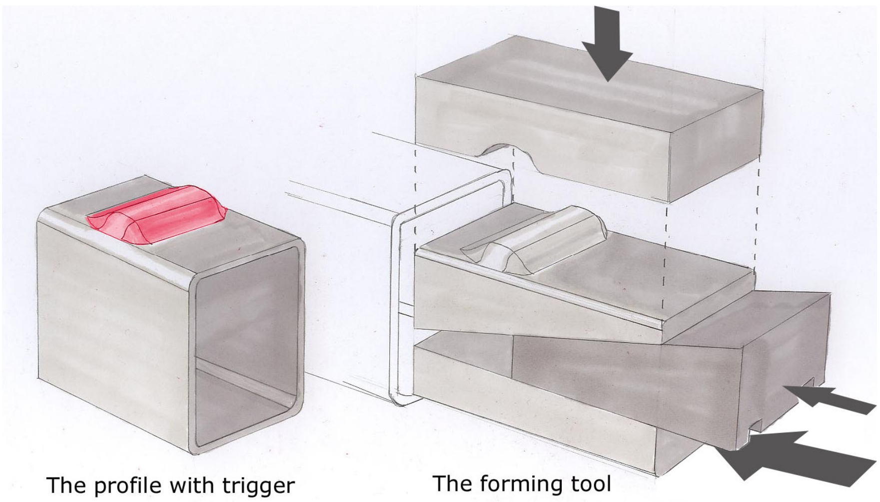


Figure 5.10: A set of single processes form the product, so that the right properties are achieved. This figure illustrates one type of single process, the forming of a trigger

The single processes represent a major part of the technology and core competence the company possesses. In product development one of the fundamental issues is to search for new solutions by expanding the solution space. This should also be done for the single processes. Product behaviour can most likely be created by several methods and represents a parallel development to the product itself. Technology development is difficult and associated with high risk, especially related to the time for readiness and implementation in the daily production. When aiming for using product platforms in the product portfolio, it is especially important to introduce technology that has an acceptable risk related to it. Many product variants have relationship to the selected technology and can be affected by problems. The introduction of new production technology should therefore be part of a planned upgrade (a substantial change) or in the launching of a new product platform. The development within these single processes must to a large extent be seen as research projects. If new single processes are introduced each time a new product variant is developed, the risk gets too high. It will introduce elements with little history related to them and make the production more unstable. In a product platform it is important that many products can harvest from the investment made in the technology development, before it is replaced or changed.

Modular design is an approach to create product variants, but the same principles can be applied to the manufacturing (Gershenson and Prasad 1997) and the single processes. In the production of the crash box each product variant needs at least one multi-step stamping tool, often two - one for the right side- and one for the left. This is a complex and technology intensive part of the production. A lot of knowledge is acquired through the development and in production. By designing the single processes, as stamping tool, welding cells, etc. with a modular approach it becomes easier to reuse physical tool parts and the tool design solution, Fig.5.11. This leads to a more product variant friendly production and more agility. Production principles, tool design etc. can be directly reused in new projects, giving shorter development time from project start to full production, resulting in lower cost.

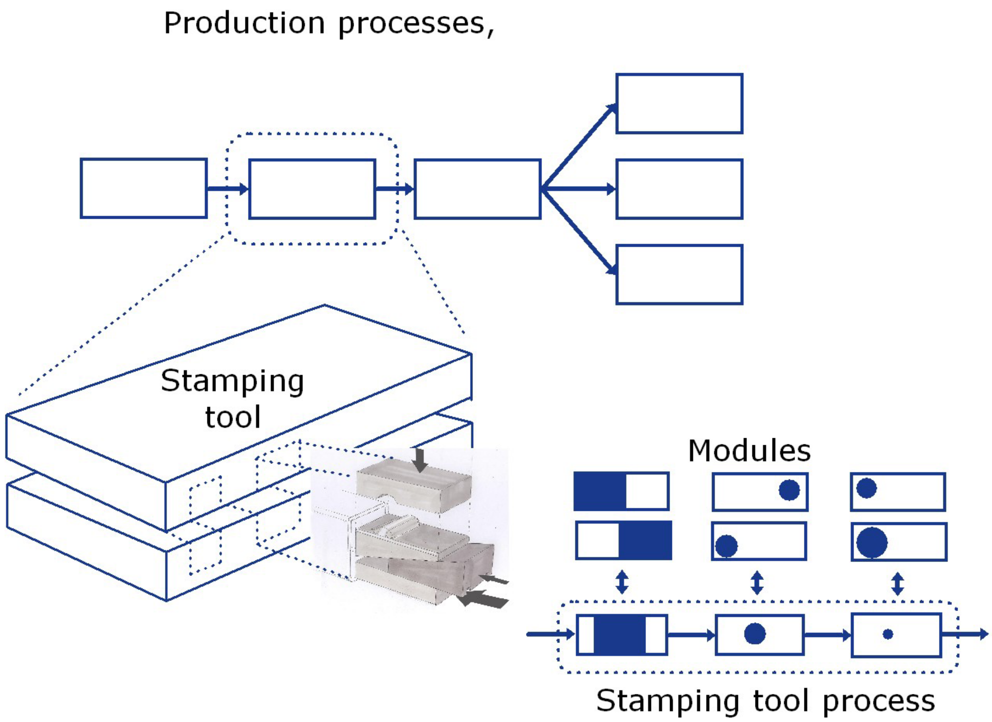


Figure 5.11: Modularisation of the single processes, e.g. regarding physical elements of the tool package and design solution

5.3.2.2 Production line

The product line is the stage where the final products are made. The product line provides the description of an industrial process that is the base of each product platform. In the Corporate Platform this is where one of the strongest drivers for reuse and standardisation should be found. It is here that the companies and especially HAST can gain much by standardisation. The product line balances information from:

- The product structure that gives strong guidance in how to shape the product line
- The single processes that provide detailed information and technology available
- The product lines' technology & knowledge on how to develop and manage product lines that are lean with efficient supply chains.

Aligning the product line to the product structures gives many challenges compared to the regular approach of one-at-a-time projects. When developing one product and the associated production line, often the line is tailor made or has too many specialities making it difficult to adapt for later product variants. These dedicated production lines can have high enough production volume in the beginning, but later too low. Reducing process steps is historically seen as a way of making the manufacturing processes leaner, but when dealing with a portfolio of many product variants this might not be the case. Reducing the number of process steps to a minimum, for a product structure, may narrow down the lines' flexibility so much that no other product can be made there. This results in a very lean and optimised product, but for the company this is sub-optimisation. It might be better to have one additional process step so that the product line easy can handle forthcoming product variants. The learning effect between two specialised production lines also has a tendency to be inadequate.

The Corporate Platform and product programme have a focus on increasing reuse. In the establishing of the production line this is very important. It is here that the potential for high reuse is present. This lies in how well the product structure can be aligned with the production processes by:

- Introducing fewer production lines manufacturing a larger set of product variants.
- Introducing postponement design of the lines, so that the product variants are created late in the value chain (Lee and Tang 1998), Chapter 3.7.3
- Fewer industrial processes introduce a better economy of scale, faster response to create new product variants and reduced risk of problems during normal operation.
- A better learning effect between the different production processes, higher production volumes
- Making the production lines more distinct, so that they together cover a wider spectrum of product variants.
- Duplication of the production lines gives increased production volume with little additional risk.

The product lines must though be made flexible that they can create products with the features and options chosen for the product programme.

The commonality for the crash box product structures within the proposed product programme can be found in a reduction in the industrial processes, sharing of the same industrial process across different product structures and in the sharing of single process steps across all industrial processes. The commonality is at a level where new and different product concepts can be developed and manufactured within the same industrial processes. Fig. 5.12 shows the market segmentation and the proposed industrial processes to these product variants.

Originally HAST's portfolio had seven different industrial processes that, with this product programme, can be reduced down to three. Ending up with three industrial processes, comes from removing existing product lines with few product variants and a low probability for upcoming product variants. This is more described in Chapter 6. There were also several industrial processes that are quite similar, but there should be potential for making them similar, when also defining the product structures to manufacture in them. With fewer than three industrial processes the product characteristics covered are probably narrowed too much. The proposed set of industrial processes is therefore three and the product programme consists primarily of horizontal product platforms such as Meyer (1997) discusses, where products in the same segments are leveraging into new variants. A horizontal platform gives the ability to make the product distinct and with a different price strategy. One of the industrial processes covers two market segments as well as being used to leverage new product variants over time. According to Meyer (1997) this is then a beachhead platform. Even if this product programme is built on three industrial processes there is no contradiction in having duplicates of the industrial process in different sites around the globe. The intention is to have few different types.

The intention in this product programme is to make the assembly so flexible that product structures with different alloy, as well as dual- and quadruple load paths product structures, can be handled in the same station. This can be seen in Fig. 5.12 where the market segment is also illustrated. This proposed flexibility introduces the need for flexible fixtures, loading and unloading stations. The assembly cells should also be able to assemble all parts in the same operation, to improve the tolerances. If the concepts need to be welded in two separate processes, this adds an extra process and reduces the potential to gain narrow tolerances on the final product.

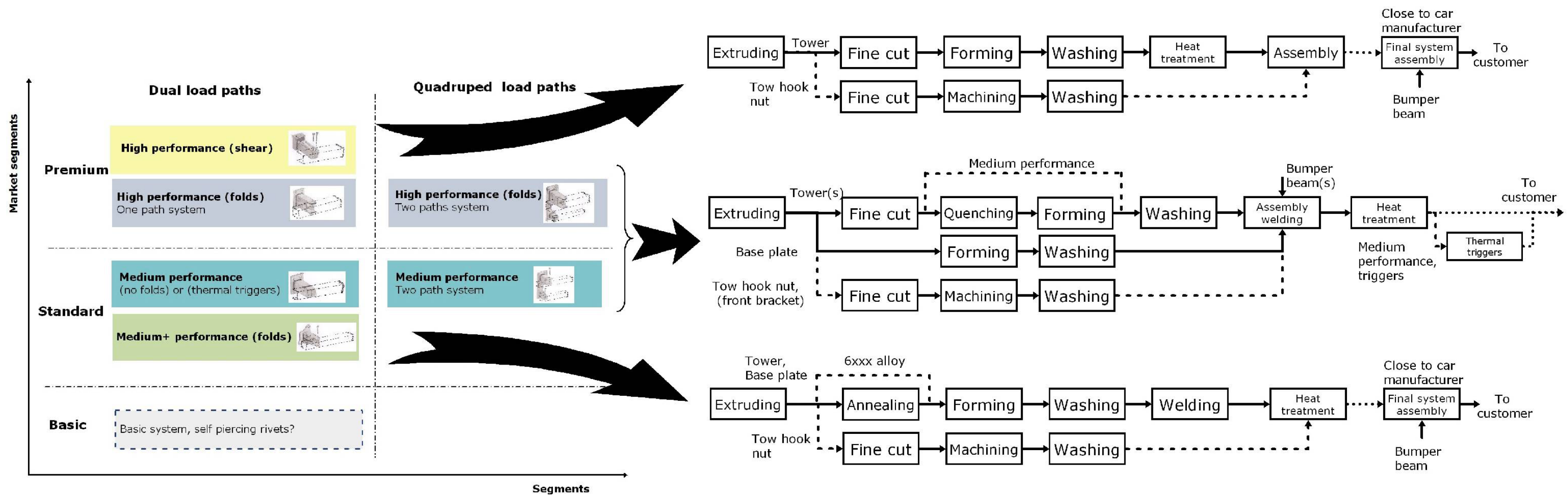


Figure 5.12: The market segments with product groups and the associated industrial process. Dashed lines in the processes flow diagram indicate alternative paths, depending on material and product structure that pass through the industrial process

5.4 The crash box case: Manufacturing

In the Corporate Platform model the section with manufacturing represents the base of core assets in the company; the knowledge and people & relationships. It is these elements that steer and drive the product development. It provides input information and knowledge to the:

- Single processes, where the process knowledge and technology structure product information in a way that enhances the sharing of good and bad technical solutions. This information represents an important element in the design process to ensure a high standardisation and avoids bad technical solutions being reused.
- Product line, where the Product lines and technology represent the information and knowledge to the processes of running the lines. The manufacturing processes need constant support and maintenance in order to run smoothly and feedback from this into the design process is important. An element that also plays a role is the management of product platforms in the timing of new product's releases.

5.4.1 Process knowledge and technology

Increased commonality in the industrial processes is one of the elements that give the company a positive economic effect. Other commonality elements are related to the design process and information flow. As found in the status description of Norwegian industry and especially HAST, there was lack of a system securing an optimal information flow between projects. This resulted in that first-class technical solutions may not be transferred over to new product variants as well as a system avoiding the reuse of bad solutions in new products. When the product programme is established this becomes more important since the consequence of an inadequate solution distributed among many product variants is much more important than on only one product variant.

The flow of information is one of the critical elements in the change over to product platforms, both regarding the derivation of new product variants and the synthesising of new product platforms. Since a product platform differs from a one-at-a-time product development in that it is intended for a range of products, the information management is far more complex. When the organisation is run with development of one-at-a-time product, the sharing of information is very much related to a flow between two points. While in a product platform context the information flow must also go in other directions to secure relationships between different projects. A large part of the information flow between design teams is to be found in the reading of stored data. The structuring of the information then becomes very important. In the study of HAST it was found that this data structure was not optimised as an information source in the product development. The data structure was categorised via car brands. This makes it easy for the marketing people to navigate and extract information, however for the engineers seeking for design solutions it is much more difficult. The possibility the engineers have to search for existing solutions and further develop them becomes too difficult. The data structures should be structured so that they support the reuse of first-class solutions.

The intention with product platforms as Robertson and Ulrich (1998) define is to also ensure reuse in the assets of knowledge. Knowledge is something people possess and can be shared from person to person. This sharing of information is something the company managers not should take as granted. This is a large topic and will only briefly be commented upon here. In small organisations and groups there are two aspects to the information flow. The people that have been part of the group from the beginning all have a good overview of the topics and where to find information. When a new person enters this group they do not have this overview and need much guidance in sorting things out. For larger organisation this rapidly becomes more complex, since communication networks will form partly along formal and informal paths. Managers that simply anticipate that messages which are sent on or delivered through several others, will have the same content in the end, are incorrect. A structured way of securing the information flow in all directions of the organisation is needed (Forsyth 2006). Of the different communication paths the stored information is important in the product development context. It can be a source of inspiration and guidelines with up-to-date information as well as enhancing the standardisation. In the Corporate Platform model it is proposed that the data structures are changed to a system that supports the design phase.

A proposition of a structured way of storing and communicating the design information in the Corporate Platform model is based on the needs of the designer. They need information about technical design issues, production and to ensure that they design a product that can have a lean supply chain. In today's structure the information is stored according to the different customers, this makes it very difficult for the designers to navigate and search for solutions and standards. There exist systems such as product life cycle management (PLM) software (UGS 2006), (IBM 2006) to handle the product data, but at the current time these system present the data in a BOM structure. It might be possible to add metadata to the stored information, so that design engineers can restructure the data according to their request. Other authors as Balogun et al. (2004) discuss the topics of knowledge management in the product process domain. They also raise the need for better structuring of the knowledge related to the product's key characteristics and down to the feature level.

The author proposes an information structure that could be organised according to these groups, Fig. 5.13:

- *Engineering,* the design information of different product structures, product platforms are stored after the industrial processes they are categorised as
- *Investment*, the company possesses manufacturing equipment that products need to be designed to fit within. Information of this kind is very important in the design process.

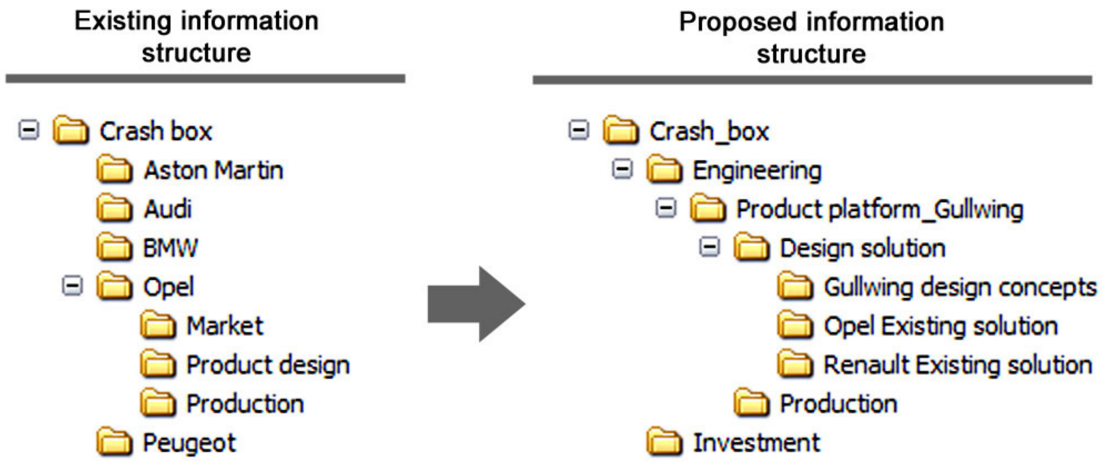


Figure 5.13: Existing information structure and the proposed information structure in the Corporate Platform model, illustrated with one product platform (named: Gullwing) category

Engineering processes require many types of information sources among them; the individual knowledge to the team participants, information from other teams/people, information from earlier projects and stored information. The reason for storing information is related to the need for documenting the development process, a source for inspiration in new projects and providing the corporate standards in the design of products. To enhance the design process of product platforms and the derivation of product variants the stored information should enhance the:

- Product information: this is the standard design elements of the products. The product variants based on a product platform need a description of what the standard of the product platform is. This could be related to the design aim of products in the associated product platform, e.g. the products should be designed with a certain performance in mind (according to the market segments), designed so that no new physical tests are needed, designed to reuse components, etc.
- Industrial process information: this is related to the processes of making the products. By designing products in a product platform context one of the essential elements is that the products fit within the industrial process. A detailed description of what the industrial processes are and what limitations exist, is a must in order to have efficient development projects.

Investment and effective utilisation of it is essential in being competitive. All manufacturing companies invest in a range of equipment and tools. In order to have a return on the capital investments, they must be in use and need therefore products designed for them. For the engineers to know what to design for, they need information about this equipment. This information is both relevant for a pure development project from an existing product platform and the research activities for developing a new product platform. In order to make this more efficient the design engineers should be presented with, for example, an information card of each piece of important manufacturing equipment with:

- Technical data of the equipment
- Critical design consideration of the equipment
- Manufacturing availability

An increasing number of different pieces of manufacturing equipment, the location of the equipment as well as performance, makes it difficult for the design engineers to know what to work with. Technical description of the company's invested assets should be in a short form available for the engineers, Fig. 5.14. The description should provide information about the technical performance as well as size limitations. This improves the flow of information to new people in the organisation as well as informing all the other design people about the equipment the company possess.

Manufacturing equipment together with the product design often has some critical elements in order to make the production flow. Not taking enough care of this in the design process can introduce a lot of expensive rework and changes. Therefore a short description of this should be included in the equipment description

The last element that plays a role in the design processes is the availability of the equipment. Designing products for equipment that are fully booked far into the future is not efficient. Therefore a visualisation of which products the equipment handles and the associated production estimates gives vital information about availability.

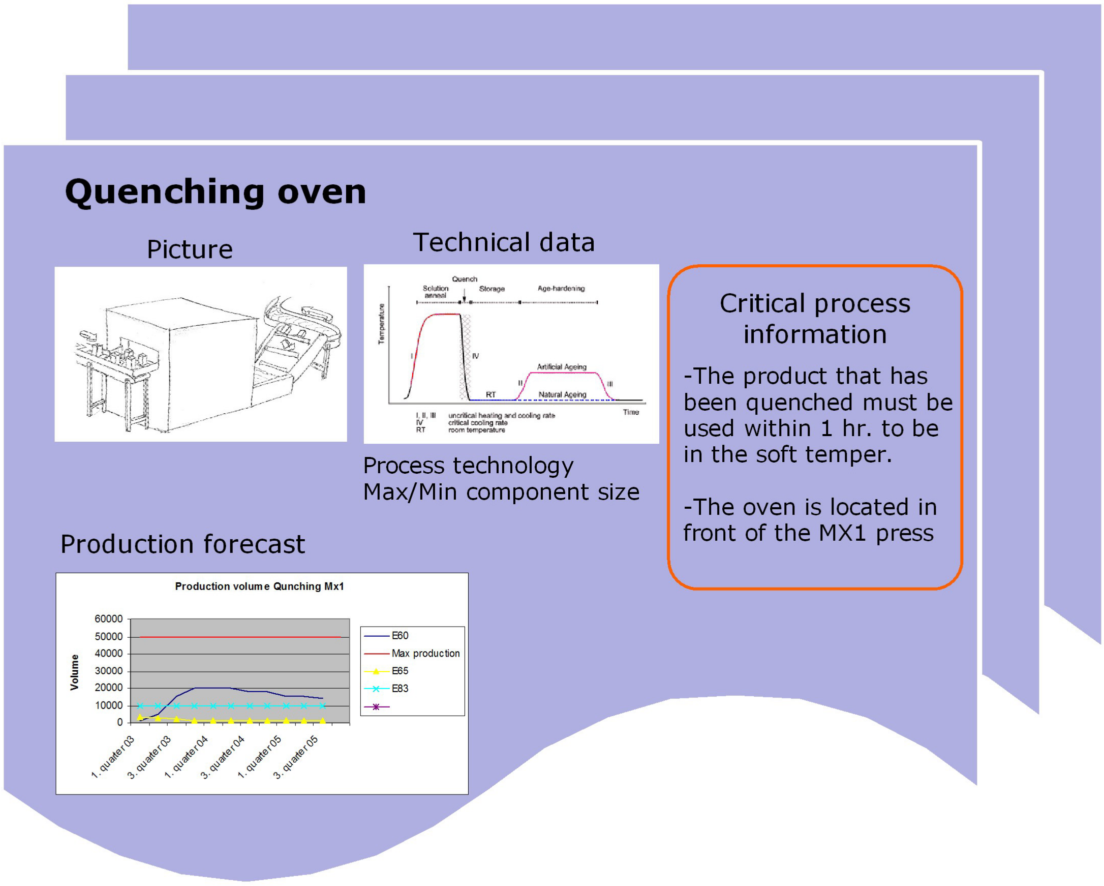


Figure 5.14: A proposal for a card structure of manufacturing information. It provides support for decision making about the manufacturing processes and their capabilities as well as limitations

5.4.2 Product lines knowledge and technology

The product lines, knowledge and technology elements are related to the operation of the lines. Peoples that are in daily contact with the manufacturing gain detailed knowledge of technologies and product structures that work well and alsothose which are problematic. In the Corporate Platform model this element has relationships with the product lines (one for each product structure) and to the process knowledge and technology. This element represents therefore the knowledge base on the product's industrial processes. This flow of product line knowledge is related to:

- The company's strategic balance of the number of industrial processes
- The supply chain of each industrial lines

As stated earlier, introducing a product platform means that several products should be based upon the same type of structure. This means that there has to be a strategy or road plan of when to launch, replace and phase out products and also for the industrial processes. Changing too quickly from platform to platform or abandoning the platform too early results in too little reuse and the economic payback may be lost. This dynamic of the birth and life of the product platforms together with the industrial process will be further commented in Chapter 6.

It is not only the production processes the engineers need to consider. As described in Chapter 3.5.2 the design processes involve the dispositions of product properties in all life phases. This also includes the supply chain in two aspects; the forward flow of materials for the products and the reversed flow for the industrial line. Changes over to product platform design introduce positive elements to these by:

- A reduction in the number of industrial processes means that the material flow uses fewer paths to supply material for the same number of product variants. The logistic paths from raw material- to sub-suppliers will be fewer and the one used will handle larger quantities.
- A reduction in different manufacturing equipment means that the reversed logistic flow providing support functions such as people and spare parts can be standardised more. All equipment needs trained people to support it during normal production, repair it and perform service on it. This leads to less education of staff, writing of procedures, instructions, change procedures etc. (Blanchard 2004).

The elements of the Corporate Platform model and the process of establishing a product programme are explained, made explicit and shown with the crash box case. These product platforms are not developed to be static, but also updated and further evolving. Product development is a continuous process with learning and new discoveries. This gives valuable information for new product variants and product platforms. The next chapter discuss the market dynamics and the management of the product programme.

6 The dynamic of products and product platforms

The functionality needed in products changes over time. The changes occur in small and large steps according to the requirements and changes. Therefore the products have to adapt to a stream of new requirements and customer expectations. In this dynamic world some product solutions are better than others and last longer. The markets they operate in may also be very different, with respect to how long they can stay in the market before something has to be renewed. This knowledge and experience needs to be nutured, in order to make the best choices in managing the product programme. The Corporate Platform model consists of two sections; the Corporate Platform section that deals with the engineering of the products and the Product development section that deals with creating derivative products and interacts with the customers. The Corporate model needs this information for setting the direction for future projects and has therefore a feedback loop into the manufacturing element. The manufacturing element is the source of knowledge and information assets in the company, Fig. 6.1. To understand the dynamic world the products are used in and how this affects the development of product platforms, there is a need to look into the market dynamics, product history and manufacturing history.

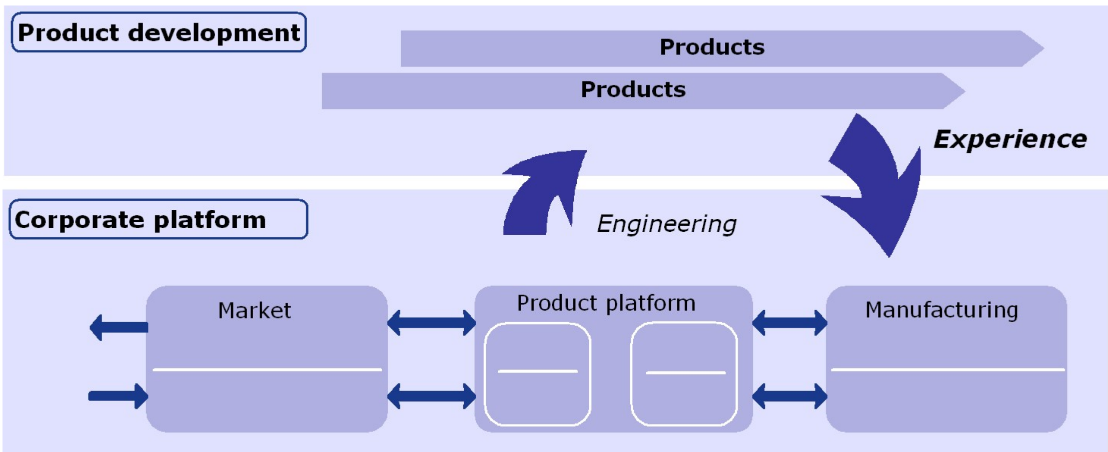


Figure 6.1: The input of product experience and market knowledge into the Corporate Platform model

6.1 The evolution of products

The evolution of products has strong links to the customer's requirements, but also to the technological innovations in the product and manufacturing processes. When the market is disrupted by a new demand or new technology a wide variety of different product structures will be generated. Each product solves the customer's required functions in a different way as well as the company's manufacturing needs. Fig. 6.2 illustrates the evolution in the bumper system of the car and how disruption appears over time. The current focus in the bumper design is around the crash box. For this particular product the technological solutions have gone in many directions, from reversible crash structures, cheap steel designs to high performance solutions. The solution space has expanded and expanded as better solutions have been developed. Already have some of the innovative design solutions been taken out of the market, among them the reversible crash structure. They lose competitiveness on some vital performance measures such as cost, weight or crash performance. In the future only some of these solutions will survive, the rest will die out. If the product behaves as all others, its functions and behaviour will be seen as *must-be* and improving this behaviour will give little pay-off. The focus is then only on cost. The product becomes a commodity.

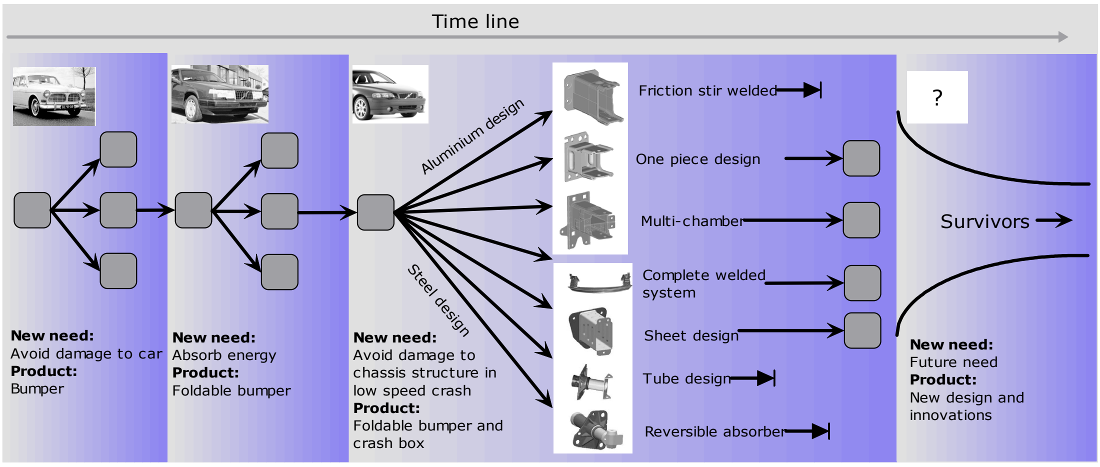


Figure 6.2: Illustration of product evolution. New needs in the market disrupt the product design, new innovations and products evolve and others die out. Illustrated for the bumper and crash box products.

Fine introduces the term "Clockspeed", which indicate how quickly the industry evolves* in three aspects; product clockspeed, process clockspeed and organisation clockspeed (Fine 1998). An example of product and process clockspeed is the evolution of the commercial aircraft with a product clockspeed of 10-20 years and a process clockspeed of 5-30 years and the mobile phone with a product clockspeed of ~1 year and process clockspeed of 2-3 years.

To meet this challenge companies have shortened the time between releases of new products. In the computer and mobile communication business the release of new product platform takes from 12-24 months. This includes the development of software, hardware, and manufacturing processes. The development of product variants on such a platform can be done in as short as 6-9 months (Rader et al. 2005). While the life of a completely new car model has dropped from 10+ years down to 6-7 years and now includes a 'face lift' within this time. To illustrate this Sanderson and Uzumeri (1997) developed a model describing the evolution of a product model and a product family. They divide the products into four categories, Fig. 6.3;

- Commodity: products that do no or cannot exhibit significant design variety e.g. eggs, carbon black, chemical feedstocks.
- Variety-intensive: are products that can be offered in many models, but the change is slow, e.g. hand tools, light bulbs.
- Change intensive: are products that go through many updates and version changes, e.g. software (Microsoft DOS, v1.1->)
- Dynamic: is for products that mix the other types, e.g. automobiles, semiconductors

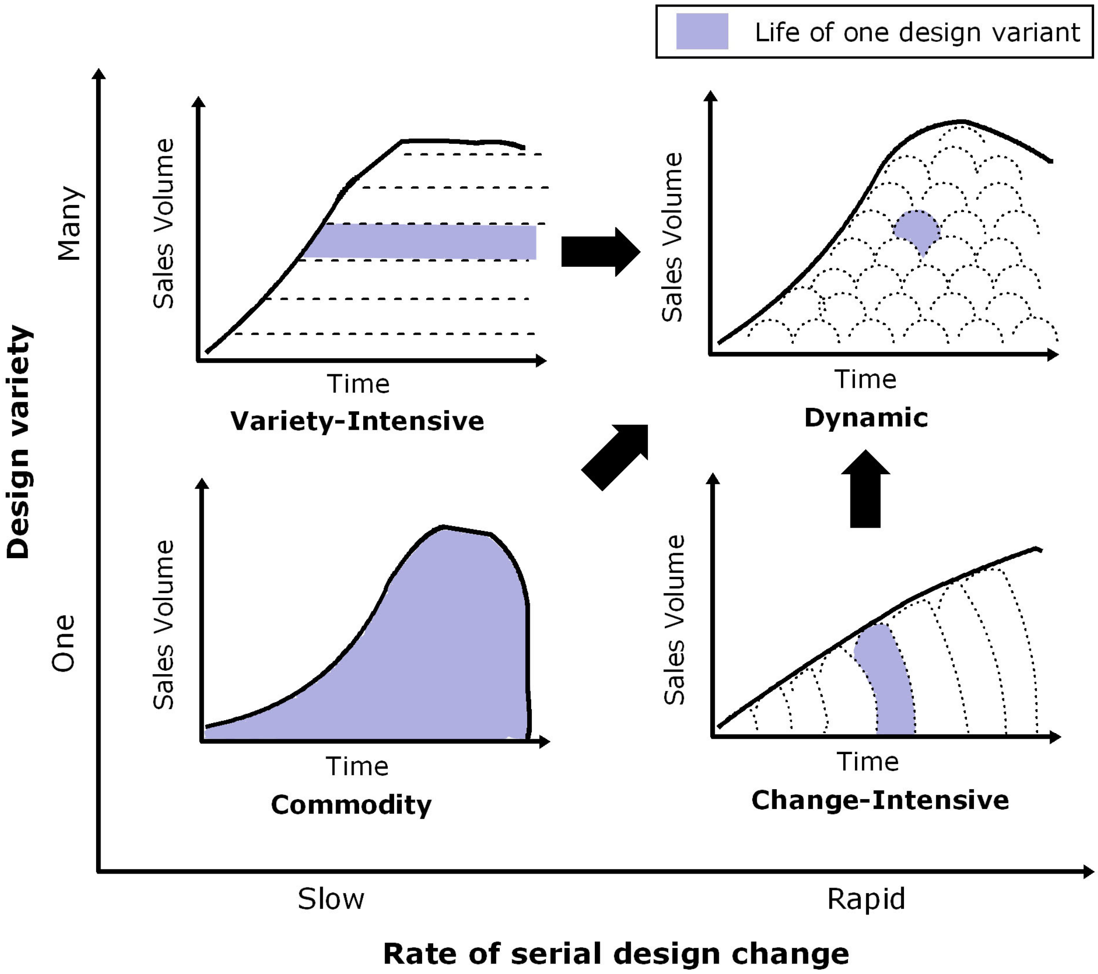


Figure 6.3: The dynamic of competing through product model and family evolution (Sanderson and Uzumeri 1997)

Products within the groups commodity and variety-intensive are related to the traditional mass production paradigms. The two other groups are formed due to a need for responding more rapidly to the customer's request. These four diagrams can also be seen as four types of product families and there can be several product families in each of the groups. They then behave the same as the models. Since the market has become more and more fragmented, it is difficult to sustain the benefits of mass production and at the same time serve each small niche with products. Modularisation and platform design try to bridge this challenge. To achieve a competitive advantage one also has to manage the product portfolio and not get out of control. It has to be managed according to market maturity, clockspeed and combined with the company's strategy.

6.2 Industrial process and product history illustration

Observing the company's product history is a step in order to maintain the information flow in the Corporate Platform model. A systematic description of the past and existing products is essential to make any well thought through reasoning about the future.

Normally the description of products and all the product variants are built up from the products Bill Of Material list (BOM) (Mortensen et al. 2001). Such a list describes all the components each product consists of and can be used to configure different components and in that way list all the product variants. For products consisting of few parts this way of describing the product family gives little feedback on how to guide the design of new products. It has a tendency to become a list of individual products, missing the links that tie them together. Instead I propose to use the industrial process for the products as the base for the product history description. It is in the industrial processes that many of the costs are generated and are committed to for future variants. The use of the industrial process for grouping products has close correlations to grouping products by product structure, but is not the same. When focusing on the product structure the intention is primarily to increase standardisation of parts and modules to achieve a larger production number of units. Setting the focus on industrial processes means that the products do not have to be exactly the same, but they must go through the same manufacturing process. This is then the viewpoint from the manufacturing aspect, rather than pure product. With this view the attention is on how the equipment is used combined with the product architecture. This corresponds to the work done by other authors such as Ulrich and Robertson (1995), Meyer (2001), Jiao and Tseng (2004) focus also on the product platform where the reuse of assets is within the manufacturing processes.

In the study of HAST's crash boxes, several interesting subjects around product variant and product family evolution were found. To make this information communicate back to the Corporate Platform model, it needed to be presented differently than existing presentation methods. It needed to combine both time aspects and essential product variant information. The product information should therefore be coupled with important time aspects of the individual projects. Both the project start and production time were seen as essential information in addition to product specific information. It was found that it was sometimes difficult to talk about the same product. Therefore graphical elements were seen important. The product data should be of a kind that is objective and consistence. This should prevent any discussions about the correctness of the information. The information included in the description of a product is, Fig 6.4:

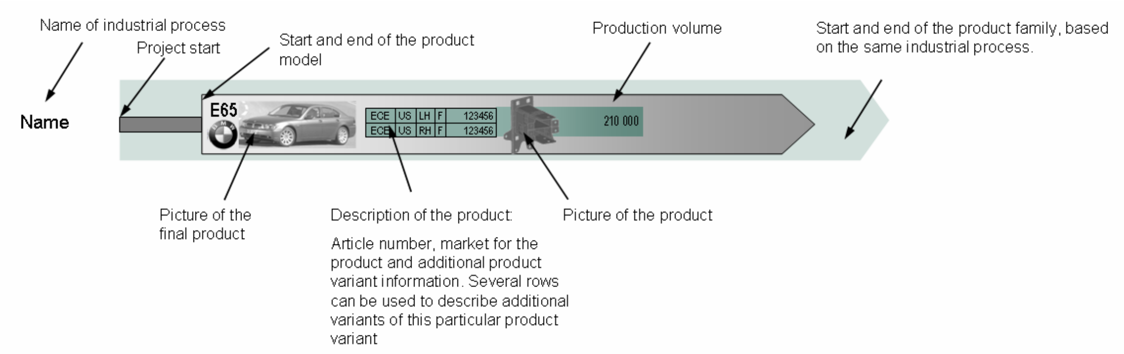


Figure 6.4: Notation and information in the product history description. Illustrated with one product model and two variants of this model, one for the left side and the other for the right side of the car.

- Products manufactured on the same industrial process are grouped, named and indicated with a common background colour for each product variant
- Project start for the product development and name of the project
- Manufacturing start and end of the product variant
- Product information; the article number of the product variants, additional product information about the market the products are sold to and the total number of units to be produced
- Graphical elements and pictures to ease the understanding of all the industrial processes used and all the product variants offered

The information contains similarities to the BOM structure by using the article number of the variants. It does though present the final product and not the hierarchical structure often used in the BOM. Suppliers to the auto industry often manufacture parts that are very similar; there may be one unique part for the right and left side of the car, slight differences between sedans and estate cars, and the European or North American market. Such small changes within the products are important to capture, but the visualisation should not be filled with noise. This kind of variation is therefore shown in rows in the small table inside the product box, instead of a dedicated box for each specific product variant.

This type of organising information from many projects is illustrative when future product strategies are to be set. When strategies are involved there will be managers and other people without a detailed know-how around the industrial process, what the products look like and in what final product they are delivered. It is therefore very descriptive to use pictures. Pictures can be communicated more easily and one can discuss the whole chart without actually reading all the detailed information. Using time as one of the axes was seen as important, this correlates also closely with a roadmap of future products. In the case of being a supplier to the automotive industry, both the development- and manufacturing time is more or less controlled by the car manufacturer. For other products it may also provide additional information of how efficient the engineering teams are as well as how long the products can be in the market.

To ensure that the whole picture is presented in the best way possible, it should be in one graphical presentation. Splitting the data into fragments increases the risk that the whole picture of all product variants vanishes. This is especially important to avoid when the aim is to present and discuss it with managers and other people that are not so involved in the actual design, but have the ability to make decisions. Adding the cost of the engineering could also be included as an extra indicator for the size of the engineering project.

The graphical presentation for a range of product variants and two industrial processes is as illustrated in Fig. 6.5. Each product variant is indicated with development time and production life. The number of industrial processes and product variants are listed according to the product history. A vertical dashed line indicates the present time. Products that have been taken out of the market are indicated with a square box and not an arrow shaped box. As seen on the figure, the time span for the products extends into the future. This indicate the planned lifetime for the product variant. As with many projects the life span of products is estimated and included in the economic calculation that takes place in the development stage.

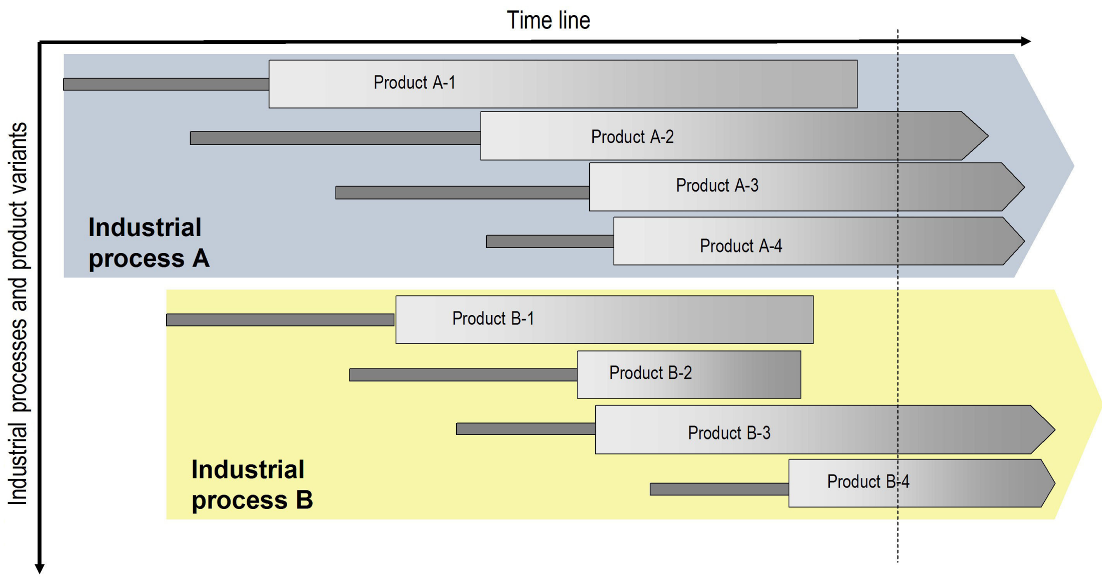


Figure 6.5: Illustration of two industrial processes with product variant boxes. Some of the product variants are stopped and this is indicated with a rectangular box and the current date is indicated with a dashed line.

6.3 The evolution of the crash box family to HAST

In this example of the crash box family of HAST, all their product variants have been included. The data has been collected through several interviews, workshop meetings and the J.D.Power-LMC (2004) database for production volumes.

The crash box product is, as mentioned earlier, a product located in the front and rear of the car and has as its purpose to absorb all the energy in a low speed crash. The product appeared on the market as a consequence of demand from insurance companies. They wanted to reduce the cost of repairs after low speed crashes typical in cities. This demand appeared in the early 1990s. HAST was at this time a supplier of bumper beams and saw opportunities in this market and become involved in development projects. Fig. 6.6 shows all the product variants the company has produced and produces. The description of the product is according to the illustration in Fig 6.4.

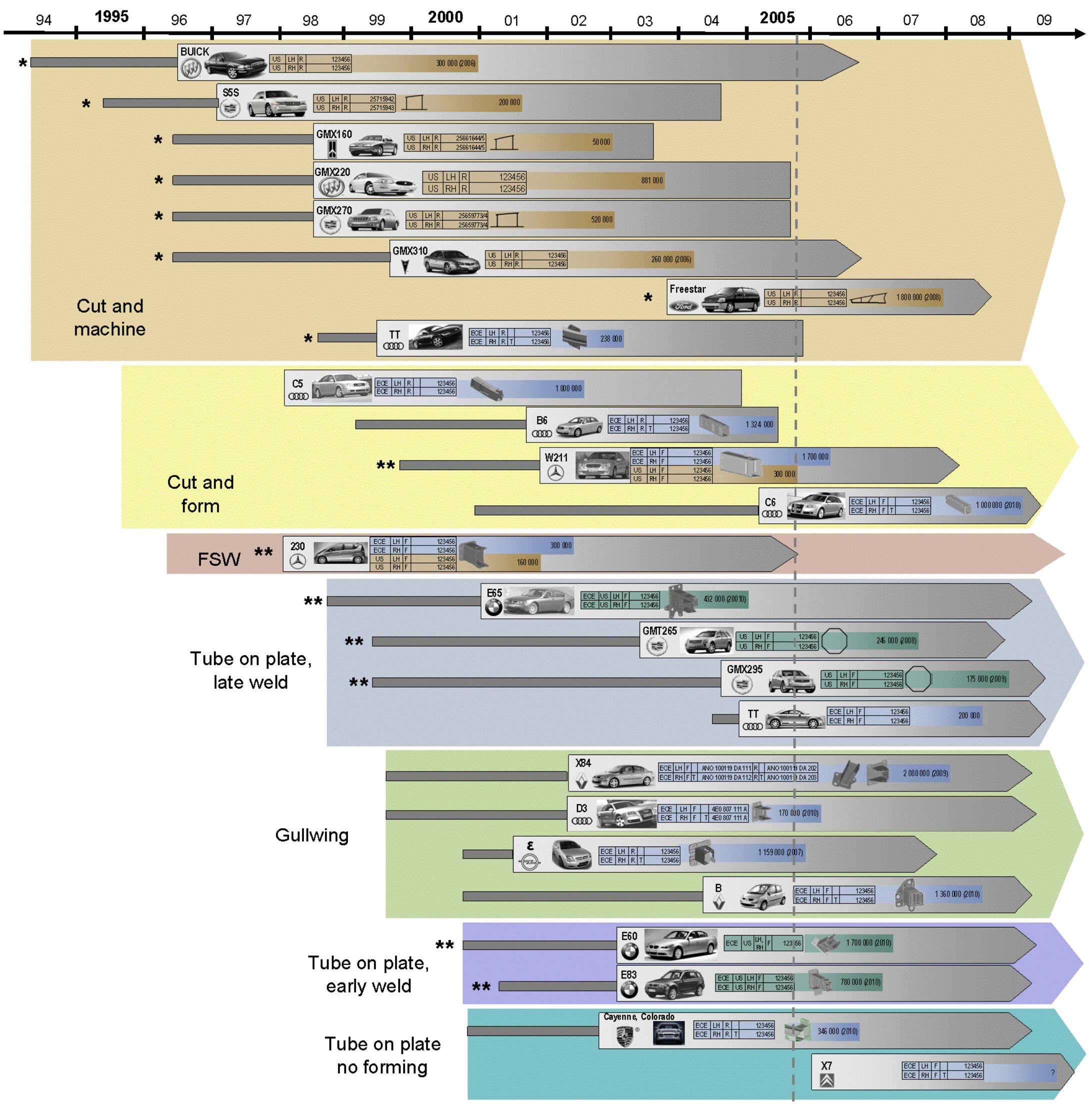


Figure 6.6: The description of crash boxes with all the product variants grouped by the industrial processes. Products with no * marking are designed for Danner requirements. *= products are designed for CMVSS requirements, ** = both requirements are used. Production volumes are based on J.D.Power-LMC (2004)

The figure shows that there are 7 industrial processes, 55 crash box variants belonging to 25 car platforms. To realize these processes, they have more than 7 production lines. There is some duplication of production lines, due to location in different countries. The production volume is also so high for some of the products that there are dedicated production lines just to manufacture them.

By analysing the overall picture and the individual products, several interesting topics can be commented on:

- The evolution of the industrial processes
- The evolution of the products' function and form
- The people involved in the development process
- The challenges of introducing many products at the same time

6.3.1 The evolution and mutation of the industrial processes

Manufacturing these products at the required volumes puts great demand on the industrial processes. The industrial processes must be capable of having a high and steady output of products. Just-in-time is an absolute demand in the automotive business, in order to avoid stopping the assembly line of the final car. Assuring customers that the product has been designed with a high quality industrial process is essential. From Fig 6.6 it can be observed that many different industrial processes have been developed to produce more or less the same result. It is a product that stops the car at 16km/h and this is closely related to the kerb weight of the car.

The industrial processes for manufacturing the crash box have gone through an evolution with some mutation steps. The industrial process is strongly linked to the functionality required and this has a tendency to vary over the years. In the early crash boxes the major function was to be a bracket with some energy absorbing capabilities. As the market started to demand cars with high crash performance, at the end of the 1990s the car manufacturer focused on this. The first mutation can be observed, leading to a tube on plate solution (industrial process FSW), a design that uses a closed tube to absorb energy. Much of the required crash absorbing system is in the front of the car and adding weight at this location is unwanted. Due to the cars' weight distribution, low weight solutions were wanted. At this time the car manufacturers accepted to pay more for each kilo of weight saved. HAST had the solution, but since this was the first generation solution, the industrial process was complex. A complex industrial process could be accepted, but after only a few year's extra payments for low weight solutions were vanishing.

The design of new crash boxes and new industrial processes followed to some extent the same old principles, making the products difficult to manufacture and too expensive. A one-piece highly formed solution (the Gullwing), was introduced to avoid some of the assembly steps. This can also be seen as a mutation. The product structure was based on an aluminium profile so highly formed that it seems to be made out of several parts, but is in fact just one component. What happens is that the complexity is moved from the assembly to the production of the component, without giving the wanted results. The latest design tendency is to provide a structure that has less focus on part reduction and more focus on simplifying industrial processes.

The industrial process and choice of manufacturing principles play a role in how the product variants can be easily derived into new products. Like crash box design has a solution space, so does the manufacturing also. The manufacturing sequence and principles used to realise the product have their own ability to create the functions in the product. It is important to understand the individual solution space to the product design and the manufacturing design. It is within this common space that new product variants can be manufactured with little effort. For some of the chosen crash box structures and corresponding manufacturing processes this common space is quite narrow, limiting design flexibility for new concepts (Jensen and Hildre 2004).

The crash boxes that are manufactured vary in production volume from 20, 000/year to 300, 000/year. This indicates that some of the batches manufactured use as little time as a few days, before there is a change over. This corresponds to the need to deliver just-in-time and therefore a whole year of products cannot be manufactured in one batch. In the overview, Fig 6.6, there are no separate industrial processes that are especially adapted to low or high volumes. There is a mix of high and low volume products in all of the industrial processes. The high number of different industrial processes indicates also that combining some of the solutions into a single industrial process should provide a higher repetition and increased standardisation. Since each industrial line has its strength and weaknesses, the strength should be cultivated for a set of product functions and a corresponding production volume. For industrial processes that cannot distinguish themselves, they may only provide noise in the system and occupying resources.

To manufacture the crash box at the required rate requires very complex multi step forming tools to form the products. There is a risk in designing the product in this manner; it may be more difficult to adapt the same process to new products. A very complex tool may have fewer sections that can be reused in a new tool. The tool itself is owned by the customer and cannot be reused across brands, but the technology to design it is one of HAST's core competences. Taking good care of this history is important. Under the study of the manufacturing sequence, of the crash boxes, a large variety of tools was observed. The products that came out of the tools were in the same family, but the principles the tool worked to were not. Since the products consist of so few parts that a modular design approach is not possible, this approach could have been used on the tooling, or the tools could have more in common. This would have had an impact on getting the line up and running as well as reducing the failure risk over time (more reuse).

There seem to be two obvious industrial processes that should be phased out, after all obligations for the products have been fulfilled. It is first of all the industrial process "FSW" and the "Cut and weld". The "FSW" has only one product variant and no new derivative products and ties up a lot of resources. This product also had a too slow production rate, becoming too expensive. The "cut and weld" process is simpler and can generate a lot of product variants, but the design is perhaps too simple to give the required performance and is out of date!

Some of the other industrial processes have also been difficult to get up and running stable with a low failure rate. There has been a long period of time with a high degree of rework and scrap, before an acceptable product capability has been established. From a product platform perspective it then becomes important to harvest from this knowledge. The process clockspeed is as mentioned, slower than the product clockspeed and in an organisation this must be efficiently used. New product variants should be based on this know-how established around the manufacturing, tool design and supply chain. If there is a constant push into establishing slightly better manufacturing processes, one should be very aware of the type of improvement; if it is a development project or if it involves new unknown technology and is more like a research project. Development projects should be based on existing know-how and quick to implement. The research projects carry much more uncertainty and require more resources to become up and running. So if a new production line is established for each new product, the carryover of know-how is much less than if the same product can fit within an existing production line. The timing of introducing new platforms is also very important. The Corporate Platform consists of limited resources such as people and know-how. Introducing too many new platforms at the same time can be a great challenge for the organisation. Finding one or a few industrial processes to base all the new designs on seems to be difficult, but is a must if the product family should evolve into a lean platform design.

6.3.2 The evolution and mutation of product function and form

The first crash box product was launched in 1996 for a rear bumper. It had a product function more like a bracket, but with some energy absorbing capabilities. This complied with market demands at the time. This product and the derivate products were also for the rear bumper. It was a simple product that utilises the benefits from the extruding process to generate semi-finished products. This product has been derived into several new products, but there has been no carry over to a newer model of the same car . Nor has a different variant of the crash box taken market share of the new car models. It is only the industrial processes, the “cut and form” that have been reused in the next car model. This combination of design and industrial process has suited the Audi car manufacture well. After the first launch of front crash boxes, several solutions and industrial processes were established. This gives an opportunity to discover how the solutions function in real life, but has the drawback of limited reuse within product simulation, testing and manufacturing. The design knowledge is spread over a range of different solutions.

Entering the market for the front crash box put more demands on functionality, load carrying capabilities and constraints on the packaging space which are in a totally different class, compared to the rear. By combining the view from the industrial process with the traditional roadmap view for products, some interesting observations can be made. First all of the crash boxes manufactured by HAST can be classified into four groups, regarding the primary energy absorbing function and the overall form of the product. The groups are:

- Open profile, buckling. A design that uses a profile extruded in the vertical direction, with open ends. The energy is absorbed by bending.
- Closed profile, shear. A design that uses a profile extruded in the longitudinal direction. The energy is absorbed by shearing of the walls in the product.
- Closed profile, pre formed. A design that uses a base plate with a tower, forming a closed and stiff design. Together giving a design that is efficient in absorbing energy.
- Closed profile, buckling. A simpler design where there are no pre-buckles to trigger the deformation pattern.

The evolution and mutation of the design and functionality of the crash box can be illustrated in a roadmap as shown in Fig. 6.7. The colour and pattern of the circles represent the industrial process for the products. The horizontal lines can be seen as evolution lines. The mutation is a vertical step and shown when one of the circles in a group is located in another group. The mutation is a larger change in functional area; rear compared to front and in the technology used to achieve the functionality.

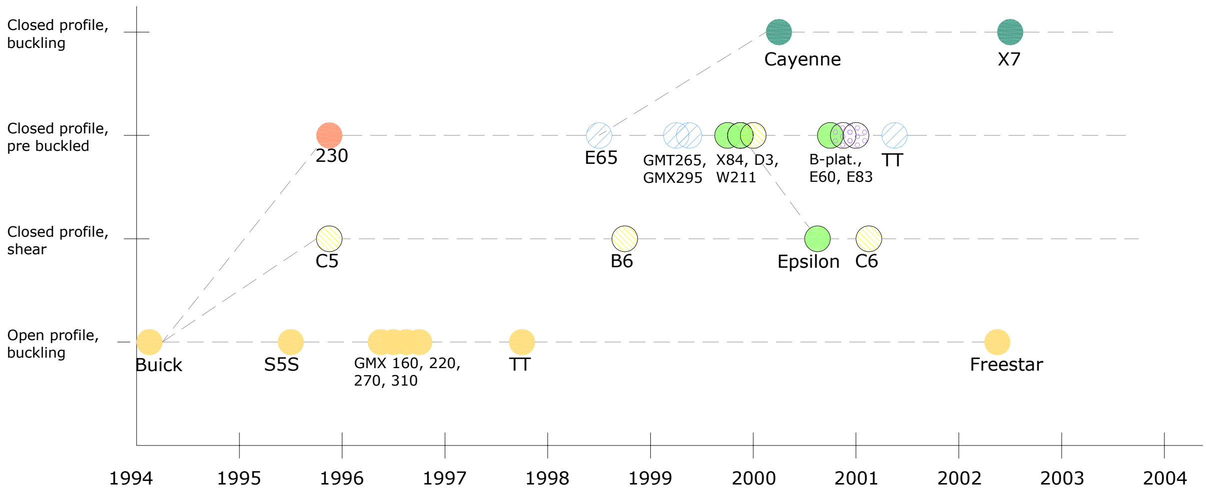


Figure 6.7: A historical picture of the evolution and mutation of the crash boxes from a functional viewpoint. The figure indicates the project start time and the colours represent the industrial process.

Within the group "open profile, buckling" there has been almost no evolution of the functional aspects of the products, resulting in a steady industrial process putting out new derivatives. Comparing it to the "closed profile, pre buckled" there is an evolution in the industrial processes (change in type of circle) and this correlates to realising new product functions in another industrial process. New product functions could be part of similar industrial process, to avoid changes. If a change in an industrial process is needed this change should rarely happen and lead to a continuous process of product variants. Hence the shift in circles should be the same or progressive. Not as illustrated in the "closed profile, pre buckled" group, where the colour /patterns is mixed. There are also some mutations, e.g. the Epsilon, "closed profile, shear" group, using the shear principle to absorb energy, but being made in a different industrial process combining two good things and making a successful product.

In addition to this primary function of absorbing energy, a tow hook nut is often mounted in or around the crash box. This is a function that demands a high towing strength and this makes the design of the products much more difficult. The placing of this nut depends very much on the styling of the car and will therefore be a challenge both for the design, the platform structure and the industrial processes.

6.3.3 The development process

The development time for each of the projects is also illustrated in Fig. 6.6. For the crash boxes this time is fixed to the car's development time. HAST may enter the car's development project early or late in the process and the development time indicates this in the figure. A short development time will indicate that the organisation has been quick in turning around and establishing a valid solution to the problem.

From the interviews it can be found that the different design teams seem to have their own set of product and production solutions. By viewing Fig. 6.6 one can see that some car manufacturers are more frequently found within an industrial process, than others. The reason for this may come from the distributed location of the design teams or as a driving force by the car manufacturer against a particular solution. Normally these design teams operate more or less as separate teams and share people only when extra resources are needed, such as when the team encounters a problem. This is combined with a product document system that does not emphasise the search for existing solutions. It is thus easier to start from scratch for the development teams. One advantage about having teams that work more or less in their own environment is that separate product solution paths are followed. If there is a need to increase the innovation capabilities with the company, this will provide a wider solution space, but for HAST this might not be the right solution at this time. Innovation might produce some smart ideas and this has happened at HAST. In the crossing of people between teams some very successful products have been designed. This has happened with the Epsilon crash box. The functional aspects are illustrated in Fig. 6.7 and in this product there is a crossing of functionality (shear energy absorbing) and industrial process (Gullwing). In this situation, it uses the best from two worlds - the design and manufacturing.

6.3.4 The challenges of introducing many products at the same time

HAST started developing the crash boxes in the mid 1990s and production started a few years later. The first start can be characterised as calm, where one industrial process (cut and machine) was launched in the US and two industrial processes in Norway (cut and form, FSW), both of them with a high enough production volume to satisfy a separate industrial process at that time. All of these processes had only one or a few product variants. At the end of 2000, the number of new product to be released rapidly grew to nine. Of these nine product variants seven were distributed on four new industrial processes. For all of these new processes it was in particular, the forming operation and assembly with welding that was challenging. Optimising the design solution and tuning the manufacturing processes to handle the tolerance and quality issues were general problems. Due to a strong organisation with detailed knowledge about material behaviour and simulating capabilities, all of these technical problems were resolved. The lines got running and products were delivered on time, but this has had its costs. These four industrial lines were located in two different sites, but the competence base of people was the same. Many of these people had to leave their daily work and become "fire fighters". The problems were piling up and all effort was used to fulfil the orders and deadlines for all the products. The problems were not the same at each line and few of the solutions could be transferred across the lines. This had its origin in use of different principles on how the complex forming tools were designed and the difference in product design. The capabilities of entering new projects were not there. There was a long time where no new orders were taken, due to all the internal focus.

6.4 The interpretation of the market and historical data

The historical description of product variants is a starting point for the discussion on how to increase internal standardisation in the company as well as providing feedback into the Corporate Platform. The case has illustrated one situation that much can be learned from. Combining this case with existing literature some pattern of best design strategy can be found.

When designing a new crash box there are two fundamental directions; the design is adapted to an existing industrial process or a new industrial process is built. Between these two approaches there is a large gap. Adapting a design to an existing industrial process, means that the risk is much lower. The major part of the design's disposition against the life phases are known from earlier products. A shorter design time and easier ramp up of the manufacturing could be anticipated. The other approach is different.
Here the risk is much higher. Both the design's architecture and the manufacturing process are new or at least the combination is. Such a project does not classify as a development project, but more as a research project. If a company does this, it should also consider what else is to come in the future based on the new industrial process. A lot of investment in equipment, designers-, operator's knowledge and testing have to be done and not having a plan for future directions might not be so smart.

6.4.1 The clockspeed and the industrial focus

The clockspeed is as mentioned earlier, an expression for indicating the change speed of the products, production and supply chain. To illustrate some of this, Fig 6.8 indicates the evolution in the product and manufacturing solution space, in order to serve the market's needs. In the beginning of a new market niche, many different solutions satisfy the customers. Then there is a transitions phase with "smarter" product structures, before some or one solution becomes the standard. Within this transition phase different manufacturing strategies should be applied for achieving competitive advantage. Flexibility is needed in the beginning, then a platform with many variants before eventually a few solutions serve the market. Cost is one of the primary drivers for standardisation, so if the product cannot be sold with any advantages other than to achieve a better price, there are two directions. Standardise and make the product simpler or leave the business.

This must also be seen as a dynamic process, which changes and repeats itself over time. As Fine (1998) says

"*history provides one absolute: All competitive advantages are temporary*".

For HAST the clockspeed for products has been quite high, since very few product variants are based on the same concepts. The production and supply chain have on the other hand been much more stable, but diverse. The company should therefore focus on establishing a commonality plan for the processes and for the product variants, create a product structure with a solution space acceptable for the customers. If cost is the primary driver, platform design and standardisation are the direction to aim for.

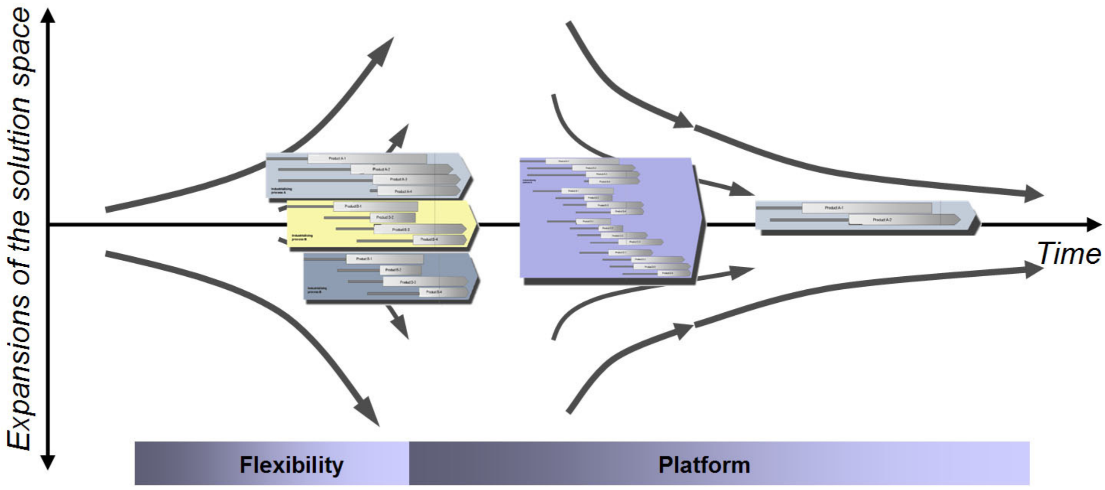


Figure 6.8: Market maturity and industrial focus.

For a long time companies have talked about core competence and how it should be used to achieve a competitive advantage. Often the core competence is related to one or a few areas of a company that can be handled very well. This might be the product development, a particular manufacturing process, supply etc. When the company is operating globally with multiple development sites, the core competence needs to be seen in a wider context. The core competence is excellent to use in gaining customers, but it says very little about the management of the company's product families. What happens over time is often that the product families grow in unplanned and uncontrolled directions. The result is product families that are costly to run and the profit vanishes.

Taking control over the product variants in a holistic way is much more efficient than optimising each product variant design, which is sub-optimising for the company. Let us first take a look at what other authors have written about this. A detailed overview of methods around modularisation and platforms is found in chapter 3, but these authors deal with this subject in a time related situation.

For the design and functional view point Maier and Fadel (2001) describe different types of single- and product family designs, Fig 6.9. To these single and product family designs they propose seven design strategies for the product structure, as shown in Table 6.1.

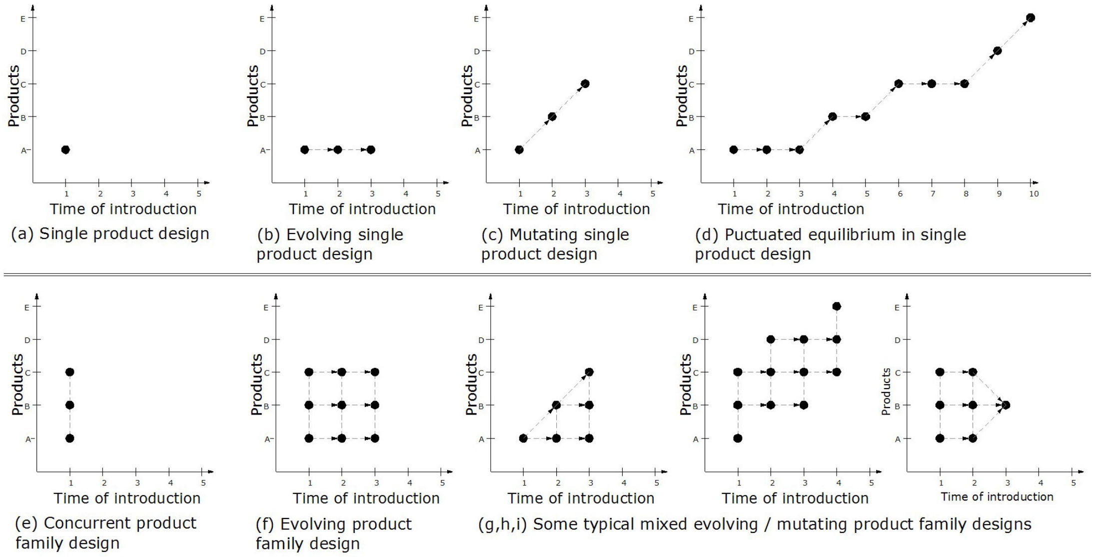


Figure 6.9: Types of single product design and product family designs (Maier and Fadel 2001)

Table 6.1: Maier and Fadel's suggestions of relationships between product families and most useful design strategies, related to Figure 6.9.
** The term mutating is a jump in improvements, compared to incremental improvements
*** Punctuated equilibrium is a mix of evolving and mutating improvements

	Type of product family	Most useful design Strategies
a	Single product	Traditional design methodologies
b	Evolving single product	Modularity
c	Mutating single product**	Modularity
d	Punctuated equilibrium single product***	Modularity
e	Concurrent product family	Scaling, product platform approach
f	Concurrent evolving product family	Scaling, modularity, product platform approach
g, h, i	Mixed evolving / mutating product family	Scaling, modularity, product platform approach

Maier and Fadel raise the important topic of what type of product development is done. Is it a single "one-at-a-time" product or is it a product family development? They argue that the most important information that affects the decisions as to what type of product family to design is the following:

- Whether or not the product will be improved over time,
- How much product variability there will be,
- How many market niches are targeted,
- What size market is being targeted, and
- What type of market is being targeted (static, i.e., mature or dynamic, i.e. developing)

6.4.2 The comparison of HAST's product history and literature's perspective

By comparing the evolution and mutation presented by Maier and Fadel and the figure of HAST's products, Fig. 6.7, one can see that HAST fit within the mixed and evolving illustration. HAST's products have though tendencies to expand in different product functionalities rather than be combined into fewer solutions. This progression has not been planned by HAST, it is rather a result of projects that have previously been run. The design strategies that Maier and Fadel propose for this are within scaling, modularity and product platform approach. This fits within HAST's direction, but in the existing crash box family it should become clear what is reused and where can variation appears. The solution space for the functional solutions should probably be kept very wide and the constraints for the engineers should be controlled within the interaction between the product architecture, production and supply chain.

The case with the crash box product also captured one of the reasons for the challenges HAST has faced. The historical description shows clearly that many different industrial processes were launched more or less at the same time, with the consequence of putting the organisation under great pressure. The case with Hydro illustrates one layout of the introduction of product variants and new industrial processes, but other scenarios are possible. The following scenarios can illustrate this, Fig 6.10:

A. One industrial process handles all the product variants instead of a range of industrial processes
B. The launches of new product platforms are planned so that the organisation's resources are not overloaded, compared to a high number of simultaneous releases of new platforms.

In scenario A there will be a significant transfer of knowledge in all subjects from product to product. The actual development time will be reduced from product to product, in the same way as people get better when things are constantly repeated. Other areas within the organisation such as engineers designing the tools and fixtures, the operators on the lines and the service personnel all benefit from a high number of repetitive actions. In the supply chain the same transport equipment and fixtures can be especially designed for this product structure. A subject often forgotten, but one important for the daily running of the lines, is the stock of spare parts, each industrial process have many especially adapted tools and fixtures. Few different lines mean that the stock of spare parts can be reduced and that again benefits the operating cost.

In scenario B there is a shift in time when the new industrial processes are launched. Launching many processes at the same time puts a strain on the organisation. There are lots of new systems that need to be fixed for errors and bugs, at more or less the same time. This is partly what happened in the HAST case and was difficult for the organisation to work through. This effect can be illustrated with a typical time- failure graph for starting up a new industrial project, as illustrated in Fig. 6.11 (A) (Blanchard 2004). This figure illustrates:

- Depending on the type of equipment, established production and equipment maturity acquired through testing, in the operating environment, there may be a great number of corrective maintenance actions to achieve the reliability needed. Immediately after equipment is installed the reliability is poor before it reaches a constant level. Very often in the design period this constant failure rate is used, without thinking about the start challenges.
- The increased failure rate in the beginning is not only for the equipment, but also for the operators and maintenance personnel that need to become familiar with the system. Until this happens, a certain number of operator-induced fails will happen.
- Even if both the equipment and personnel operate the system well, it might not be able to run at full speed, due to the logistic support at all levels.

In the case of the crash box several industrial processes where launched rapidly after each other. If we assume that there is no learning between the projects the failure rate will accumulate for the organisation according to Fig. 6.11 (B). The organisation has now not only to handle each of the high failure rates of the individual projects, but those that are accumulated too. This accumulated failure rate can demand more resources from the organisation that it is capable of delivering. External support or even more employees can be needed, before a steadier period is achieved.

Is the case that there is transferred knowledge and experience between the projects; one can assume that the start up failure rate is reduced together with a slightly lower constant failure rate for each new project. The accumulated failure rate for the projects become lower and much more constant, making it easier for the company to have a steady employee work-load.

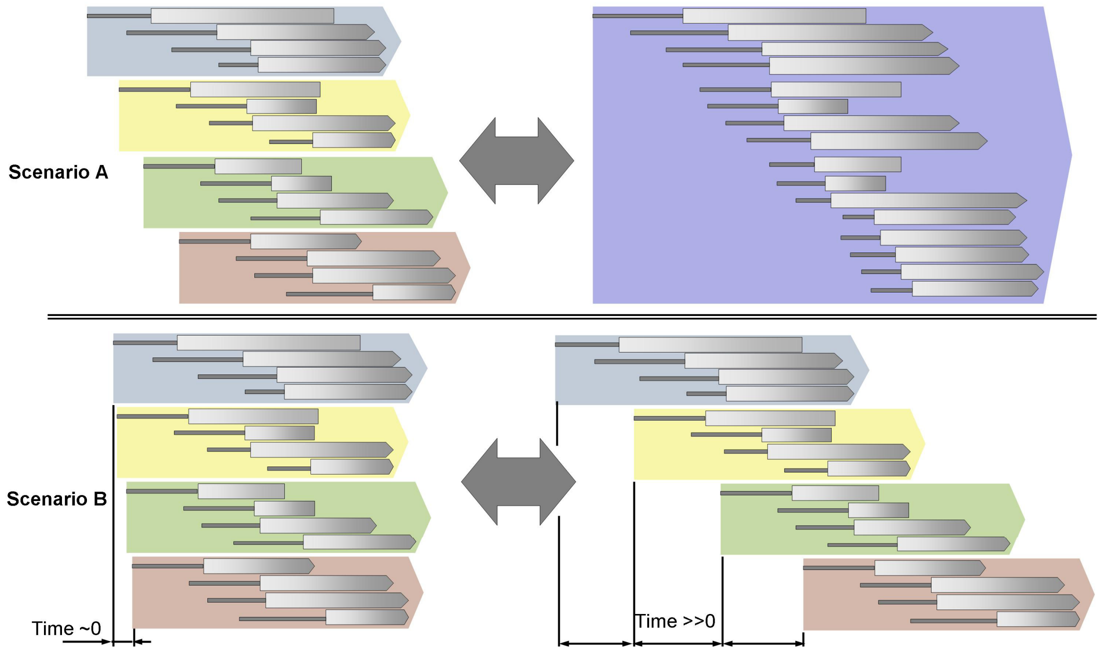


Figure 6.10: Possible scenarios of the historical description: Industrial layout A illustrates multiple industrial processes compared to one industrial process to manufacture the same products, Industrial layout B illustrates the time of introducing the products to the market.

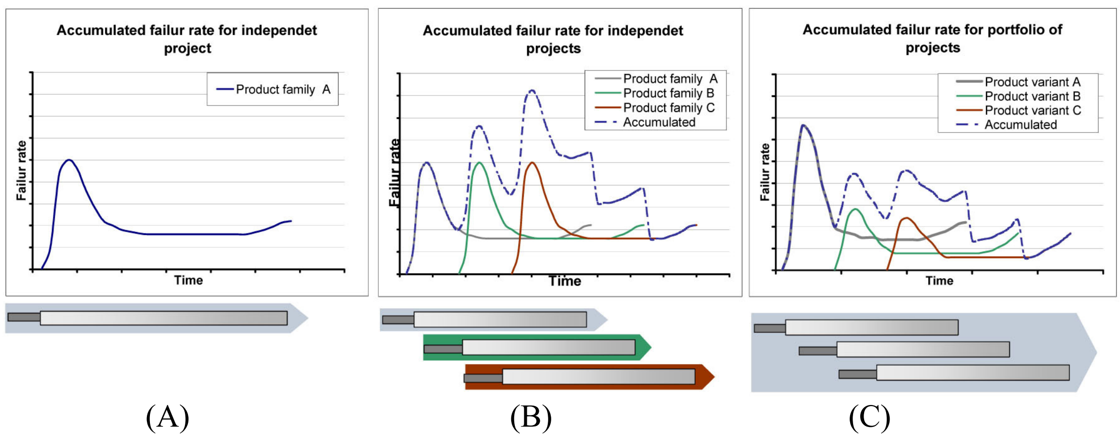


Figure 6.11: (A) Typical failure rate of manufacturing a product, a high failure rate in the beginning, a steady period and increased wear in the end (Blanchard 2004), (B) failure rate of manufacturing multiple independent products and accumulated failure rate, (C) failure rate of multiple products that are based on the same product platform

7 Evaluation and conclusion

Highly competitive global markets force companies to change their way of doing business. Improving Norwegian companies' competitive advantage is necessary, in order to sustain their global competitiveness. A major trend in designing product families is the increased interest in using product platforms. The major automotive companies have among them adopted platform and modular strategies. Now, also sub-suppliers and smaller companies with less complex products find interest in this strategy of designing products.

7.1 Objectives and research questions

The objective of this research is to provide a model systematised the design process in order to achieve a more efficient development of customised product variants. By having many customers acquiring more or less the same type of products, standardisation can be improved and this leads to a better competitive advantage. Most of the methods and models found in the literature focus their attention on products capable of having a product structure that can be configured into product variants. The configuration is often done through a combination of product platform and modular design. The detailed product family design methods focus mostly on the relationship between the components in the product structure, by mapping out the interconnections. HAST manufactures among others, the crash box product. This product consists of so few parts and complicated manufacturing processes, that these product family design methods provide little useful information. A research study has therefore been established to look into the following research questions.

The main research question of this study is:

How can production-, supply chain- and technology knowledge be described as a Corporate Platform useful for customizing products?

This question contains several topics, both regarding the disciplines and the level in the organisation they affect. In order to answer this question an approach dividing it into four sub-questions was found appropriate. The answer of these four sub-questions should provide the answer for the main question.
Sub-questions:

RQ 1. *How are product platform- and modular design described and handled in theory?*

The development process involves the need to make dispositions for the product regarding many life phases. For one-at-a-time products this might not be so critical, but for product platforms it becomes more critical. Performing the product development with cross disciplines methods and design teams are important. The literature study (Chapter 3) found indications that there still is a strong tendency in the methods to keep within one engineering discipline as functional design, manufacturing processes and supply chain. It was found that the methods for a configuration design of product families are well established within the disciplines, but with improvement potential in the cross disciplines areas. This reflects that few of the methods involve the ideas of postponement in the production of the product variants. The majority of the methods found were also primarily focused around some details, but there were a few methods that take a more holistic view. The areas in product platform and modular design that are weakly described are; design methods for products that are not configurable, the establishment of best requirements to base the product platform concepts upon. The evaluation of product platform concepts, with many product variants, has a tendency to end up with an average result. This makes it difficult to separate even very different product concepts in an evaluation. The literature study has revealed that there are several holes in the design methods for product programme.

RQ 2. *How are product platforms described and handled in the industry?*

In the industries examined (Chapter 4) limited consciousness was found around product platforms and reuse of assets. Both the automotive companies had some degree of reuse of design solutions, but were not so aware of them. There was also a difference in the focus between the furniture and the automotive industries. The furniture company made products for consumers and could control the product portfolio completely. This resulted in that Ekornes could have a very strict focus on standardization. All the product variants developed were only allowed to fit with the existing production line, and when new product variants were developed they took the place of outgoing variants. The automotive companies had not the same type of control over their product portfolio. They were more interested in finding the best solution for the customers, regardless of their internal consequences. Between the automotive companies and the analyzed products there also were differences. Kongsberg Automotive have a long tradition in making the servo. The product structure is reused, but the development teams have potential for improving the reuse in the design process. For HAST the product has not established a preferable structure. This has resulted in many product structures and many industrial processes. The product family shows signs of one-at-a-time projects. There are limited signs of reuse between the projects, both in the design and manufacturing of the product variants. Much of the lack of reuse found in the investigated companies comes from an insufficient system aiding the design team to reuse solutions. The design team have to relate themselves to a large amount of information and it seemed that searching for existing solutions was more difficult than developing a new one.

RQ 3. *How can a Corporate Platform be modelled?*

The product assortment can be modelled by the Corporate Platform model (Chapter 5). The model gives opportunities to balance the distinctiveness needed in the products and the commonality needed in the company (HAST) in order to have a competitive advantage. It consists of three elements; Market, Product platform and Manufacturing. These elements are aligned with the final customization of the product variants. The model gives the ability to establish a product programme, by aligning the three elements. It provides product structures and industrial processes giving customized product variants and sustains a high internal commonality for the company (HAST). The aligning process starts with a systematical analysis of the arrangement of product features and market strategies. These features are developed into a product programme that consists of one or several product structures serving the segmented market. The development of the product structures is done in close interaction with the production and the structure of the industrial processes. The product structures developed form the base on which customized product variants can efficiently be derived. Deriving product variants from the product platform gives the ability to rapidly deliver new product variants and with low risk. In this systematic design process, information is made explicit to enhance the understanding and use of product platforms. This model is intended to be used by the development teams and in the process of establishing the right product portfolio for the company.

RQ 4. *How to handle the product assortment evolution?*

Developing a product programme is not something that is done once. The product operates in markets that are dynamic and so need the product programme to be so too. The Corporate Platform model is therefore intended to manage product variant information by having an input of product experience (Chapter 6). A model visualizing the evolution of the existing product family based on the industrial process is developed. The visualization gives possibilities to indicate product information and industrial process especially for non-configured products. The information is presented in a time line perspective with many graphical elements. These elements are used to improve the communication between engineers and also to managers and people not directly involved in each project as well as provide input to the Corporate Platform. The visualization gives a detailed description of the product assortment's evolution and all the products within the product family. Combining the visualization of the product family with the experience of manufacturing and the traditional functional grouping of product variants provides important design information back into the Corporate Platform. Manufacturing and supply chain information is then taken care of in a state that is beneficial for the development team, to be used in the next development and research projects.

7.2 Conclusions

This research has resulted in the Corporate Platform model, providing a solution for how to develop a product programme for HAST's crash boxes. The model systemises the way customised products, new and existing, should be aligned with the market and the company's internal request. A systematic approach to product variant design gives the possibility to improve the internal standardisation in the company. The enhancement on the standardisation is based on Robertson and Ulrich's (1998) product platform framework. This standardisation is reflected both in the physical aspects of developing product solutions and in the softer aspects the design teams interact in. The model provides an insight into all the elements that are part of a product programme, from the market, the product structure and the industrial process to the treatment of company knowledge. The development of a product programme from the Corporate Platform is an alignment process, with several iterations, of all the elements. In the case of products such as the crash box it becomes important to find the best alignment between the product structures and the industrial process for the whole product programme. One should avoid sub-optimisation as done when only focusing on one product and project at a time.

Product as the crash box goes also through an evolution regarding the design and production, with small and large steps. In a product programme it becomes important to try and understand the market dynamics that affect the product design. HAST needs to have an active relationship with the launch and closure of product variants as well as whole product platforms, in order to achieve a lean product portfolio. Information and experience from the products and how they behave both in the market and in manufacturing are important to capture and present for reuse a later time. A more structured knowledge base increases the ability for people to swap between design teams and hence sharing of ideas. The Corporate model provides a suggestion on how to structure the product design information to ease this.

7.3 Validation

The novelty of this research lies in 1) the formulation of a model making the elements part of a product platform used to develop customised products on non-configurable products explicit, 2) introducing a stronger link between product platform design and the manufacturing elements, 3) relating the market dynamic to the development process of both the product and manufacturing, and (4) exploring a group of Norwegian companies' use and understanding of product variant design.

The research objective is broad, and consequently the research aimed to be exploratory rather than providing scientific proof. The model has construct validity as the collected empirical information accurately corresponds to the models' behaviour. There are no internal conflicts between elements in the model and there is a relationship from the market to the company's core assets. The model goes also in depth in the process of establishing the product platform structure and industrial process. The market elements and the management of the organisation's knowledge are more broadly covered.

Research within engineering design is challenging due to the nature of product development. The empirical data used is taken from an environment constantly in change, but reflects the situation companies operate in. The research is focused strongly around cases and hence the validation of the results is very good for the analysed crash box. The reliability of the empirical data may lose its strength as the distance from this type of product and industrial processes increases. However many general product development methods are used in the model and they have proven their strength in previous literature.

The cases in this research provide an insight into the core of the problems raised in the objective. Each of the cases goes into depth and describes the topics of the model. All cases are more or less independent of each other, but together they provide an answer to the overall objective. During the research most of these cases have been published in the engineering design society. The articles have gone through a peer review and been accepted for conferences. This indicates that the engineering design society has accepted the work done and found it worthy.

The work with the Corporate Platform model has also been accepted by HAST, by the initiation of a new research project using the model. This project is focused around a product with the same type of characteristics as those found in the crash box. The project aims to develop a product programme that will be the base for a management decision. The decision is on ‘go or no go’ for further develop of this product.

7.4 Further research

During the work on this thesis several topics for further research have been discovered. These can be related to:

- The evaluation of product platform structure and industrial process concepts
- The management of product platform data

Evaluating and finding the most appropriate product platform concepts is a difficult task. In this process, there are in particular two steps that need further investigation in order to be properly described. First the product platform is intended to leverage many product variants. Therefore the requirement for the product platform needs to involve ranges and not only static values. Defining and setting the optimum requirements for the product platform is a process that needs further research. The next thing related to these early phase challenges, is in the evaluation process of the product concepts. Developing product platform concepts might be done according to traditional product development methods, but it should be evaluated after how well the concepts fit within the requirements. One might think that traditional product concept evaluation can handle the product platform evaluation, but this is not so easy. An evaluation of product platform concepts has a tendency to give an average value for all concepts, especially when there are no reference products. This has its roots in the fact that multiple product variants of the concepts have to be evaluated in order to get an overview of the platform performance. Such an evaluation will give good values for some of the product variants and not so good for others. This gives an average result for the product platform concept as a whole. The platform should also be compared to several different product platform concepts that are different, but targeted at the same requirements. The evaluation of these totally different concepts will more or less yield the same platform results. This evaluation problem is also relevant for which industrial processes that should be related to the concepts.

The management of product platform data is the other main area where more research is needed. With this I mean that there is a need to connect both the focus on the softer aspects as well as the development of the physical products better, in order to further search for reuse potential. In product development there has for a long time been focus around establishing products with the optimum set of functions and properties. For a company this is just one set of elements that is important in a product programme perspective. The flow of information is one element that is very important in this setting. This involves both the stored information and how people interact. As found in the research, the stored information had a structure influenced by other interests than product development, more in the direction of company-customer interaction. In order to make the product development process of product variants more lean, a data structure such as the type proposed in the dissertation should be aimed at. There exist some Product Lifecycle Management systems that can store information of this type, but even these systems have large improvement potential in this context. The flow of information in organisations is a topic that is well known in the sociology field, but it should to a larger degree been connected to the complex process of developing a product programme. Finding the optimum information sharing and data structure between people involves many more aspects than covered in this research and is therefore an area that needs further investigation.

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Appendix

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Appendix I: Design for variety: A review in design methods to establish a product family architecture

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DESIGN FOR VARIETY: A REVIEW IN METHODS TO ESTABLISH A PRODUCT FAMILY ARCHITECTURE

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Abstract

This article presents an overview of research in product variants design. The articles selected present methods to solve the challenge of establishing product variants, and are selected to be of help for a design team. Both modularity and platform design have been discussed for quite some time, but in recent years discussions have increased. The methods developed over time have different purposes and are intended for optimising the product in different life-phases. Different design methods are therefore discussed, with an indication of which design phases they position them selves in. They are compared to the three different points of view; functional-, technical- and physical, that illustrates the product development process from establishing customer's needs to the manufacturing and supply chain of the family. The majority of existing methods are working on transforming the customer's needs into the product family and very few methods take the next steps and maps it to the manufacturing, maintenance and recycle processes.

1 Introduction

The evolution in product development is changing from focus on mass production to mass customisation. This change has led to the development of different methods to establish product design that fulfil the individual customers' needs and simultaneously maintain the benefits of mass production. The points of view used in these methods are very scattered as to where in the life-cycle they have their focus and from which abstraction level; strategic to operational. For "one at a time" product there exist a uniform design methodology for all the life phases [Ulrich & Eppinger 1995 and Pahl & Beitz 1996], but they are not comprehensive enough to cover all the areas and detail levels involved in establishing a product family architecture (PFA). A product family consists of multiple products, designed to enter the market at different times or in different categories. Since this involves making decisions for many products at the same time, the economic risk is higher as well as the profit if it succeeds. To improve the chances of doing the right thing at the right time, proper methods are needed.

This review article will present the latest methods to establish a PFA. The selected articles are on the operational level and present methods that are useful for a design team in solving the challenges of designing a product family. The methods are related to modularisations-, product platform design and how to handle the technical "language" needed to map all information into a product family. Articles related to development of only "one at a time" products are not included. All the articles are from well-recognised journals, conferences and design books. The articles selected have all methods that focus on solving the challenge of establishing a family architecture.

1.1 The fundamentals in design for variation

When it comes to transforming design strategies into products, much has happened since the mid- nineties. [Ulrich 1995] was one of the first to clarify the importance of product architecture and that establishing the correct product architecture is a key driver for the performance of a manufacturing firm. He defines "*product architecture as the scheme in which the function of a product is allocated to its physical components*". With this it follows that the specified function may interact with the physical component in many different ways. Ulrich argues that the major types of typology are modular- and integral architecture. A modular architecture includes a one-to-one mapping from function to physical component, while an integral architecture has a complex mapping, fig. 1. Viewing this in the context of a product family [Sanderson and Uzumeri 1997] define a "*product family as a set of models that a given manufacturer makes and consider to be related*". This is a very broad definition, but by adding the need to have a high degree of reuse in creating the product variants, [Maier and Fadel 2001] define a product family as: "*... a group of products that shares some common technology*". This family may be designed with; modularity and product platform approach. Modularity is by [Ulrich and Eppinger 1995] defined "*as chunks (subassemblies) that implement one or a few functional elements. The interactions between the chunks are well defined and are general fundamental to the primary function of the product*". A well designed modular structure can allow changes to one chunk without affecting the rest of the design. Product platform is by [Meyer M. 2002] defined as "*a common subsystem or subsystem interfaces that is leveraged across a series of individual products by means of shared product architecture*". A more comprehensive definitions of platform is presented by [Kristjansson et.al. 2004]

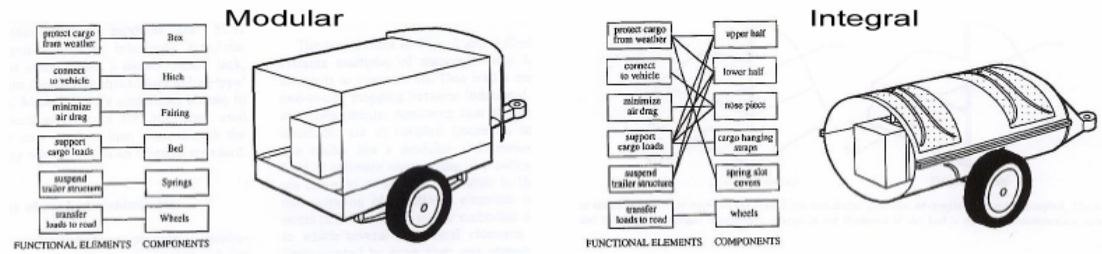


Figure 1: Description of the scheme of modular and integral mapping from functional elements to physical components, [Ulrich 1995]

Establishing the correct product architecture for the product family is a difficult task, as different approaches can be taken to create the variants as well as which life-phases to include in the design process (manufacturing, assemble, use, service and recycle). Each product in the family must be evaluated against their meeting of the life phases in order to find the best common approach. Many different design methods have been proposed and some of them will be discussed further in the text. A review of general product development literature can be found in [Krishnan and Ulrich 2001]. They cover design methods as well as design strategies with a broad view on this academic field. The question of the amount of variety the firm should provide to the marked, and the reasons for why the customers seek variety is discussed in [Ho and Tang 1998].

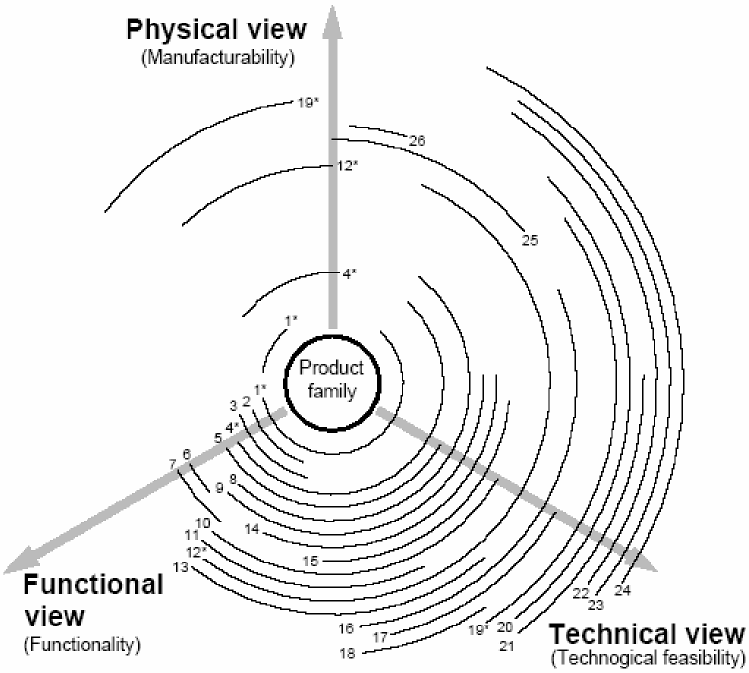
2 Design models

To model a new and slim design assortment there is a need to define the current status. A "picture" of today's products assortments gives valuable insight in this. Such a picture may be taken from different points of view in the design process, so that it can include more than only the bill of materials. The cromosommodel [Andreasen 1992] that describe the domain theory has been adapted by [Mortensen et.al. 2001] and extended to yield the Product Family Master Plan (PFMP) method. This method is suitable to take such a "picture". The method maps the product assortment between the transformation-, organ- and part domain. The model may handle the whole product family, with all of its variants. It list and view the product assortment in a holistic way, but it does not say anything about what to do to improve the company's economy of scope or about the related supply chain that is part of the realising the products. [Du et.al 2003] present also a similar "language", graph grammar, in generating product variants, their attentions are more on configuration side rather than the early conceptual phases. The focus is on organising of data and knowledge rather than on the product development process.

3 Design methods

To develop a successful product is difficult even when only a single product is to be designed. Considering multiple products at the same time is far more complex. To prevent designers from being overwhelmed with information and demands, it may be helpful to view the challenge from multiple sides. [Jiao and Tseng 1999] presented a model that considers the PFA from three different points of view; a Functional view, a Technical view and a Physical view. The functional view represents the customer side, where the customers interests are the focus, including addressing all customer requirements, against which product strategies are defined and competitors are analysed. The technical view handles the implementation of the technology, solution principle and how the products are designed. The physical view looks at handling the manufacturing side where design for manufacturing and the production equipment are evaluated until the products are realized. A modified version of this model has been adopted in order to illustrate the research topics that are covered in the selected articles. The modification relates to make the transaction between the views smooth. Fig. 2 illustrate the authors opinion on were the discussed articles have positioned them selves. The articles are also indicated at which focus areas they have; modular and/or platform). This figure must also bee seen as one layer related to the operational side, compared to the strategic level. Articles positioned between the physical and functional view axes covering life phases related to sale, maintenance and recycle have only in minor extend been commented, as they are part of more comprehensive methods.

As always the articles are written by persons with different background, where some aim the methodology at consumer products while others look at high performance industrial products. Creating a PFA involves two major approaches; Modular design and platform design. Finding the appropriate strategically approach for the company has been discussed by [Maier and Fadel 2001]. A well-defined strategy is important to establish before the design is implemented.



		Modular	Platform
1. Ho & Tang	(1998)	X	X
2. Robertson & Ulrich	(1998)	X	X
3. Krishnan et.al.	(1999)		X
4. Ericsson & Erixson	(1999)	X	
5. Mortensen et.al.	(2001)	X	X
6. Yu et.al.	(1999)	X	X
7. Otto & Wood	(1998)	X	X
8. Martin & Ishii	(2002)	X	X
9. Jiao & Tseng	(1999)	X	X
10. Gonzales-Zugasti et.al.	(2000)		X
11. Huang & Kusiak	(1998)	X	
12. Gershenson et.al.	(1999)	X	
13. Sudjianto & Otto	(2001)	X	
14. Palani Rajan et.al.	(2003)	X	X
15. Gershenson et.al.	(2003)	X	
16. Simpson et.al.	(2001)		X
17. Dahmus et.al.	(2001)	X	
18. Kokkolaras et.al.	(2000)		X
19. Gu & Sosale	(1999)	X	
20. Jiao & Tseng	(2000)	X	
21. Salvador et.al.	(2002)	X	
22. Meyer & Dalal	(2002)		X
23. Jiao & Tseng	(2004)		X
24. Jensen & Hildre	(2004)		X
25. Gupta & Krishnan	(1998)	X	X
26. Lee & Saito	(2002)		X

Figure 2: The author's opinion on where the articles are positioned, when [Jiao and Tseng 1999] points of views are used. Methods that are scattered in these view points are marked with *

[Maier and Fadel 2001] methods aid managements and designers in determining which type of product family that is appropriate based upon earlier knowledge. In this context they propose seven different types of product families, from single and evolving single products to mixed evolving mutating product family. The method find the manufacturing paradigm to the company, which relate the companies to four groups mass production, mass customisation, continuous improvement or invention. All the seven types of product families are then mapped to one or more of strategies regarding; single design, product platform design, scaling design and modularity design. Implementing such a strategy to design a product family is usually not the first thing a company does, they usually have a history of single products that have evolved over time. [Ulrich and Robertson 1998] discuss how a company can change from doing "one at a time" product over to managing product platforms. They provide partly a step by step description of the product platform planning, with focus both on the products (in a wide perspective) and the design team challenges. One of the main reasons for designing a product family is to get some economical benefits. In many of the articles this link between the design and the economical aspect is based on others knowledge in that this should give a economical advantage. [Krishnan et.al. 1999] address this important subject. They provide a model capturing the cost of product platform development project and the marked demand. The model chooses the best suitable product variants from a set of candidates.

Performing benchmarking of in the house products and the competitors may gain valuable information as well as reversed engineering. [Otto and Wood 1998] proposed a method for reversed engineering based on traditional product design for single products, but the method also looks into many aspects that may be vital in designing a product family. Understanding and establishing the correct customer needs is clearly important to design a successful product. [Yu et.al. 1999] follows this approach and present a method to define the portfolio architecture based only on customers' demand. Their method seeks to find the best architectural approach in more or less the same way as [Maier and Fadel 2001], but they neglect the design and manufacturing costs. The focus is on establishing a statistical view, with distribution of customers needs over time. From the shape of the statistical distribution, different architecture for each features in the product are proposed (Platform generation, fixed portfolio architecture, platform family or adjustable portfolio architecture). A statistical approach to guide the typology of the portfolio requires a large customer group to gather enough needs. This makes this approach perhaps more useful for consumer product rather than industrial products, where such data may be hard to get.

3.1 Modularity design methods

Modularity design arises from decomposition of a product into parts and subassemblies. Independency between these elements is the core elements in modular design and hence the product functions must be grouped. [Pahl and Beitz 1996] propose this classification:

- Basic functions are fundamental to a system and in principle not variable. They are implemented in the basic module and are essential
- Auxiliary functions are usually also of the "essential type"
- Special functions are usually implemented in separate modules that are of the "possible" type
- Adaptive functions are necessary for adaptation of other systems. These are of "essential" or "possible" type.
- Customer specific functions are usually designed individually and adapted to the system in a non module.

[Stone et.al 2000] proposed a method to identify modules from the functional structure, by consider the dominant flow, branching flow and conversion flows. [Sudjianto and Otto 2001] have extended the use of a functional structure too also model a family across different brands as well as within one brand, fig. 3. The impact on brand width on brand share is discussed in [Ho and Tang 1998].

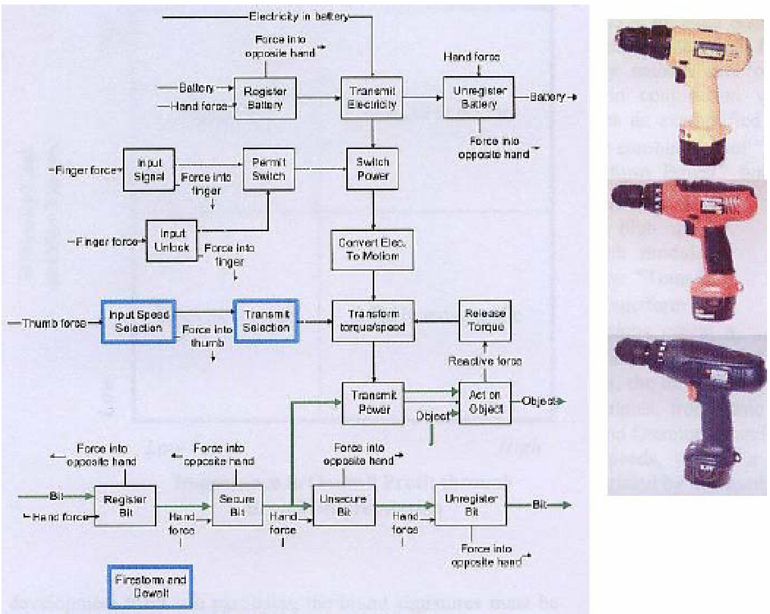


Figure 3: Cordless drill family functional structure for Black & Decker, Firestorm and Dewalt. All unshaded boxes are shared across all models [Sudjianto and Otto 2001].

[Dahmus et.al 2001] proposes a method for architecting a product family that shares interchangeable modules. Their method consists of developing a functional structure for each of the separate products and then finding the common functions structure for the family. The family function diagram consist of all the single diagrams and all the flows interactions (electrical, mechanical, gas and fluids). The flows path through sub functions defines the modules. To visualize the whole family structure they introduce a modularity matrix. The neat thing about this method is that it is easy to use and can be used across product classes. Since the method is based upon a functional decomposition of the product structure, the products in the family must have an easy dividable functions structure. The method deals only with the early phases of establishing a PFA. Functional structure modelling is a common way of establishing modules. [Huang and Kusiak 1998] use also this approach in defining the modules. They use flow and force interactions illustrated in a matrix to categorize the different modules. By using matrixes possible separate and swappable modules are identified for electro, mechanical and electromechanical components. The method is suitable for early conceptual design and on structures that can form many modules. Therefore it may be most appropriate to use in electro or the combined electromechanical field.

A slightly different approach to finding the most suitable modules in the product has been done by [Ericsson and Erixon 1999]. They use the Quality Function Deployment to ensure that the correct requirements are derived from the customer. The functions are listed in a hierarchical structure, decomposing it down to independent structures/parts. These independent technical solutions together with their modular drivers (the reason to form a module), gives the possibilities to group and find appropriate modules. In their modular drivers' development and design, variance, manufacturing, quality, purchase and reuse or other reasons may be used to form the modules. Their method uses a very holistic approach to find and establish the modules; however they do not go in depth off how the grouped technical solutions should form the modules or how the functional flows are within the product. [Salvador et.al 2002] are also discussing the production side of products based on modularity. Their research looks into different modularity options on providing cost efficient solutions when the production volume is high or low. A measure for evaluating the commonality at the component level and on the process level has been proposed by [Jiao and Tseng 2000]. The process commonality index measures the level of commonality present in the manufacturing, by finding the component that uses the same manufacturing process and introducing the set-up time (cost) for the tools. This index gives then information about which parts or modules that should be worked on, in order to reduce the cost. This type of information may be very helpful if the set-up time is an essential cost driver for the analysed products and also to give the process commonality that is present a value. [Gu and Sosale 1999] focus their attention on creating modules by looking at the strength of connections between the parts in the product. They use an algorithm and matrixes to find the best suitable modules for many different life cycle phases. Their method does however find the modules out from the relationship listed in the matrixes. Modules that are proposed may not be possible to form. [Gershenson et.al. 1999] view also the modules from multiple view points as Ericsson and Erixon. The modules are created with regard for both the functional aspect and the life –cycle process (manufacturing, service and recycling). The modules are viewed both from function and process independence or similarity. A component tree and process graphs are generated to describe the product at different detail levels. A matrix describes the similarities and dependencies for the components and processes, leading to the modules. The methods opens up for designing the modules at different detail level, since an extensive dividing of the modules will at some level make the structure not modular. The modularity performances are also measured by an index's.

3.2 Platform design methods

The other major approach to establish the PFA is by using a product platform structure, from which variants are leveraged. The main purpose of the product platform design is to increase the internal commonality and increase the external variety. Product platform is therefore a base that is developed to be the fundamental part of many products delivered to the marked over a time or/and in different categories (High cost & performance, mid range and low cost & performance). [Meyer 1997] describes this in a marked segmentation grid, where the platform may be of a vertical type (platform I), a horizontal type (platform II) or a combination, fig. 4. With the defined type of platform the work of establishing architecture may be started. [Ulrich and Eppinger 2004] propose a general method and the basic ideas of establishing a platform architecture, that also may consists of modules. The method is based on functional flow modelling to establish the chunks and identifying of the interactions between the chunks. They also indicate the important of the product architecture in the performance of the supply chain, but this is only briefly discussed.

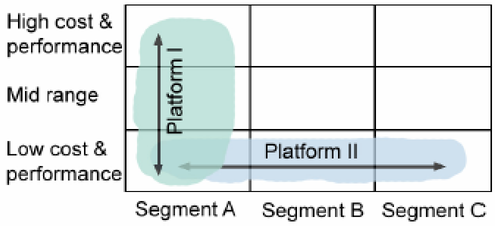


Figure 4: Marked segmentation for platform design, [Meyer 1997]

An overall approach of a platform design process is proposed by [Gonzalez-Zugasti et.al 2000]. They discuss the approach to implement a product platform design on a conceptual stage. [Martin and Ishii 2002] present also a comprehensive design for variability method, stretching from the conceptual phase and into a detail description of the products variability. Their method find index related to the amount of redesign a component required to meet future requirements and an index telling the couplings strength between neighbouring components. The methods uses well approved methods that are combined with assumption of the future direction. The method gives valuable information of the changeability the design has without needing too much detailed information. What the method does not cover is discussions around using commonality in the production processes related to establish the architecture. A different method, not so complex is proposed by [Rajan et.al 2003]. Their designs for flexibility method also establish a list of potential changes and effect of these changes. They have also adopted a traditional tool from "single" product development, the FMEA (failure mode effect analysis) and converted it to a Change Mode & Effect Analysis (CMEA). The CMEA gives indexes on design flexibility and potential for change. This method take also in to consideration the readiness the company is to perform these changes, but this is only stated as a rough assumption. Suggestions of improvement on the design or manufacturing are not covered.

To establish a well evaluated design a proper trade of analysis of all the alternatives should be conducted. [Simpson et.al 2001] have looked at scalable product platforms, where they compare a very comprehensive trade of analysis. They use a scalable electromotor as a case and iterate to the optimal platform. Further they compare this to single developed electro motors under the same conditions. The advantages and disadvantages of the performance to the PFA are discussed and they also include some manufacturing considerations. The numbers of variables to meet the requirement are evaluated against the commonality that can be acquired in the manufacturing. [Kokkoloras et.al 2002] also propose a trade off method using a cascading approach that also gives results directly comparable to the requirements. The product family is mathematically modelled and detail input is provided so that the results may come out as weight and stiffness, in their case. Performing a valuable analysis must therefore have good input to secure that results are trustable. Modelling the product family mathematically may also be difficult in some cases, while very suited in others.

All the above-mentioned methods focus merely on the section functional and technical views of establishing a PFA. The manufacturing that must be there in order to create the final products are only commented or inadequately discussed. The product used in examples and cases also consists of many components and/or sub-assemblies. This approach excludes many products that do not have a large assembly structure. [Meyer and Dalal 2002] introduce the platform architecture method for nonassembled products (film and integrated circuit). Their approach aim at understanding the dynamics of process intensive platforms and evaluate the performance. They do not present a specific method of platform design for nonassembled products, but they introduce the possibility. [Lee and Saitou 2002], and many others have discussed design and the products meeting with production for a long time, but not so in depth of a PFA. The subject that has been discussed in [Ho and Tang 1998] is the power full effect of delayed product differentiations. The assembly sequence is a key theme to address in optimising the supply chain. Product variations have a tendency to demand rapidly changes in the production. [Jiao and Tseng 2004] methods measure the flexibility a process (manufacturing) platform has to adapt to customise products. They use the manufacturing cycle time to measure this. A slightly different approach to evaluate the designs solutions space (variability) against the manufacturing process, have been proposed by [Jensen and Hildre 2004]. Variance in the design is compared with the flexibility to the manufacturing processes. The needed change in the processes due to the design variation is evaluated and gives an index indicating the estimated cost of change. [Gupta and Krishnan 1998] focus on establishing the optimal assembly sequence for a product family. Their method tries to maximize the commonality in the assembly sequence and minimize the number of subassemblies. The method may be used both for modular design, platform or a combination. To utilize the method the PFA have to be established with constraints in order to be able to execute an algorithm. A defined architecture must therefore be present before this method can be applied. It also treats all connections in the assembly with the same complexity. Introducing the assembly sequence as an important section of designing a PFA, and it plays an important role in establishing an optimal economy in the production.

4 Advantages with design for modularity and platform

The major difference between using modular or a platform approach to establish a PFA lays in the type of marked the product meets. Both [Meyer 1997] and [Simpson et.al 2001] propose that modular product facilitate horizontal leverage strategies while product platform (scalable) may facilitate vertical leverage strategies, fig. 4. Establishing a PFA based on modularity has several advantages when it comes to developing custom specified products, ease the manufacturing process and considering the life-phases of the product. Modularization can be done when focusing on these different aspects. Modules can be swapped, removed or added after request and they are used across the whole family. The customer may change the functions of the product by changing modules, but the weight and volume may be larger than compared with an integral architecture or a platform approach, due to the need to make the modules independency and interconnections. For the manufacturer a late differentiation of the product, lowers the buffer inventories and simplifies the manufacturing processes, [Lee and Tang 1997]. This enhances the internal commonality and is a key issue in effective manufacturing for both modular- and product platform designs. Preparing custom build product from an existing modular design may not be easy, if the required modular structure does not fit. The life span for a modular family must also match the effort used to establish it, [Pahl and Beitz 1996]. A more comprehensive review of product modularity definitions and advantages has been studied in depth by [Gershenson et.al. 2003].

Product platform based design has several different abstraction levels, from; common parts to common technology (manufacturing, know-how). The major focus has been on part reuse, but recently focus is also on reuse in the manufacturing and the rest of the supply chain, thus not as inclusive as for the modular approach. This new focus leads to even greater enhance of economy of scale, by reducing manufacturing and inventory cost as well as overall design cost, [Simpson et.al 2001]. The performance of a product platform may also be adjusted with the level of commonality. Similar economy benefits are found when the product platform is based on using common technology and know how to establish the PFA. The technology used should then be state of the art and ahead of the competitors.

5 Concluding remarks

Designing a product family is a topic that has been extensively covered in the last year, and specially related to modular design. This review presents some of these well recognized methods in the field of variant design, both related to modular design and product platform design. Various approaches in variant design have through the years been proposed, some very general, other highly specialised and other very related to the profession. The author has therefore indicated where in the life phases and in what topic the different methods cover. The point of views have been related to the; Functional view, Technical view and Physical view. The major group of the methods are however focused around the functional- and technical view, transforming the customer's needs into the product and its variants. These methods work also best when the product consist of an assembly of parts. The product platform approach has only briefly moved into the field of nonassembled products. There is also a lack of taking the full step into evaluating the manufacturing side and later life phases of the product family, creating a holistic view of the product family all the way from the customer's voice to the late life phases.

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Appendix II: Product platform performance in meeting with the manufacturing

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Product platform performance in meeting with the manufacturing

Jensen, Tormod and Hildre, Hans Petter

Keywords: Product platform, Product family, Variant design, Process design, Design for manufacturing

1. Introduction

A major trend in product design is the shift, from focusing on developing "one at a time" products to developing product families. This shift in design strategy give the opportunity to quicker release of new products variants, quick respond to new market needs and to utilise the manufacturing equipment in a better way. A product family is typically designed around a common product platform that shares the base structure, process or core competence and hence increases the reuse in the manufacturing.

Different methods to support variant design have been developed during the last decade. The view of these methods have mainly been focusing on customer satisfaction and "part" reuse, fig. 1. These methods create a product family that provides variations for the customer and internal commonality, by platform approaches [Simpson et.al. 2001] and modularisation approaches [Dahmus et.al. 2001, and Huang and Kusiak 1998]. The matching between the product family and the related manufacturing processes and technology have marginally been included in these design methods.

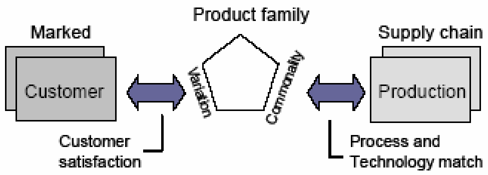


Figure 1: Product family relationships to the marked and supply chain

The manufacturing process have thus been extensively covered for "one at a time" products [Bootroyd et.al. 2002]. For a family of product some authors [Martin and Ishii 2002] and [Palani Rajan et.al. 2003] have established an indicator telling the cost or amount of redesign a component needs to meet the future marked. This information from their methods is related in some manner to the manufacturing process, but they do not cover that aspect in depth. Making the link between a product family and the belonging production sequence have been in some extend been discussed for modular product by [Gershenson et.al. 1999] and for a general product family by [Gupta and Krishnan 1998]. Their methods needs products that consist of many parts or modules in order to give valuable results. The authors [Meyer and Dalal 2002] have thus extended the product platform definition to also incorporate nonassembled products that are process intensive, but no design method is presented. A methodology capable of indicating the product families match towards the supply chain is therefore missing.

This article will try to present a method that fills some of this gap. The aim is to develop a method that give the designers of process intensive products the possibility to do performance ranking of their product variants, both for new concepts and fine tuning of the design. Ranking the different product platforms with their ability to reuse manufacturing processes is important in order to establish a well evaluated and economical product platform, as well as finding limits and possibilities in the design.

2. Manufacturing Change Performance Index (MCPI)

The presented method is based on a study conducted for a company, producing crash boxes for the automotive industry, fig. 2. This is a product that is mounted behind the bumper beam of vehicles and absorbs energy in crash. The gatherings of data have been done by interviewing process development staff and study the complete production process for the in house products. The product designs have been studied for all of the company's products, a number of competitor's solutions, a total of 48 different solutions. This study of the products gave valuable information in finding the parameters that the customers wants to have options on, in order to give the design high flexibility. These variables were then used to evaluate the changes in the manufacturing. Due to the sensitivity of much of the data, they are only limited presented.

This study have been used to develop a method that is capable of evaluate the manufacturing process for product platforms. This method can be used to evaluate the flexibility for the manufacturing process or how different manufacturing processes affect the same product platforms. The method takes consideration to the reuse of parts, processes and in some extends knowledge. Extending the method to include more than only part reuse has been essential, since the crash box may consist of as few part as one. The proposed method consist of a two step approach; A mapping of customers demands to the corresponding engineering needs and performing the main manufacturing analysis on these needs. The analysis leads to indexes between 0-1, indicating how easy or difficult changes are to handle. A low score makes the changes easy to perform.

Figure 2: Crash box and its position in the car, behind the bumper on each side (illustration only)

2.1 Step 1: Mapping the Customers needs

The first step in this method is to find the functions in the product that the customer is interested in. For product delivered to other industry like original equipment manufacturer (OEM) the customer typical want individual specified performance of the product. Adapting products individually to each customer leads to a large portofolio. Step 1 consists of extracting all the different requirements that needs to vary in the portofolio. These are typically expressed as a change (n), illustrated in fig. 3. The product design is then compared to these needs, and the respective engineering needs that have an influence of satisfying the change are found and listed (m). These engineering needs are typical related to the products geometry or material (for example length), by physical laws. Often may the customers needs be satisfied by adjusting more than one variable. A mark (x) is used to illustrate the link.

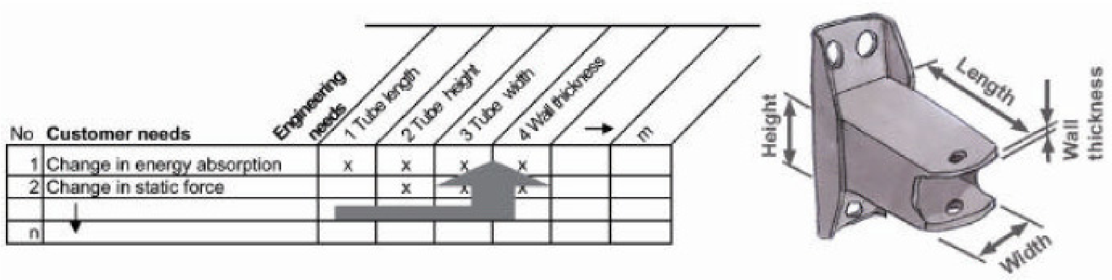


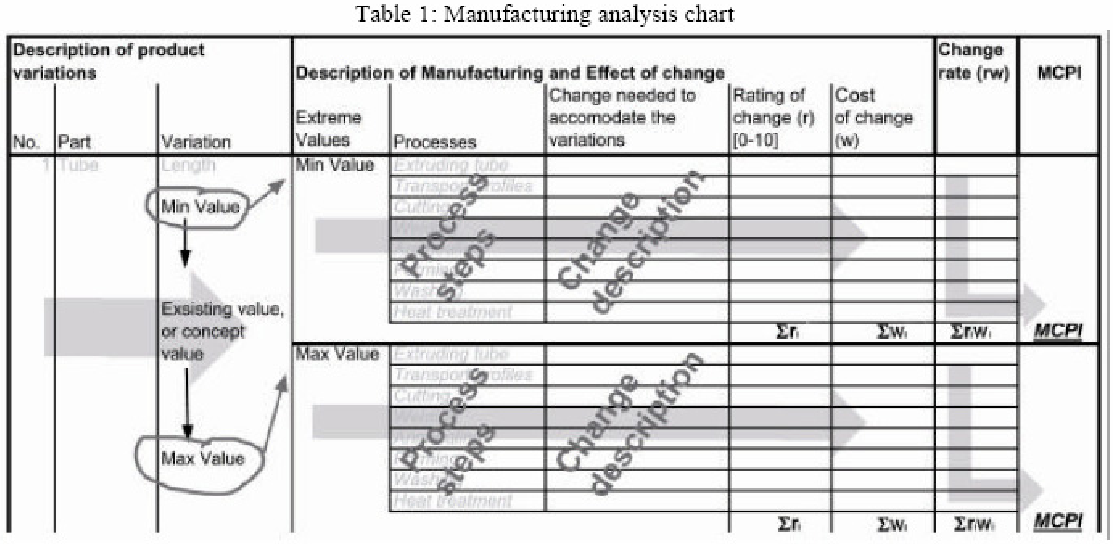
Figure 3: Customer needs mapped to the related Engineering needs

2.2 Step 2: Manufacturing change performance analysis

The second step is to perform the analysis and find the MCPI's. The flexibility of the platform is compared with respect to the chosen engineering needs, in step 1. By walking through each column in table 1, engineers are exploring the behaviour of the design and the belonging manufacturing process. The analysis table, consists of two main descriptive columns; Description of product variations, Description of manufacturing and Effect of change, and the calculation. The MCPI is calculated from a rating and cost (weighting) of each process steps the part goes through to be a product. Description of the columns is as follows:

Description of product variations: This main columns consists of three sub-columns; *No.*, *Part*, and *Variation*. The *No.* indicates which of the engineering needs that are analysed. The *Part* describes which part or section of the product that needs to be changed to accommodate the customer needs. In the *Variation* column the type of variation (for example length) is described as well as the chosen variation band. Both the decided minimum- and maximum value must be specified and the already specified value on the platform should be indicated. Both extreme values should be selected wide, in order to investigate the solution space for the product platform. The transition within the band is either smooth or going in steps, depending on the product design and the manufacturing. This is indicated with, arrows for smooth transitions and double pointed line for steps, which gives a better visual view of the type of variation.

Table 1: Manufacturing analysis chart



Description of Manufacturing and Effect of change: This column consists of five sub-columns; *Extreme values*, *Processes*, *Change needed to accommodate the variations*, *Rating of change* and *Cost*

of change. The *Extreme values* are directly transferred from the variation column to the min and max analysis. In the *Processes* column all the process step for the part and its belonging assembly processes is listed. They are identically repeated for the last extreme value. The detail level of the process should be at the same level for all the engineering needs analysed, in order to compare them better.
The *Change needed to accommodate the variations* is a field that describe the change each process steps have to accomplish, in order to satisfy the design as it uses the min/max value. This first evaluation of the manufacturing process is done by stating the change in a written form. The designers imagine that the proposed design is scaled to the min and max value. Such a design change, generate possible adjustment or challenges for the available manufacturing equipment. The change may lead to changes in one or several process steps, depending on the sensitivity the variable has to the production. These change are described to give the evaluation a written statement that later can be used by the numerical evaluation and give a traceability for the rating and MCPI index. The numerical rating follows the regular way of evaluating concepts and design, with a *Rating of change* and *Cost of change* columns. The rating is partly inspired from the Use-value analysis described by [Pahl & Beitz 1996] and is done with a scale from 0-10, as illustrated in table 2. The *Rating of change* column rate the difficulties it is to accomplish the needed change, as described in text form.

Table 2: Rating description

Rating	Description	Comments
0	No change required	The proposed value does not introduce any change in the existing process
1	Very minor	The change introduce only some minor adjustment in the exsisting process
2	Minor	The change introduce only minor adjustment and minor changes in fixture equipment
3	Very low change	The change introduce the need for adjustments, low changes in fixturing equipment, minor tool changes
4	Low change	The change introduce the need for changes in fixturing equipment, tool changes
5	Moderate redesign	The change introduce new fixture, changes in the tool and other minor changes
6	High level of redesign	The change introduce redesign of the tooling, based on exsisting solution
7	Very high level of redesign	The change introduce total redesign of the tooling and the related equipment
8	Total redesign with some reuse	The change introduce redesign of the process, but the equipment can be reused (tooling is replaced)
9	Total redesign	The change introduce redesign of the process, but the main equipment can be reused (tooling is replaced)
10	Total redesign of process and tools	The proposed value introduce total redesign of the process and the need to invest in new machine equipment (and belonging tool)

Cost of change is indicating the relative cost of doing changes to the process steps, without relating it to the rating. Each process steps needed to produce a product have usually different complexity; some steps may be cheap to change while other is costly to do only minor adjustments on. To capture this difference in cost of change, each process steps is assigned a percentage of 1. This percentage represents the average cost of change to adjust or replace the specific process steps. 1 is therefore the assumed cost sum for the complete manufacturing processes. This gives the opportunities to include all type of process steps, from small and simple to very advanced. The process steps that are costly to change are given a high percentage. The same weighting is always repeated, when the manufacturing sequence is the same. The evaluation on both extreme values uses therefore the same weighting.

Change rate: This column indicates the change rate each processes is given, by multiply the value of *Rating of change* and *Cost of change* columns. These values are summarised and gives the un-normalized MCPI index.

Normalized: In this column the summarized change rate index is normalised and gives the MCPI, for the manufacturing process. The index is calculated according to equation 1. and is normalized with the ideal solution (score 10 with this rating). Where r_i is Rating, w_i is Weighting and N is the number of process steps.

$$MCPI = \frac{\sum_{i=1}^{N} r_i w_i}{10 \times \sum_{i=1}^{N} w_i} \qquad ($$

A low MCPI index indicates that the change is easy to accommodate and has a low cost related to it. The lowest value is 0. A well designed product platform has therefore a low MCPI index related to the important variable parameters. In the opposite case a change that need a comprehensive redesign of all process steps will have an index of 1.

3. Example of the MCPI on structural car parts

In this example the MCPI method is applied to crash box platforms. The MCPI method is illustrated completely for one platform and the results from three other product platforms is graphically compared. The crash boxes are build from one or several highly formed and shaped parts, as illustrated in fig. 2.

Step 1: Identification of the customers needs. In this example these needs come from the car manufacturer. Some of their needs are related to the energy the crash box can absorb in a crash, the static force needed to start deformation (secure that the box deform first) and packaging (the allowable space, avoid conflicts with other parts). Mapping these customers needs to engineering needs gives us different parameters to vary, as illustrated in fig 3; Tube length, Tube height, Tube Width, and Wall thickness. As illustrated with the mapping, customer needs may be related to the same engineering needs, introducing several possibilities of satisfying that need.

Step 2: The MCPI table is illustrated in fig. 4. for one of the engineering needs and the graph shows them all, as specified in step 1. The analysis presented is done with the engineering need, Tube length. The variation of the Tube length is in this analysis defined to span from the minimum length of 50mm and to the maximum of 200mm. If the product platform can handle this range it will have the opportunity to handle a wide spectre of energy absorption capabilities and be a versatile solution. The existing product on this platform has a length of 170mm, as indicated in the Variation column (the middle value). The length variation can be redesigned to accommodate all length between the boundaries, indicated with arrows, but there is need for a major shift in equipment above 170mm. This is indicated with a statement.

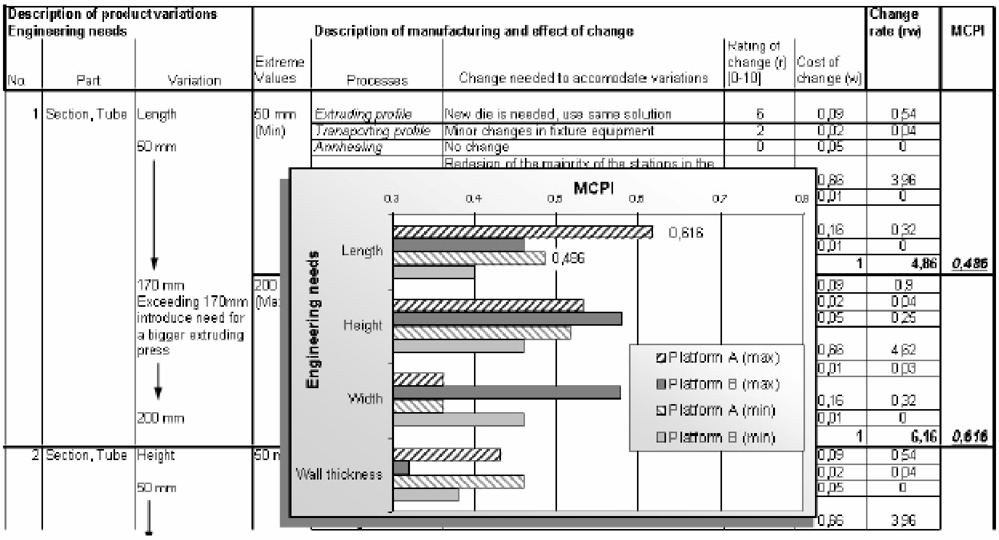


Figure 4: MCPI's for a crash box platform and these indexes are compared to a different product platform

In the description of the manufacturing and effect of change columns, the platform is analysed with the extreme values specified (50mm and 200mm). In the section of processes description, all forming, assembly and the major handling processes are listed. When the design is altered from today's tube length of 170mm to 50mm a new extruded aluminium profile is needed. The design can not be changed for this variation without having a new semi finished material (aluminium profile). This generates the need for a new profile die for the extruding process. In this case, it can be developed from existing knowledge. Information like this is written down. After stating the needed change it is given a rate according to table 2, and it coincidence with the value 6.

The estimating of cost of change value, in each process steps, is done by comparing all the processes and find their average cost when the station is adjusted or replaced to new variants. This information is then scaled to match the total sum of 1. A process steps that is costly (high investment) or difficult to change (work consuming) are given a high value. These estimations must be done on the assumption of the average cost of change, and not linked to the rating. The change rate is calculated and in this case the MCPI index yield 0.486 (min value) and 0.616 (max value). This indicates that a change in reducing the length of the tube is much easier than lengthen it. Why this is the case should be part of the process description.

The graph presented in fig. 4, illustrates the MCPI for several engineering needs analysed for two different product platforms. The x-axis indicates the calculated MCPI and the y-axis list the engineering needs that describe the variation for the platforms. The platform analysed in the MCPI table is named platform A, and is presented together with platform B in the graph. Platform B is a similar product, but has differences in the manufacturing. The same type of analysis performed on both platforms gives indications on what variations that is easy to change and the difficult one. The increase in length variations for platform A is considerable more difficult to provide than for platform B. Comparing the two platforms when it comes to the variation width, platform A is significant easier to make changes to, both when it comes to increasing or decreasing that dimensions.

An example on using the MCPI method to compare different processes for the same product design is illustrated in fig. 5. The analysis is performed on crash box platform B and B*. Comparing the end product gives no indication that there should be differences in the production, but the number of process steps and sequence is different. The MCPI gives different values for how easy/difficult the change of the length is. Increasing the length of platform B* is the most difficult, while it is the easiest to shorten. Platform B is also easiest to shorten, but the difference in shorten or lengthen it is small. What to choose, must be evaluated when all variable parameters and their extreme values are compared.

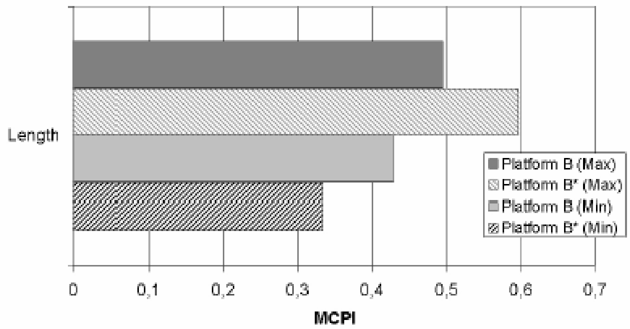


Figure 5: The MCPI used to illustrate the effect of changing the length, when different processes are compared, for the same design.

4. Discussions

The products that we are surrounded with may be categories as change-, variety intensive, simple and dynamic [Sandeson and Uzumeri 1997]. Products often found in variety intensive consumer products (for example hand tools) are often made of "simple" parts. Towards the category simple (few types) one might find more complex products (for example structural car parts) with a slower changeover. Typicaly related to high volume production, where investment in equipment and process knowledge is large. Most of the existing methods use a decomposition approach, exploring the end product and then created the platform and family. This approach will not capture the processes and knowledge that lies behind each part. For products that have "simple" parts this is perhaps not so important, but for other, this is perhaps the most important aspect in platform design. Process intensive products have often the need to have high investments in manufacturing equipment and the knowledge to operate them. Taking this into account should be part of the product platform definition. The MCPI methods deal with this aspect. The method capture both the designs ability to adapt to changes and the manufacturing responds to the changes. In order to use the method properly a detailed knowledge about the processes is needed. Since the effect of the chosen parameters and their value must be evaluated. The method do however not treat the full effect of, change in one parameter and the introduction of needed changes in the neighboring parts/sections. One way of handling this is to introduce a comment to the description of the variance and process.

Under evaluation of new concepts the method gives several opportunities;

- The MCPI method can be used to explore the best suitable combination of common and variable parameters. In step 1. of the method the different customer and engineering needs is listed. Exploring each variable, giving a view of the changability to the variation parameters and hence which should be chosen.
- The MCPI method can be used to find the best suitable product platform for the existing manufacturing equipment. The type and value for the variations parameter are then very central. By finding the extreme values, the capability of the existing equipment and products is known and products can easily be derivate with low risk. If on the other hand the product required properties outside the checked range, it may need new investment and perhaps more research, leading to increased risk.
- Designing the product family and the belonging manufacturing process from scratch, the MCPI method can be helpful in finding the appropriate manufacturing equipment. Different manufacturing processes can be checked out, with regarding to their ability in handling the required variance. As the process sequence is established the product platform has been specified and hence is it possible to invest in production equipment that is not oversized. Production equipment that has a higher flexibility that is needed is usually more expensive in investment and may have a lower production rate.

The use of a rating and relative cost of processes, gives good sensitivity to capture large changes or very simple changes, in the manufacturing. The index in it self does not capture if there is one process steps or many small changes that together give the high MCPI index. Only way to verify this is to look at the rating and written comments. Using the written information should also be part of the evaluation of equal indexes. When performing the analysis it becomes important to state and be aware of jumps in technology or equipment need as the parameters values varies. Since this model uses a cost system of total 1. distributed across all processes, comparing different product platforms should be done at the same detail level and cost distribution of the same processes as equal as possible.

5. Conclusions and further work

In this paper we have shown an approach to evaluate product designs from a manufacturing point of view. The method explores the match of the product design and possible variations by looking at the respond from the manufacturing processes. This way of looking at variants in a product family is well suited for products consisting of a series of processes steps. Companies with such products can use the method to explore their design's solution space and find the most suitable way of providing variance to the customer, while securing high internal commonality. A known solutionspace for the design gives also opportunities for quicker release of new variants with lower risk. The method evaluate each manufacturing process steps individually with respect to the parameters providing variation, indicating how easy or difficult the change is to fulfil. By having this type of performance description linking product design and its belonging manufacturing, one might explore different manufacturing processes, evaluate the solution space for different product platforms and finding out how flexible the manufacturing equipment should be. This MCPI method moves the design knowledge for product platform to also including the manufacturing processes, as often neglected by "part reuse" methods.

Further work will be done on setting the method in a more holistic picture, where the manufacturing processes is included as a more important member in the creation of a product family. Opening up the possibilities to swap the cost of change system over to handle real costs, would also be interesting. This will give data that is more accurate and capturing major investment steps better.

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Appendix III: Designing product families: experience of four Norwegian manufacturing companies

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DESIGNING PRODUCT FAMILIES: EXPERIENCES OF FOUR NORWEGIAN MANUFACTURING COMPANIES

Tormod Jensen, and Cristian Nilsson

Keywords: Product families, Product platform, Platform description, Design for variety

1 Introduction

Highly competitive global markets force companies to change their way of doing business. A major trend when designing product families is an increased interest in using product platforms. The large automotive companies where early in adopting platform and modular strategies to improve the economies of scale, but now also smaller companies and suppliers with less complex products find interest in this way of designing products. A constant focus on cost reduction and increased global competition leads the way to designing the products in a smarter way. The purpose of using product platforms is to increase variety for the customers and simultaneously improve the internal re-use from components to peoples know-how.

Definitions of product families and product platforms have been presented in the literature of the last few decades. Sanderson and Uzumeri [1] define a "*product family as a set of models that a given manufacturer makes and consider to be related*". This is a very broad definition, but by adding the need to have a high degree of reuse in creating the product variants, Maier and Fadel [2] define a product family as "*... a group of products that shares some common technology*". This family may be designed with modularity and product platform approach. Modularity is defined by Ulrich and Eppinger [3] "*as chunks (subassemblies) that implement one or a few functional elements. The interactions between the chunks are well defined and are general fundamental to the primary function of the product*". A well designed modular structure can allow changes to one chunk without affecting the rest of the design. Product platform is by Meyer and Dalal [4] defined as "*a common subsystem or subsystem interfaces that is leveraged across a series of individual products by means of shared product architecture*".

The definition of product platform that is used in this article has been proposed by Robertson D. [5], "*the collection of assets that are shared by a set of products*." These assets can be divided into four categories:

- Components - part design of the product, tools and fixtures
- Processes - the equipment used to make or assemble components into products, the design associated production process and supply chain
- Knowledge – design know-how, technology, applications and limitation, mathematical models and testing method
- People and relationships – teams, relationships between team members, relationships between the organization, customers, suppliers and the design team

A more comprehensive discussion about platform definitions is presented by Kristjansson et.al. [6]

Much has happened since the mid- nineties regarding product design strategies. Establishing the correct product architecture for the product family is a difficult task, and different approaches have been presented to create the architecture using modularity [7], [8] and platform [9], [10]. Several authors have looked at how the industry implement and use these design concepts, among them Tatikonda [12] and Muffatto [13]. They have examined the planning and execution of different types of projects within a product family platform series, from a strategic viewpoint. Juuti [14] takes a broader view; including the whole value chain and look at how capable and mature the organization is to utilize the concept of platform. Other authors like Halman [15] have looked at how the development organization implements platform thinking and the risk they encounter in the process. Most of this work is related to industries that mainly consider the platform to be an aspect of the product architecture, and ignore many of the other possible aspects of platform strategies referred to in literature. The product architectures referred to are also often of the type aimed at the end customer and were the companies decide most of the product requirements themselves.

The objective of this article is to explore how consumer-sale companies and OEM-suppliers (original equipment manufacturer) use the concept of platform in their product portfolio. The focus is on how the companies use and structure their know-how in order to establish a productive product portfolio. The following two research questions are explored; how can the concept of platform be applied in different industries and products? This is an attempt to investigate if there are different ways of utilising the concept of platform, depending on the type of industry, if they are a consumer-sale- or OEM-supplier company and if the complexity of their products varies. The second research question; how is the platform knowledge communicated in the companies? This question tries to sort out how the communication and understanding of the platform is done internally in the companies, among designers, and between designers and manufacturing, managers, suppliers and so on.

2 The study

The study is based on a series of interviews. Four companies are analysed: two OEM-suppliers, Hydro Automotive Structures and Kongsberg Automotive, and two Consumer-sale companies, Ekornes and Stokke, which produce relaxing furnishes. All of these companies are located in Norway, a country with high labour salaries and relatively long distances to the global customers. The customers are mainly in the European Union, but also in the USA and Asia. They all have a long logistic chain in order to reach the market.

2.1 The methodology

The research methodology was chosen to include both consumer-sale companies and OEM-supplier organisations, in order to highlight possible differences in the use of platforms and in the role of platform design.

2.2 Data gathering

The study is based upon 9 interviews, in Hydro Automotive Structures, a business unit within Hydro, Kongsberg Automotive, Ekornes and Stokke. The interviewed persons where partly selected by our contact person with the company or by direct contact by us. The interviewed persons were primarily managers and senior engineers all working with product development or in R & D departments. Most of the interviews were performed individually and in their working environment. All the persons were males and were either with a doctor's degree in engineering, graduated engineers or engineers that had worked their way up from apprenticeships. All of them have been working in the company for many years. Each interview lasted from 1.5 to 3 hours. The interviews were focused around one of each company's products, in order to be able to dive deeper into the development process and the companies' overall way of doing things.

2.3 Data analysis

All the interviews were transcribed in order to perform a detail analyse. The questions and responses were classified and grouped by topics, based on Robertson's [5] lists of core assets (components, process, knowledge and people & relationships).

3 The studied companies

All the studied companies have long tradition in making their products and all have long time market experience. For the moment all of them are doing well and seem to have good profitability.

3.1 OEM-suppliers to the automotive industry

Hydro is a large oil and aluminium company, with activities in all parts of the world. Within the aluminium business they are a manufacturer of aluminium as a material, semi finished products (sheets and extruded profiles) and final products. The business unit in the study is Hydro Aluminium Structure (HAST), which manufactures automotive crash management structures such as bumpers, sub-frames, and whole space frames. The production volume varies from low to high production, were bumper structures are in the upper end. It is the bumper structure design and production that will be discussed further in the article and this is HAST's main product, fig 1. A bumper system is placed in the front and rear of the car, and consists of a cross beam and crash boxes at each connection points to the chassis. The system is designed to absorb the energy from a 16km/h offset crash, without damaging other parts of the car structure. The products consist of few, but highly formed parts. The main technology in these products is in the material properties, the forming ability, the lightweight design and the integration of these into products with high energy absorbing capabilities. HAST delivers these types of structures to a majority of the European car makers. These structures can be found in all from low-cost- to premium-brand cars. Each product is customised for the customer, leading to a large number of product variants, approximately 70 new variants pr. year. The customisation of the products is a must to be able to be in business, and is not seen as a problem. All products have in common that they must fulfil the same government and insurance tests.

Figure 1: Bumper system and position in the car

Kongsberg Automotive (KA) is also a global first-tier supplier, which manufactures gear shift systems, seat comfort systems and commercial vehicle systems for the majority of the car and truck producers in the world. Commercial vehicles systems include, among other products, the clutch operation system, fig 2. The clutch servo reduces the pedal force needed to activate the clutch, making it more comfortable for the driver to change gears. It is the servo unit that will be presented further in the article. The servo uses pressure air to boost the hydraulic pressure from the clutch pedal. KA manufactures this product in many variants, fitting all from small to large trucks and busses.

Figure 2: The clutch operating system and the clutch servo

3.2 Consumer-sale companies

Ekornes ASA is the largest furniture manufacturer in the Nordic countries and owns, several brands among them Stressless®. Stressless is one of the world's most famous furniture brands. Ekornes is located in an outskirts part of Norway, with fjords and high mountains, putting an extra demand on transports. Their main product the Stressless, fig. 3, is a collection of chairs and sofas with multiple functions as tilting back rest and adjustable head rest. The Stressless products are produced with a relatively high variety for the customer, while keeping a strict control over how these variants are created. The production volume of the Stressless is around 1100 chairs per day and 100-200 sitting units of sofas per day. The development and management of Stressless furniture will be discussed further and this is also their main product. The company designed their first reclining chairs in 1971. It was delivered in few variants and the production volume was high. The sales and profits were good, but as time passed a more modern look was needed. The chair went through some changes, without adding too many variants, until the mid 80-ies. Releasing new and exciting products to the market was seen as a way to improve the sales. Highly skilled industrial designers created many new products. Unfortunately most products were created with individual industrialising terms, resulting in an inefficient production. Six different manufacturing processes were handled which dispersed the product portfolio. Time spent at production on ramping up for new models and changes between them, was becoming a problem. The volume manufactured on each component fell and the cost of producing a chair rose. Ekornes was technically bankrupt in 1990, and some major changes were needed to save the company

Figure 3: Stressless® chair and sofas, all seats have tilting back rest.

Stokke is also in the furniture business, located close to Ekornes. They are smaller than Ekornes and focus their products towards a different customer group. They have two product assortments, one for children (chairs and beds) and one for adults called the Movement collection. The Movement collection focuses on allowing the user to always to find a new sitting position. The form and colour of these chairs appeal to a narrower customer group willing to have something special, while not compromising on correct sitting. Stokke launched Europe's first adjustable recliner and have continued to develop functional and modern chairs, fig. 4.

Figure 4: A reclining chair, model peel™

To get an overview of the key values for the four companies, table 1 present the operating revenues, net profit and number of employees.

Table 1. Key values for the companies in 2004, * = HAST is a sub units within these numbers, ** = 2002, based upon 1€=8,47NOK

	Hydro, extrusion and automotive*	Kongsberg Automotive	Ekornes	Stokke
Operating revenues (€, million)	3258	261	267	84**
Net profit (€, million)	32.7	31	40.5	-
Number of employees	-	2265	1546	460**

4 Platform interpretation

The purpose of product platforms is to create variety for the customers while keeping a minimum of in-house variety. Increasing the reuse in as many assets as possible is important to improve the company's ability to perform well on the global market. Regarding product platform design, Robertson [5] defines assets in platform design to be more than standardisation of components, as mentioned before. He includes components, processes, knowledge and people & relationships. The analysed companies do the reuse within these four assets in very different ways.

Their own perception about how they design and manage their product portfolio is partly the same as found in literature, although the term "platform" is not widely used. Ekornes focuses on standardisation and establishing industrialised conditions for the products. Stokke have their attention on creating attractive and functional products that fit within their supply chain. Stokke has a well-functioning network of suppliers of competence and components. KA uses the concept of platform, as KA has positive experiences from designing the servo product around a platform. The term "platform" was however not used until recently, when a new family of products was designed. This product family was designed with a variation strategy from the beginning. HAST has a strong focus on optimal use of the production lines. Products as the bumper beam are therefore designed to fill the production lines. HAST also has a new product family, crash box, which is included in the bumper system. For this product, HAST is in the process of designing a product platform architecture.

4.1 Components assets

Ekornes is a company that has first hand experience with both loose and strict control over the product variants. In 1992 they restructured their product portfolio and a standardisation process was started. In 1993 this process had removed 75 % of the components, meaning higher volumes for each component. The focus went then from removing components to optimising them for manufacturing and focusing the variants to different customer groups. The product platform was based upon components standardisation and postponed differentiation in how the variants were created. A central technical aspect of the platform is how the design of the undercarriages, steel frames and foaming of the seat is tuned to fit the automated production line. The chairs are created in three different sizes, were the width is the variable parameter. This parameter can easily be varied without having too many adjustments to the production line, since all the interfaces between the components are kept constant. The main differentiation of the product portfolio happens when the final foam and leather/textile is assembled, but even here Ekornes is strict about standardisation, as the development manager says:

A new colour is a variant and we must also at this point think standardisation. The standardisation must not slip at the last segment. If we can remove more variants than we replace, that is desirable.

Ekornes is in a position to have full control over their product portfolio. They can decide when a new product is to be released or taken out of the market. The customers are not interested in an excessively fast turnover of new variants, so only a limited number of variants are changed each year. This, combined with the high level of component standardisation has reduced the production cost so much that the high employee salary in Norway has little influence on the final product cost. Ekornes has also arranged so that most of the manufacturing is in-house. Because of the high volume of products Ekornes produce, it can arrange an efficient logistic chain to the customers.

Stokke has a different strategy for running their business. Stokke does not have a product portfolio based on reuse of high volume production. The products are produced in low volumes and target a niche in the furniture market. They have strong focus on creating chairs that allow multiple sitting positions. By having special competence around the critical parts that allow the movement, Stokke can use external consultants in the design process, which give the chairs a very unique form and identity. The use of external consultants helps Stokke to push the chair design front. One very vital part of their way of doing business is a lean supply chain and manufacturing on-demand. Transport is done by road, and although delivery can take several weeks, the supply chain is considered sufficiently fast by the customers.

Kongsberg Automotive is also a company that has a long tradition of making their products, like the clutch servo. The design of the servo first appeared in the 70-ties and has evolved since then. The product is built around a scalable platform, with approximately 200 variants, partly illustrated in fig. 5. The high number of variants is needed to satisfy the different customers and their truck models. The customization is mostly related to the response the truck driver wants to feel, the servo force needed on the clutch and the servos interconnection points (fluid-, pressurized air connections and mounting connections) to the gear box. The product is built around a large cast component, fig. 2, which is customized with minor changes to meet the customer requirements. This is also the most costly component in the product, since it requires an expensive die-cast tool. Adapting the most complex component each time might seem unwise to an outsider, but the main technology in the product is actually related to some interfaces within the product. Although these interfaces connect relatively inexpensive components, they have very strong links to the overall functionality and quality of the product. The products have long lifetime, approximately 7-8 years before a mid life update and another 6-7 years after that. In addition KA must often supply spare parts for up to 10-20 more years.

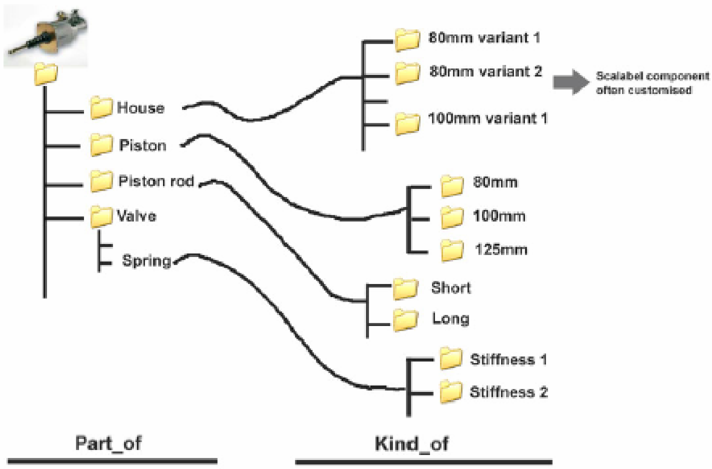

Figure 5: Part of the product architecture to the servo, illustrated with the Product Family Master Plan [17]

Hydro Aluminium Structures has a different approach to the use of their product platform than the other companies have. Their products have a very high degree of customization, more than all the other companies in this study. The customisation is also of the character that it is not easy to accommodate in the final assembly step. So the customization is performed early in the design process, with close contact with the customer. As the customers develop each new car, for example over a 4 years period, there is a lot of parallel design of components and therefore the customers often change the functional and packaging requirements several times after the design work has started. As early as 1969 Hydro started to manufacture the bumper beam and have now managed to gain large market shares for their product. The HAST product platform could be characterized as being several technological concepts that are adapted to the customer, but can be manufactured with minimal investment in tooling for the production line. HAST's portfolio of bumper systems is very large, both regarding the total number of product variants and their production volume. The variants vary with regard to, for example, if the product is aimed at a European or a North American car, the required energy absorption capabilities and the chosen manufacturing processes. The production volume ranges from 1000 to 800 000 units for each product variant. This type of portfolio makes it possible to design the products to suit one of the production lines, and secure that the all lines are filled with appropriate products.

The other part of the bumper system, the pair of crash boxes, is a component that appeared in the mid 90-ties, as the focus on crash behaviour increased. HAST started the product development, from scratch. The first generation of crash boxes had good performance, but the industrialising processes chosen have proven to be too expensive. The next generation of crash boxes will have a better match between the product architecture, flexibility of design, industrial premises and cost. The portfolio is redesigned to accommodate more of the platform capabilities they have achieved in bumper design.

4.2 Process assets

Ekornes has a component-standardized product architecture that is very suitable for the production process. Production is designed around a postponed differentiation of variants and is highly automated. A new factory has been built to optimize the material flow and establish the best premises for automated production. For example, most of the work on wood and metal structures is done with robots, making an earlier expensive structure much cheaper. They also focus on having as much of the activities related to the product under their control and close to the main factory. Thus, the logistics internally in the company are reduced and the external supply chain is simplified. The supply chain uses both ship and road transport to and from the factory.

Stokke is at the opposite end than Ekornes, with the production based much on manual production. Stokke uses many specialized suppliers that do similar work for other furniture companies. The suppliers can thus have continuity in their work.

KA focuses on manufacturing the main part of the servo in–house (cast house and piston) and outsource the other components. The cast servo house has several surfaces used at manufacturing and for test set-up. These are kept constant through the product variants, making the manufacturing sequence and testing less sensitive to new variants. As the largest servo was designed, additional fixture surfaces for the manufacturing were established. This can be seen as a generation update of the platform, since the production technology also has improved over time. Several of the cast house versions have also from the beginning been designed with multiple connection possibilities for hydraulic fluid and pressure air and they are machined open according too the variant produced. KA aims at reducing the stock of semi finished products as well as cast dies to a minimum.

At **HAST** the manufacturing process is a vital part of the product platform. It starts with the material used. Since Hydro also is a primary manufacturer of aluminium, a melting factory for a special alloy is located close to the production site of both the semi-finished products and the final formed components. The bumper beam component is made of stretch formed extruded aluminium. This is an advanced method of forming semi-finished products into the final product shape. Through many years, HAST has managed to standardise several elements in the design and production of these components and related tools. Several lines have been designed, each with a different number of forming steps. The designers can chose a production sequence in the design phase, which matches the required production volume. HAST invests heavily in production equipment and can handle high volumes, provided the lines are up running most of the time. For the crash box, a good match between the design architecture and the manufacturing process (like for the bumper beam) has for the moment not been established. Another challenge that HAST has concerns the assembly of the system, which often is done close to the car manufacturers plant. The components must thus be designed and manufactured in a way that makes it possible to assemble them after a transport and still be within the required tolerances and product performance boundaries.

4.3 Knowledge and product information

The market division at Ekornes plays an important roll in maintaining the product portfolio. The product development manager can get full access to sale statistics to each product variant, statistics about each of the 2500 Stressless shops world wide, and information on the type of marketing campaigns that have been done at each shop. Product variants with falling turnover are investigated. Action is taken with additional marketing to extend the product life or replaced with a more modern variant. New variants are specifically designed to target the same customer group as their predecessors, without affecting the sales of the other variants. The product development manager expresses the market orientation of the product design as

"We have a product development division that has an industrial anchoring, but also has a connection to the market that makes us able to create modern and timely products that can be industrialized on a rational way."

When it comes to stored product information, electronically or on paper, there is a large difference between the furniture- and the automotive industry. In the furniture industry the products are not so technically complex, so most of the documentation is sale related. They rely very much on previous experience people posses and perform only some simpler tests to verify the product. Ekornes has in the group objective and values written down a product strategy emphasize designing with product platform. The technical product information to both Ekornes and Stokke comes from CAD systems and outside that little information related to product platform is stored. A product developer at Stokke said

"To find an appropriate level of documentation, we have to weight the time spent on documenting against the risk of having too little documentation."

In the automotive industry the product knowledge goes much more in depth than in the furnish industry, meaning there is a bigger need for technical documentation. Furthermore, the automotive customers have requirements in how products should be documented and quality guaranteed.

At **KA** the product platform of the servo is based upon an old concept. Through the years they have gained knowledge from their own tests and customer's feedback, refining the technology within the product. A lot of development and tests, both simplified tests and on years-long road tests make the foundation for the technology. Even minor changes to the design, can trigger the need for new testing. Testing is time consuming and very expensive, so keeping it at a minimum is much more important for the platform cost than strictly focusing on components reuse. The database with test results has become very large and to extract the correct information for reuse in new projects is sometimes found to be difficult. For the earlier product versions the test information may not be stored with sufficient product data to be fully reused as documentation for new variants, since testing has become more demanding over the years. The customer usually requires that the product goes through a long run test that last years before it enters the market. Changes during this period are usually not allowed. KA has also tried several methods to secure that the platform is used as best as possible, in addition to the existing quality systems. One method tried during the 90-ies was to write down why changes were made, on detailed level. This should then simplify the design work next time, but it became quite time consuming and it was found difficult to retrieve the wanted information from the database later on due to difficulties in organizing the information in a good seek able manner. Nowadays the most important information from the development projects are stored in a "Book of experience", which is a few pages with relevant information which the project leader for a new project shall read prior to starting up similar projects. To stay in the upper front of servo design, KA's products are constantly benchmarked against competitors'.

HAST products are designed to have excellent performance in both low and high speed crash, yet having a very low price. The complexity in design is to control every aspect of the aluminium's temperature- and forming history far down into the micro scale, through the whole process. Simulation is therefore done among in the manufacturing forming steps, assembly (welding) and on the product level, so that the final crash behaviour and the product cost are optimal. The high number of projects per year makes it important to routinize parts of the design process. For example, for the design of a new bumper beam variant, several starting models (CAD models), from previous projects are used in the early design phases. They give valuable information about crash performance, mass of material used, manufacturing steps needed and cost. Several systems assist the communication between departments and disciplines. One of them is a detailed description of all the production lines aimed at having designers as users. These descriptions go in depth around the manufacturing possibilities and limits. This system is maintained by the manufacturing process departments. To further improve the reuse of experience and knowledge, a "design portal" is under development. This is a place for the designers to get ideas and use previous experiences to avoid pitfalls, etc. Behind this portal there is large amount of data from many projects down to a very detailed level, for example related to simulations, physical tests, and production experiences and so on. This design portal is seen as a tool to secure correct reuse of product and process experience. HAST's primary reason for a detailed documentation is that they are a large product development organization, spread around in different countries and wants to avoid doing the same mistakes several times.

For the crash box component the experience is far lesser. A concept that can function as a design platform has not been established and the structuring of design knowledge is only just began. Even if these two components (beam and crash box) use much of the same basic technologies, they are implemented differently and this causes challenges. The crash box interaction with the manufacturing is very different, due to how the assembly is done and the design of the very complex stamping tools.

4.4 People and relationships

Ekornes and the Stressless product is a good example, in how to see that industrializing the product is one of the key areas in product platform design. For a period the industrial designers had a lot of influence and they did not understand the mechanisms that provide efficient production. But after that the organization structure was changed to match the product platform developed. The product development organization was organized as a factory within the factory, with all phases of the production represented. Skilled persons from the production were transferred to the development organization. The use of external consultants was abandoned and the internal designers focused on matching the design to the production line and securing that all the people within the product development factory knew the company's industrial premises. As the platform was introduced there was a change in the decision structure. All new product variants must be accepted by the product development manager as the first step. Then a product council decides which variants to display on a furniture exhibition and with the response from customer a new collection is chosen. The council consists of people from the marketing, production, product development and executive directors. There are no other people from the financial departments other than the executive director of the company in the product council. This composition of the organization and council is done to secure that new product variants fits within their industrialized processes and secure the future.

At **Stokke** the product development group is small (9 people) so the internal communication of knowledge and experience float easily. Since they use consultants to design the form of the chairs, they have established a very efficient contact network of people who are expert in different engineering and manufacturing fields. People from the product development team train also the sales people so they get in-depth knowledge about the products.

KA has from their early day's had a fluent contact with their customers. As the product is tested and verified by the customer, a change is only done if highly needed. It would increase risk which can only be reduced by new testing. This is mutually understood by both parties. The platform technology and associated processes is developed primarily in cooperation between R&D and the model factory ("Center of Excellence") in Hvittingfoss. Then this technology and associated processes are emulated in the KA factories outside Norway.

In **HAST** the product platform is strongly linked to the management of the knowledge and experience people possess. HAST is an organization that has a lot of engineers and special competence on material (aluminum) property and manufacturing processes. Each new project is always manned with people from different disciplines. If projects run into design difficulties, people from other design teams are brought into the project to help, but in spite of this sometimes the designers miss a better flow of information across the design teams. To find new projects, the market department traces the market and contacts the potential customers who they know well. HAST is usually involved in new projects in their early stages. A car is developed through several years (cars around 4 years) and through this time the car design is very dynamic. The packaging and functional requirements change constantly as the development of the car progresses. Hydro must be able to customize their product platform to the initial requirements and to the changes that appear. They must be able to quickly change the design without altering the industrial premises. This process demands a close contact between people but also intensive exchange of product data. The customers to HAST usually conduct their own tests, both virtually and in physical models. HAST links their product models directly into the customers' systems.

Table 2 summarises the findings of how the concepts of platform can be applied to the studied companies.

Table 2. Summarise of the main characteristic of the companies platforms

	Ekornes	Stokke	HAST	KA
Components	High standardisation High tool re-use	Low standardisation	Low components and tool re-use	Medium re-use of components and tools
Process	Routines design process Vertical supply chain integration (in house) Factory adapted to platform	More flexible and informal design process High focus on supply chain	High re-use of design concepts / technology High re-use of manufacturing principles and infrastructure	High re-use of design concept / technology High re-use of manufacturing
Knowledge & information	"Culture" for industrialisation	Informal channels of knowledge communication Innovation intensive	Highly specialised know-how around material and product performance Much design data is stored	High re-use of product history experience
People & relationships	Strong link between product development and retailers	Strong network of suppliers	Dynamic and intensive communication with customers	Strong internal relationships also between global units

5 Discussion

All the companies in this study use the concept of product platform differently. Ekornes has adapted the principles of product platform for the whole company and use it to achieve a very high commonality internally and variations for the customers. The way Ekornes use product platform and organize their product portfolio is closely related to differentiating the product portfolio and remove components from the portfolio as found in articles from Meyer [11] and Mortensen [17]. They have the opportunities to utilize product optimization in depth, due to the full control over the product portfolio, when to release or remove products from the market. In addition the technology in their products is far less complex than found in the studied automotive companies. Stokke has a smaller product portfolio and manufacture their products in small volumes. They focus on designing and reuse key elements in the chairs, supply chain and then use externally industrial designers to create the form of the chair. They use a strategy that failed for Ekornes, but a success for them. Due to targeting product to a customer niche and how the product variants are developed.

The automotive industries are in a different position than the consumer-sale companies. Their control over the products, release of new variants is strongly related to the release of new car and truck models. The product platform is therefore used as a way to reduce the complexity, by increase reuse in the design process and reuse of production principles and equipment. Looking at relevant literature for utilising the product platform this way, Meyer [4] and Jiao & Tseng [18] discuss the use of platforms in industries that manufacture nonassembled products, as film and semiconductors. Their focus is mostly on establishing product and process efficient indexes. The author [19] discuss the designs variability and the belonging manufacturing flexibility for process intensive products, but still the amount of product platform research done for this type of industries is far less than for consumer-sale related companies. In fig. 6 modified version of Riitahutha [16] figure. The architecture is connect to three elements, increase variety, increase commonality and reduce complexity. In this study the consumer-sale companies seems to be most positioned between increase variety and increase commonality The OEM-suppliers more complex products (technology) work more on reducing design complexity and being able to do quick redesigns. There are always some requirements that will change with time and evaluated the product architecture solution space for such change, seams to be very important for the OEM-suppliers. The future is not easy to predict, but some requirements related to vital performance seems to follow certain trends. Doing reflections around the future is important. The invested capital in design, knowledge and production equipment is large and a long lifespan for the platform is preferred.

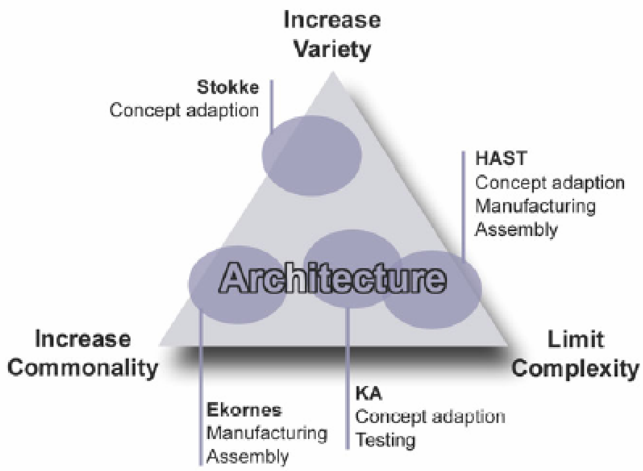

Figure 6: Dimensions in product platform development and the main focus areas for the companies in this study [16]

When it comes to communicate the platforms commonalities and distinctiveness, Ekornes has a strong culture driving for standardisation in all part of the organisation. The product complexity and turn over speed of new variants at Ekornes is thus limited, so the need for a large information flow is not as great. The product development management has good ability to control when new variants are released and old removed. All the other analysed companies the drive for standardisation is not as strong as Ekornes, but both at KA and HAST it are increasing. HAST who have so many projects each year, can not channel all information through a few key persons. They need to spread the knowledge and ability to decide on reuse issues to several persons. HAST and KA are both manufacturing on demand and having a system that supplies the designers with red (bad), yellow and green information from the existing variants, could be a way to improve knowledge reuse. Both have lot of detail information about each variant and on each component, but have improvement potential regarding the information flow.

6 Conclusion

This study has investigated how two different industries organizing their product portfolio to easy generate product variants based on platform. The term platform was found not to be so widely used, but more the concept of re-use of assets. One customer-sale company used the platform in a more concrete manner, with high focus on standardization. The automotive companies focused more to find reuse within other assets as knowledge, due to their high technological products. None of the studied companies had a complete description of their platform, but information was communicated on demand. The informants acknowledge the important and the challenge of manage product platform information, so that it easily can be stored and retrieved.

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Appendix IV: The Corporate Platform – a model to create a product program

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The Corporate Platform – a model to create a product program

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Abstract
Product platform and modular design methods have been used to efficiently create product variants. Modular methods have primarily been use to ease product variant configuration. Platform methods have been successfully used reusing assets among a predefined family of products. Design methods for non-configurable products that can not be defined in a predefined family have not been focused. This article presents a model framework of how companies can manage and structure their core assets needed to efficiently customize new successive non-configurable variants. Because variants are customized in a successive manner the company is continuously adding new competence that will be used designing new variants. This modelling frame is called Corporate Platform. The model includes alignment of four main aspects; Market, Product Platform, Manufacturing and Product Development into the specific product variants. By having a broader view and structured approach to product and product platform development increased reuse can be achieved.

Keywords: Product platform, Product variation, Design for manufacturing

1 Introduction

Highly competitive global markets force companies to change their way of doing business. A major trend designing product families is an increased interest in using product platforms. The major automotive companies have already adopted platform and modular strategies, in order to improve the efficiency. Now, also sub-suppliers and smaller companies with less complex products find interest in this strategy of designing products. The purpose of using product platforms is to increase variety for the customers and simultaneously improve the internal re-use, within the company. There are several definitions of a product platform in the literature. The definition used in this paper is proposed by Robertson & Ulrich [1] and is: "*the collection of assets that are shared by a set of products*." These assets can be divided into four categories:

- Components - part design of the product, tools and fixtures
- Processes - the equipment used to make or assemble components into products, the design associated production process and supply chain
- Knowledge – design know-how, technology, applications and limitation, mathematical models and testing method
- People and relationships – teams, relationships between team members, relationships between the organization, customers, suppliers and the design team

When it comes understand the complexity of product variants, regarding the product structure, several authors have proposed design methods. Sanderson and Uzumeri [2] talk about product variety and the change process of both the individual product variants and whole product families. They characterise products based on the customer type. Meyer and Lehnerd [3] present a model for how to target the different product platform and variants for different market segments as well as avoiding cannibalism. Mortensen et al. [4] have developed the Product Family Master Plan (PFMP) method, a method suitable to take "the big picture" of today's product family. The master plan gives both overview of the possible variation and commonalities. The mentioned methods do not include manufacturing aspects. Meyer & Dalal [5] and Jiao & Tseng [6] underline the importance of focusing on the manufacturing processes as an important aspect in platform design. For a modular design approach Ericsson & Erixon [7] have developed a method suitable of taking a broad view on the product variants and find the appropriate way of making the product family modular. The existing literature has though little or non-focus on how to create the product variation in a structured way for products not capable of being configured or modularised.

2 The study

The study was conducted in close relationships with Hydro Aluminium Structures (HAST), which manufactures automotive crash management structures such as bumpers, sub-frames, and whole space frames. The production volume varies from low to high production (->2 000 000 units), with bumper structures in the upper range. These products are characterised as being non configurable. Each product variant is customised, in order to fit the different car models. A very strict focus on satisfying the customers needs, have resulted in a product family that is based on many different industrial processes and is too costly to operate. The intention with the study is to develop a model, making it possible in a structured way to convert a product family over to a leaner product program. This by focusing on increased reuse of the assets the company possess, in a broader sense than only component reuse. These assets are based on the definition to Robertson and Ulrich [1].

2.1 Data gathering

The study is based upon workshops and a communication with the company for several years. It consists of 4 in-depth interviews, a case study and several earlier studies [8], [9] & [10]. The persons interviewed were primarily managers and senior engineers, working with product development or research. All of the in-depth interviews were performed individually and in their working environment. The same people also participated in the workshops. All the persons had either a doctor's degree in engineering or were graduated engineers all of them have been working in HAST for many years. All the interviews were transcribed in order to perform a detailed analysis. The questions and responses were classified and grouped by topics, based on Robertson's [1] lists of core assets (components, process, knowledge and people & relationships). Ideas and work were discussed and changed during the workshops. A close interaction with HAST was present at all time.

2.2 The product

The bumper structure with the crash box and respective production will be discussed further in the article, fig 1. A bumper system is placed in the front and rear of the car, and consists of a cross beam and the crash boxes at each connection point to the chassis. The system is designed primarily for two different requirements, a Danner test for the European car models and CMVSS requirements for the North American car models. Of these requirements the Danner is the most demanding requirements and is used for models operating on both the European and North American market. This test requires that the bumper structure absorb the energy from a 16km/h offset crash and leave the car's chassis structure undamaged. The core assets in these products is control of material properties, the knowledge of forming ability, the lightweight design and the integration of these into products with high energy absorbing capabilities Together these technologies allows HAST to make products that consist of very few, highly formed parts. HAST delivers these types of structures to the majority of the European car models. These structures can be found in the range from low-cost to premium-brand cars. Each product is customised for the car makers, leading to a large number of product variants. The customisation of the products is necessary to be able to be in business, and is not seen as a problem. All products have in common that they must fulfil similar regulation and insurance tests.

Figure 1: Bumper system consisting of a beam, two crash boxes and a tow nut.

3 The Corporate Platform model

The Corporate Platform model developed consists of four major elements related to the, Market, Product Platform, Manufacturing and the Product development. The product development represents the final customisation into the specific product variants, fig. 2. The model uses existing design methods in a new context, in order to improve the reuse of more than the components in a product family. All elements, except the final customisation are divided in two levels, a detail level and a more general level. Within each of these boxes there are several processes that should be carried out, and between them a flow of information. To visualise all the complex relationships that exist between the dynamic customer interaction and to the more static corporate knowledge this Corporate Platform model describes the major interactions. By understanding the interaction and what processes to go through the different elements can be mapped out. This should result in a more controlled product development, where there are clearer separations between research and development projects, resulting in lower risk and cost. The user of this model is the design teams and the managers affecting the structure of the product portfolio. The elements in the Corporate Platform model will be thoroughly described in the coming chapters with an example and below is an overview presented:

- *Market*; the market element is where the interaction with the customer appears. The customers have a request of getting a product that fulfils a certain set of functions. The model is based on structuring the product according to some vital product performances, lining up the market segmentation [11]. The customer and trends analysis provide data on the differentiations that the market segmentation should be built upon. All these anticipated demands on variation must be analysed, and a selection of functions should be targeted to fulfil. All this information is the fundamental for developing the product platform.
- *Product platform*; the market information is combined with manufacturing knowledge and the creation of a product platform and product variants is started. The first step is to establish the few basic features that can characterise the products and the ranges they must vary within. Closely related to these features are also the belonging production processes. This synthesising process is more like finding the best alignment of all the elements in the Corporate Platform. The result is one or several product structures that form the base for further detail engineering, and become the customised products. The reason for splitting up the product platform into a product and production section is the relationships the crash box has towards the production

line. A specific product line can have several solutions of product structures that fit within the lines. The opposite situation can also happen with the crash box where one product structure can be realised through several different production lines.

- *Manufacturing*; is the knowledge base that exist within the company. The knowledge is something people possess and improved through experience and learning. It is shared as an information flow on different media as conversation and written information. In a large and global organisation as HAST the sharing of information between peoples is not always so easy, so written information must in a large extend be used. Structuring the stored information is one important factor.
- *Product development*; the product structure and product line is further engineered to become specific product variants.

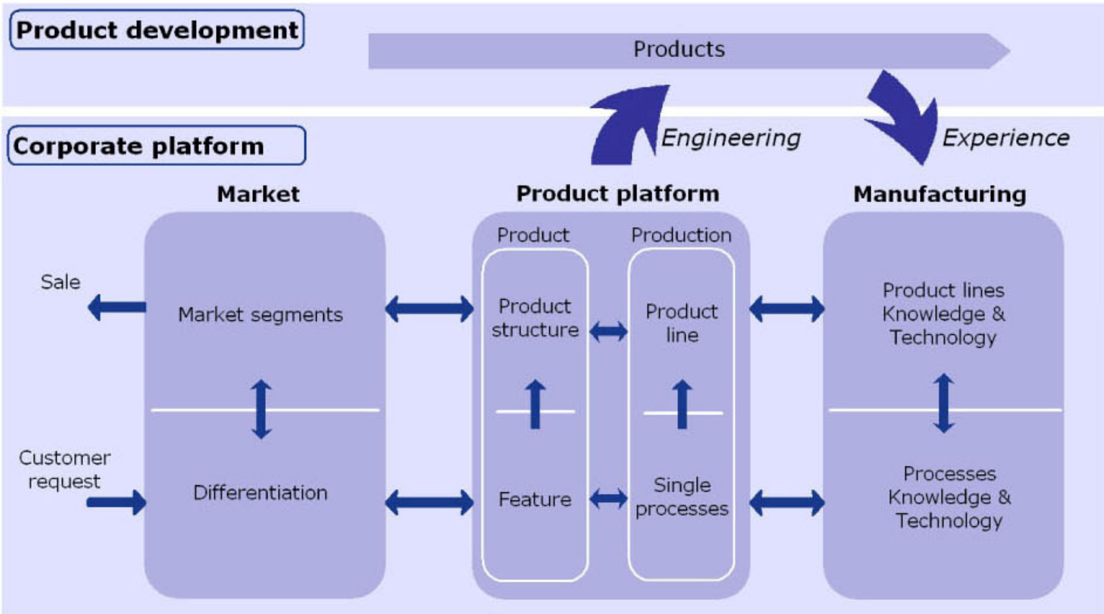


Figure 2: The Corporate Platform model with the four major elements and the sub topics

3.1 Market relationships for the crash box

The product development process is very dependent on gathering and understanding the needs that the product must fulfil. This gathering of data from a range of customer is related to identifying the product differentiation that must be part of the product platform. Presenting the variation should be done with care. In a product program one want to have a certain control over where the variation should be. There might be so many parameters that can be manipulated and including the customer with all can be to confusing [12]. A market segmentation grid [11] can sort this out and improve the communication.

3.1.1 Product differentiation

The driver for the shaping of the product program is the customer's need. These needs must be understood and translated into product characteristics that can form the base for developing product. This is just according to traditional product development, but not only a single project / product can be used to shape this foundation. This can be done with:

- The Kano models [13] three customer satisfaction lines. For the crash box it could give; Attractive: crash performance on the tougher tests, One-dimensional: price, weight, mounting/replacing easiness on car, Must-be: crash performance on legal tests, corrosion resistance

- Future needs and trend scenarios [14], [15] the changes that the stakeholders may change in the coming years that affect the design of the platform. For the crash box this might be change in crash tests.
- Mapping out the dimension variation. In order to understand the required variation needed, the majority of the dimension, surface, material, etc. variations should be mapped out.

3.1.2 Market segments

For mature businesses it is rare not to find products where a step-up functions exists in its products. Businesses in the same category as HAST should have interest in distinguish its products. Too little focus on product features may change the customer's view on the products and it becomes more a commodity rather than something special. If it becomes a commodity the only thing for the business to compete on is cost. This alone, may in many cases be difficult to do business on. Platform strategies and product program aims to simplify the portfolio by adapting the product structure in a smart way to the segments (horizontal, vertical, beach head), as discussed by Meyer [3]. In today's crash box portfolio HAST has no segmentation of the products, they do however have products that can utilise different performance to meet the different customers. Fig. 3 shows a proposal for how to transform today's crash box portfolio over to a market segments that emphasize the products distinctiveness characteristics. This is done through an alignment process of all the elements in the model a will be further discussed in the coming chapters.

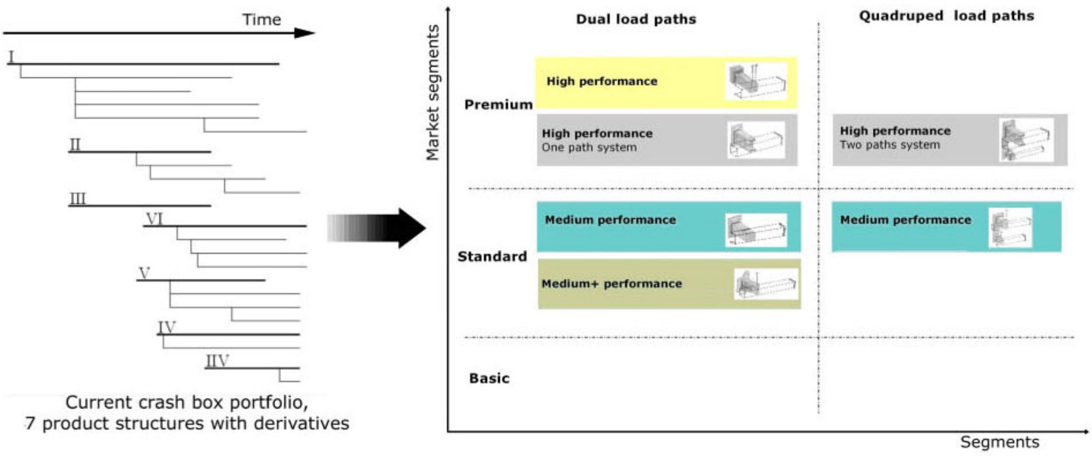


Figure 3: The proposed change in the crash box portefolio over to a layout with a distinctiveness plan for the product program. Segmented in a premium, standard segments with options for different load paths. Today there are no segments and a unstructured product portfolio

3.2 Product platforms for the crash box

The product platform section of the Corporate Platform is divided into two parts; designing the product structure and the design of the production processes. Both parts have two levels; one where the focus is on the product and production features, the second where the features are combined into a product structure and production line.

3.2.1 Product

To establish the product program that might consist of several product platforms needs a systematic approach to develop a distinctiveness plan and commonality plan. To open up the solution space and align it with the market segments one should start modelling with features and not directly on the product concepts.

The product feature can be derived from the customer's request of product functionality and future trend scenarios. Usually a few product features are capable of describing the whole range of products as the crash boxes, manipulating with feature seams to be easier to use for a range of product variants than listing all the requirements for the family. To these features there is a set of options of the variants provided. A combination of each feature options, describes one product variant. By taking this matrix and combining it with a restriction matrix, the product program starts to be formed. This gives the possibility to model with the features of product variants before a concept is made, fig. 4 shows a portion of the three structure of the crash box. By making all the possible combinations of the options in this matrix, all possible product variants can be listed. Even a small feature matrix results in a large number of options combinations. Of the option combinations made there may be some that are not allowed, physically impossible or not wanted. The restriction matrix implements such restrictions. The combination of these matrixes can be handled in the software as the Complexity Manager [16]. The product feature tree structure gives information about feature combinations that is most likely in the customer's interest. The tree structure must then be aligned so that groups of feature combinations most likely can be developed into as few product concepts as possible as well as matching it to the market segments.

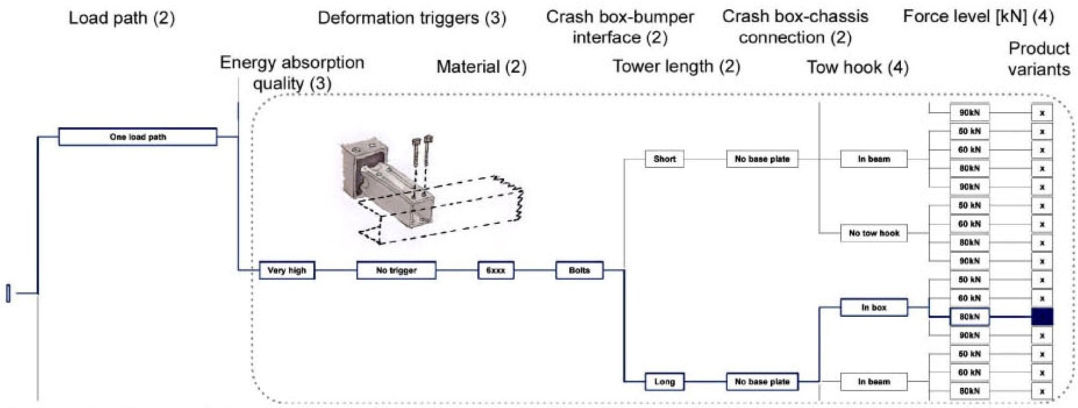
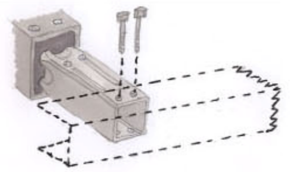
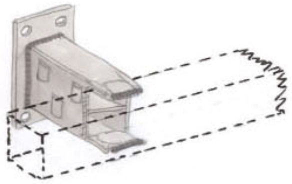
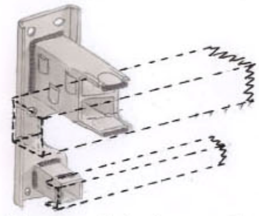


Figure 4: Part of the feature tree structure for the crash box. The bold line illustrates one set of features representing one product variant. The dashed box represent a group of features that form one product structure

The product structure describes what should be the predefined product platform concept, from which the specific product variant can be engineered. The different in developing a product program compared to the traditional product development is the increased complexity in inputs and demands on the design results. The feature tree gives a very good starting point for concept modelling.

The synthesis process of developing product platform concepts for the established feature combinations follows the traditional product development methods. Suitable synthesis methods in this process are especially the morphology diagram [14], principle and quantitative structures [17] as well as similarity laws useful [14]. Finding a mach between the required feature groups and a or several product structure is a complicated alignment process. There might not be only one product structure combination that gives the optimum result. There is though one very important aspect regarding this design process, the extra input induces several discussions on topics that might never been rose. These extra discussions add valuable information to the outcome of the designed products. For the crash box product inputs from the features, market segments, product line and crash box experience have resulted in 4 product structure concepts, table 1. These are primarily based on existing solutions, which are slightly changed. The change corresponds to an adaptation to the product program and implementing of the market trends. Each of the 4 different product structures is a product platform, together they can be derived into 15 major branches of product variants.

Table 1: The product structures description for the product program with the distinctiveness (2 of 4 structure groups are shown)

High performance	
	
The product structure is based on a bolted assembly to the chassis and bumper. The bumper beam is of an open profile in the attachment to the crash box.	
High performance, dual load path system	**High performance quadruple load paths system**
	
The product structure is based on complete welded systems. All the welds are made in the same fixture, since the product structures have gliding planes to secure the required tolerances. The welding cell should be flexible enough to weld both dual and quadrupled load paths systems. The lower load path consists of an open profile beam.	

3.2.2 Product platform production

Behind this distinctiveness plan and market segmentation the products have to have some commonality that can provide a boost for the company economy. In the case of HAST's crash boxes the commonality can not be focused around components reuse, but must be found in the industrial processes and the engineering processes.

The single processes represent the production technology at a detail level. For the crash box product to achieve the required properties many single processes are stacked together to form the product line. It is in the layout and stacking of these single processes that standardisation can be done. The single processes represent a major part of the technology and core competence the company possess. It was found that an uncoupled parallel development of the single processes technology and the product concept development could cause problem in achieving a stabile manufacturing. Therefore if too many special technologies are developed and not introduced in a planed manner, it can be very harmful for the flexibility of the product program. The development within these single processes must also be seen as research projects. Product behaviour can most likely be created by several methods and represent a parallel development to the product it self. If new single processes are introduced each time a new product variant is developed, the risk of failure gets to high. It will introduce production elements with little history related to them and make the daily production more unstable. This is not wanted when using product platforms. Therefore launching new single processes should be considered as important actions in the renewal process of the product platforms.

- *The product line* is the stage where the final products are made. The product line provides the description of an industrial process that is the base of each product platform. It should be easily adapted to each engineered product variant. In the Corporate Platform this is where one of the strongest drivers for reuse and standardisation should be found. It is here that the companies and especially HAST can gain much by standardisation.

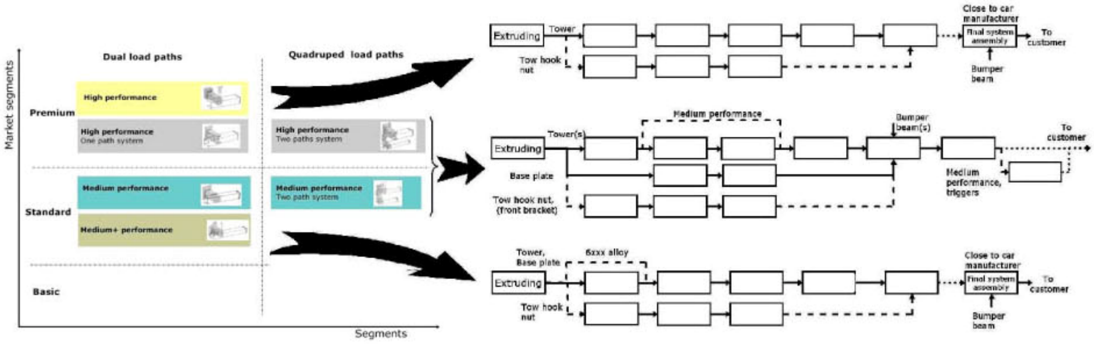


Figure 5: The market segments with product groups and the belonging industrial process. Dashed lines in the processes flow diagram indicate alternative paths, depending on material and product structure that pass through the industrial process

With the proposed product program layout the commonality is found in using fewer industrialising processes and making them so flexible that they provide the required variation. Fig. 5 shows the market segmentation and the proposed industrial processes to these product structures. Reducing process steps is historically seen as a way of making the manufacturing processes leaner, but for the crash box product this might not be the case. Reducing the number of process steps to a minimum, for a product structure, may narrow down the lines flexibility so much that no other product can be made there. This is sub-optimising and is efficient for one product variant, but not for the product program as a whole. Originally HAST's portfolio had seven different industrial processes that with this product program can be reduced down to three. With fewer than three industrial processes the product characteristics covered is narrowed too much. The proposed set of industrial processes is therefore three and the product program consists primarily of horizontal product platforms as Meyer [3] discuss.

3.3 Manufacturing

In the Corporate Platform model the section with manufacturing represent the base of core assets in the company; the knowledge and people & relationships. It is from these elements that guide and drive the product development. It should provide a boost in reuse of experience from past products and production processes.

One thing is to focus around the physical product, but as Robertson and Ulrich [1] state, that also knowledge and people and relationships plays an important role. It was found in HAST, that there was lack of a system securing an optimal information flow between the projects, the globally distributed design team and the manufacturing sites. This resulted in first-class technical solutions did not be transferred over to new product variants, and bad solutions where not excluded in new products. The flow of information is one of the critical elements in the change over to product platforms, both regarding the derivation of new product variants and the synthesising of new product platforms. Since a product platform differs from a one-at-a-time product development in that it is intended for a range of product, the information management is far more complex. When the organisation is run with development of one-at-a-time product, the sharing of information is very much related too a flow between two points. While in a product platform context the information flow must also go in other directions to secure relationships between different projects. A large part of the information flow between design teams is to be found in the reading of stored data. The structuring of the information becomes then very important. In the study of HAST it was found that this data structure was not optimised as a information source in the product development. The possibility the engineers had to search for existing solutions and further develop them was too difficult. The data structures should be structured so that they support the reuse of first-class solutions. In small organisations and groups there is two aspects related to the information flow. People that have been part of the organisation or group from the beginning, they all have a good overview of the topics and where to find information. When a new person enters this organisation or group they have not this overview and needs much guidance in sorting things out. For larger organisation this rapidly becomes more complex, since communication networks will form partly formal paths and informal path. Managers that just anticipating that messages sent from on persons and through several others, have the same content in the end, is incorrect. A structured way of securing the information flow in all directions of the organisation is needed [18]. In the Corporate Platform model the data structured are proposed to be changed to a system that supports the design phase, by letting the information follow the product platforms and not the individual projects to each customer. This type of organising and managing the data might be possible with the new product life cycle management programs [19].

4 Discussion

The model represents a framework of describing the important elements in creating a product program. It opens up the ability to develop products in a structured approach that focus on reuse of assets in a broader sense than traditional product platform development. The model interacts with the traditional product development methods and is no contradiction to them. The existing design methods focus very much on the development of product structure and the reuse of components. Several authors among them Robertson and Ulrich [1], [5], point out the need to focus on more than only component reuse. The results from this study underline this. It was found that the organisation could achieve significant improvement in the reuse of asset in the product development phase and in the way the product information is treated. The model includes the description of both market and organisational elements, related to product variant design. These topics are large and especially the organisation elements is seen as important areas for further develop the creation process and management of product families.

5 Conclusion

Improving the company's efficiency has for a long time been very focused around single design, process improvements and component reuse. The Corporate Platform model takes this to a different level; by including the manufacturing aspects and knowledge flow in the product platform development. It makes it possible to improve the efficiency of developing and manufacturing a range of non-configurable products, but also other types of products. The model describes the product variants relationships to the company's assets and introduces a way of aligning the product preferences with the company's preferences. It has a strong focus on the manufacturing aspects of developing a product program and maintains a lean manufacturing.

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DESIGN 2006

PRODUCT FAMILY DESIGN FROM A MANUFACTURING POINT OF VIEW

T. Jensen and H.P. Hildre

Keywords: Process platform, Product platform, Product variants

1. Introduction

Highly competitive global markets force companies to change their way of doing business. A major trend designing product families is an increased interest in using product platforms. The major automotive companies has already adopted platform and modular strategies, in order to improve the efficiency. Now, also sub-suppliers and smaller companies with less complex products find interest in this strategy of designing products. The purpose of using product platforms is to increase variety for the customers and simultaneously improve the internal re-use, within the company.

There are several definitions of a product platforms in the literature. The definition used in this paper is proposed by Robertson D. & Ulrich [1998] and is: "*the collection of assets that are shared by a set of products.*" These assets can be divided into four categories:

- Components - part design of the product, tools and fixtures
- Processes - the equipment used to make or assemble components into products, the design associated production process and supply chain
- Knowledge – design know-how, technology, applications and limitation, mathematical models and testing method
- People and relationships – teams, relationships between team members, relationships between the organization, customers, suppliers and the design team

When it comes to take control over a product family that has evolved in an uncontrolled manner, several authors have proposed methods to handle this challenge. Sanderson and Uzumeri [1997] talk about product variety and the change process of both the individual product variants and whole product families. They mainly characterise products based on the customer type, within four categories; commodity, change intensive, variety intensive and dynamic. Meyer and Lehnerd [1997] have also a strong focus on the customer aspect, but also how to position the products in the market. They discuss product- and process clock speed, which are related to how long products can stay in the market. They also present a model for how to target the different product platform and variants for different market segments as well as avoiding cannibalism. Mortensen et al. [2001] have developed the Product Family Master Plan (PFMP) method. This method is suitable to make "the big picture" of today's product family. The master plan gives both overview of the possible variation and commonalities. The mentioned methods do not include manufacturing aspects. Meyer & Dalal [2001] and Jiao & Tseng [2004] underline the importance of focusing on the manufacturing processes as an important aspect in platform design. Both of them have develop indexes for understanding how the manufacturing processes affect the product variation as well as the product platform.

The existing literature has little focus on how to visualising the product variation from a manufacturing point of view. Some authors have described variations consequences on assembly, but manufacturing processes and supply chain aspects are not included. The objective of this article is to discuss how to model a product family from a manufacturing point of view that can be used to illustrate challenges met leveraging a new platform based on common core assets.

2. The study

The study was conducted in close relationships with Hydro ASA. Hydro ASA is a global oil and aluminium company, with several business units. The business unit in the study is Hydro Aluminium Structures (HAST), which manufactures automotive crash management structures such as bumpers, sub-frames, and whole space frames. The production volume varies from low to high production (->2 000 000 units), with bumper structures are in the upper range. In order to establish a new portfolio program that is suited for HAST, there is a need to have an in-depth analysis at the existing products and industrial processes. Today's product family has evolved with limited control and HAST wants to change the direction of this family, by being better in controlling the product architectures, production and supply chain. The study is therefore built around a case, describing and visualising one of the company's product families, in order to find where changes should be applied.

2.1 Data gathering

The study is based upon 4 in-depth interviews, workshops, a case study and an earlier study [Jensen, T 2004]. The persons interviewed were primarily managers and senior engineers, working with product development or research. All of the in-depth interviews were performed individually and in their working environment. The same people also partisipated in the workshops. All the persons had either a doctor's degree in engineering or were graduated engineers all of them have been working in HAST for many years.

2.2 Data analysis

All the interviews were transcribed in order to perform a detailed analysis. The questions and responses were classified and grouped by topics, based on Robertson's [1998] lists of core assets (components, process, knowledge and people & relationships). Ideas and work were discussed and changed during the workshops. A close interaction with HAST was present at all time.

2.3 The product

The bumper structure with the crash box and respective production will be discussed further in the article. This is also HAST's main product, fig 1. A bumper system is placed in the front and rear of the car, and consists of a cross beam and crash boxes at each connection point to the chassis. The system is designed primarily for two different requirements, a Danner test for the European car models and CMVSS requirements for the North American car models. Of these requirements the Danner is the most demanding requirements and is used for models operating on both the European and North American market. This test requires that the bumper structure absorb the energy from a 16km/h offset crash and leave the car's chassis structure undamaged. The core assets in these products is control of material properties, the knowledge of forming ability, the lightweight design and the integration of these into products with high energy absorbing capabilities Together these technologies allows HAST to make products that consist of very few, highly formed parts. HAST delivers these types of structures to a majority of the European car makers. These structures can be found in the range from low-cost to premium-brand cars. Each product is customised for the car makers, leading to a large number of product variants. The customisation of the products is necessary to be able to be in business, and is not seen as a problem. All products have in common that they must fulfil similar regulation and insurance tests.

Figure 1: Bumper system consisting of a beam, two crash boxes and a tow nut.

3. Results

The crash box family consists of a product with few parts, beeing customised for each customer. Instead of using the Bill of Material (BOM) list to build the description of the product family, we propose using the industrial process. This fits well with a process intensive product with few parts. According to Robertson and Ulrich [1998] the product platform also includes processes, knowledge and people & relationship, in addition to components. Especially the assets needed to realise the products, as processes, knowledge and people & relationship have been focused in this study. It is within these assets the challenges for this type of product can be found. With the industrial process we mean the sequence of activities that realise the material and components into products. Industrial process can be defined as: *to organize (the production of something) as an industry* [yourdictionary]. The term industrial process is very central in how the crash box are categorised and visualised.

3.1 The description of the product family

Let us first describe what we mean by industrial process. An example of the industrial process for a crash box can be illustrated as shown in fig 2. Within this industrial process there is a flow of material between factories and between countries. All components in the product are based on extruded aluminium profiles and the production is made in batches.

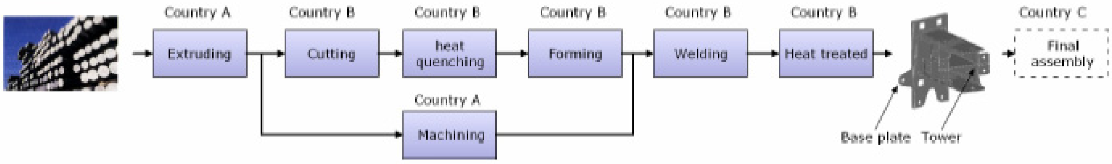

Figure 2: A typical simplified description of an industrial process.

It was found that the presentation of historical product data should be of a kind that is objective and consistent. It was also found that the product information should be coupled with important time aspects of the individual projects. Both the project start and production time was seen as essential information in addition to product specific information. The description is build around the individual processes that realise each of the different crash box platforms that HAST manufactures. The information contains similarities to the BOM structure by using the article number of the variants. Suppliers to the automotive industry often manufacture parts that are very similar. There may be one unique part for the right and left side of the car, slight differences between sedans and wagons and for the European or North American market. Such small changes within the products are important to capture, but the visualisation should not be filled with to many details. This kind of variation is therefore shown in rows in the small table inside the product box, instead of a dedicated box for each specific product variant. The information included in the description of one of the products is as illustrated in fig 3:

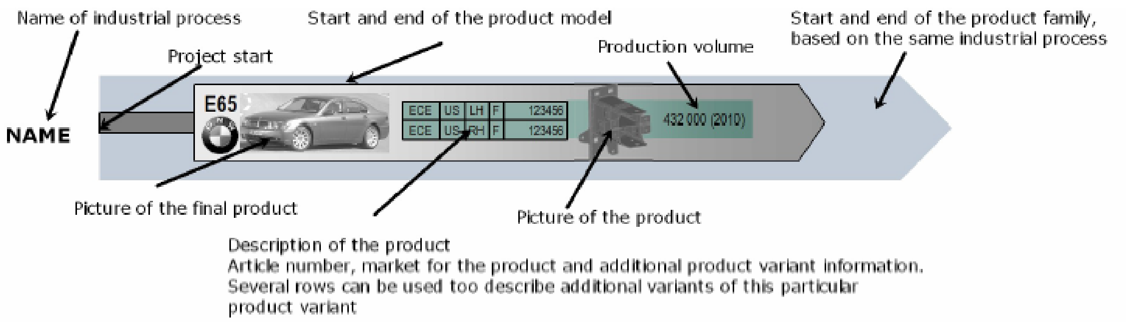

Figure 3: Notation and information in the product history description. Graphical elements ease the communication. Illustrated with one product model and two variants of this model, one for the left side and the other for the right side of the car.

This way of presenting the products is then grouped according to the industrial process as fig. 4 show. Each product variant is indicated with a development time and production life. A vertical dashed line indicates the present time. Products that have been taken out of the market are indicated with a square box and not an arrow shaped box. As seen on the figure the time span for the products extends into the future, this indicates the planned life time for the product variant.

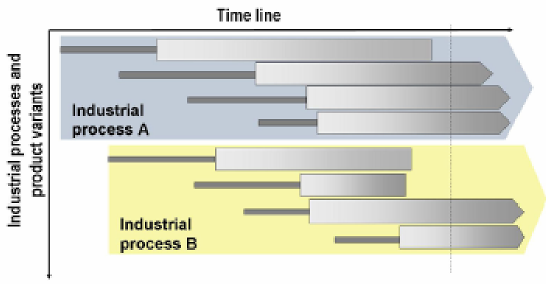

Figure 4: Illustration of two industrial processes with product variant boxes. X- axis is the time line and Y-axis is the industrial processes with product variants. Some of the product variants are out of production and this is indicated with a rectangular box and the current date is indicated with a dashed line.

3.2 Case illustration when the product family is organised after industrial processes

In this case, the crash box product family is used. HAST has several development and manufacturing sites in Europe and North America. The crash box product is a product located in the front and rear of the car and has as its purpose to absorb all the energy in a low speed crash. The product appeared on the market as a consequence of demands to increased the crash performance and from insurance companies. The car manufacturer wanted a safer car and the insurance company wanted low repair cost for low speed crash. These demands appeared in the early 1990s. Fig. 5 shows all the product variants HAST has produced and still produces.

The figure shows that there are 7 industrial processes, 55 crash box variants belonging to 25 car platforms. To realize these processes, they have more than 7 production lines to manufacture them. There is some duplication of similar production lines, due to location in different countries. For some of the high volume products they have dedicated production lines.

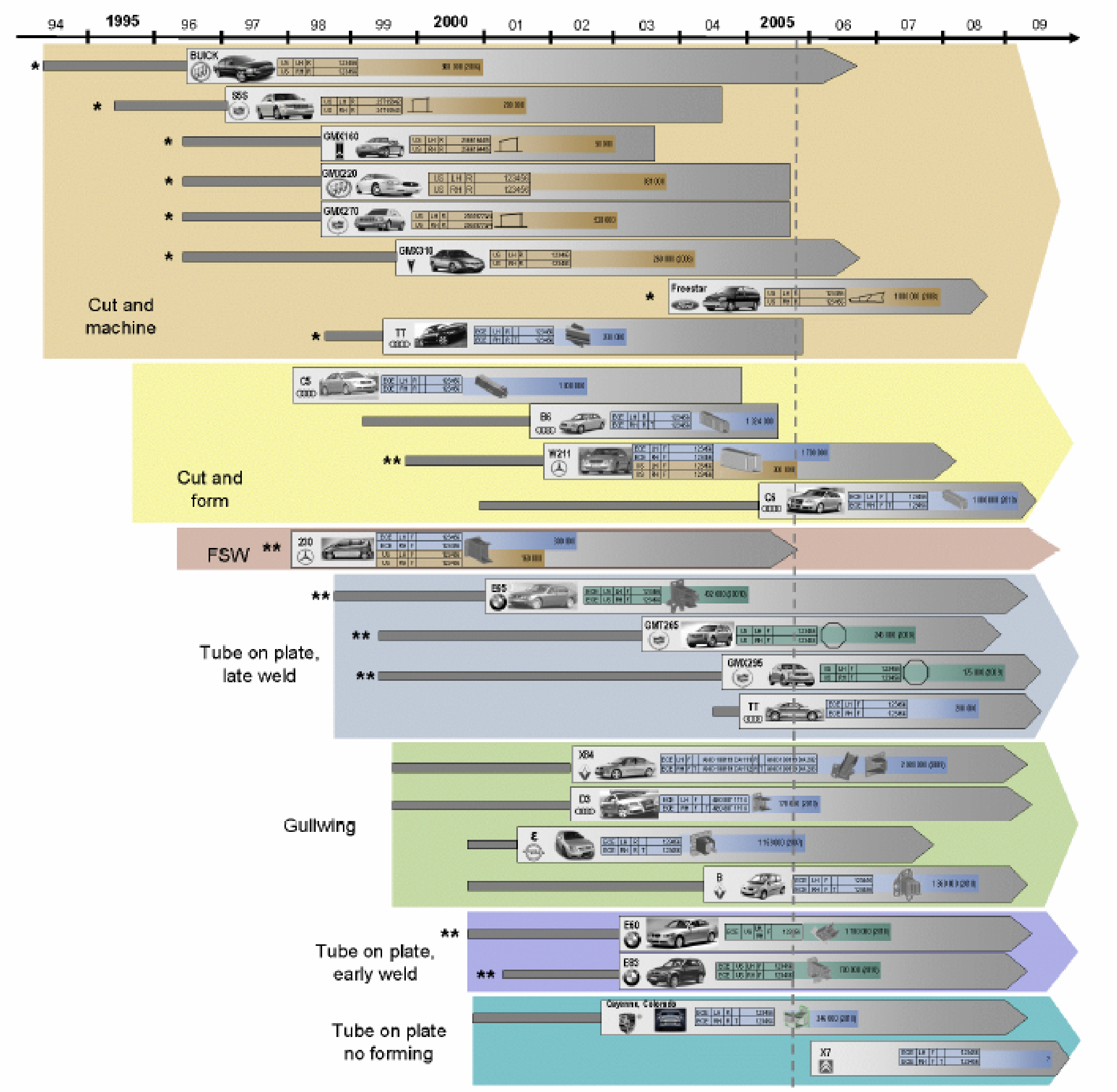

Figure 5: The description of crash boxes with all the product variants grouped by the industrial processes. Products with no * marking are design after Danner requirements. *= products are designed for CMVSS requirements, ** = both requirements are used.

By analysing this way of presenting the product family and the organisation, several interesting topics can be commented and be used as input of a new platform. These topics are:

- The evolution of the industrial processes
- The evolution of the products' function and form
- The development process

3.2.1 The evolution and mutation of the industrial processes

Manufacturing these products at the required volume puts great demand on the industrial processes. The industrial processes must be capable of having a high and steady output of products. Just-in-time is an absolute demand in the automotive business. Assuring that the product have been designed with an high quality industrial process is essential.

The industrial processes for manufacturing the crash box have gone through a mix of evolution and mutation. The industrial process is strongly linked to the functionality required in the product and this has a tendency to vary over the years. In the early crash boxes the major function was to be a bracket with some energy absorbing capabilities. As the market started to demand cars with high crash performance in the end of the 1990s the requirements changed. Much of the required crash absorbing system is in the front of the car. Due to the cars' weight distribution, low weight solutions are very beneficial in the front. A complex industrial process could be accepted, but after only a few years extra payment for low weight solutions was vanishing, new designs were needed.

The design of new crash boxes and new industrial processes followed to some extent the same similar principles, making the products difficult to manufacture and too expensive. A one-piece highly formed solution, was introduced to avoid some of the assembly steps. This can also be seen as a mutation. The product architecture was based on a aluminium profile so highly formed that it seems to be made out of several parts, but is one component. What happen is that the complexity is moved from the assembly to the production of the component. The use of very complex forming tool has also introduced new challenges. These complex tools have also been designed and manufactured by different sub-suppliers. This has resulted in tools that use different working principles to achieve the same product functions. The loss of standardisation in the tooling has given additional problems in the manufacturing and especially in the start up of a new product variant. The latest design tendency is to provide an architecture that has less focus on part reduction and more focus on simplifying industrial processes.

There seems to be two obvious industrial processes that should be phased out, after all obligations for the products fulfilled. It is first of all the industrial process "FSW" and the "Cut and weld". The "FSW" has only one product variant and no new derivative products and ties up a lot of resources. This product also had a too slow production rate, becomes too expensive. The "cut and weld" process is simpler and can generate a lot of product variants, but the design is perhaps too simple to give the required performance and is out of date! There is also a mix of high and low volume products in all of the industrial processes. The high number of different industrial processes indicates also that combining some of the solution into a single industrial process should provide a higher frequenze of repetition and increased standardisation. Since each industrial line has its strengths and weaknesses the strengths should be cultivated for a set of product functions and a corresponding production volume.

3.2.2 The evolution and mutation of product function and form

The first crash box launched in 1996 for a rear bumper had a function more like a bracket with some energy absorbing capabilities. This product has been derived into several new products. After the first launch of crash boxes for the front, several solutions and industrial processes were established. The designer's solution space has been expanding aiming, for new solutions. Entering the market for the front crash box put more demands on functionality, load carrying capabilities and constraints on the packaging space is in a totally different class, compared to the rear. By combining the view from the industrial process with the traditional roadmap view for products, some interesting things can be found. First all of the crash boxes manufactured by HAST can be classified into four groups, regarding the primary energy absorbing function and the overall form of the product. The groups are:

- Open profile, buckling. A design that uses a profile extruded in the vertical direction, with open ends. The energy is absorbed by bending.
- Closed profile, shear. A design that uses a profile extruded in the longitudinal direction. The energy is absorbed by shearing of the walls in the product.
- Closed profile, pre formed. A design that uses a base plate with a tower, forming a closed and stiff design. Together giving a design that is efficient in absorbing energy.
- Closed profile, buckling. A simpler designs where there are no pre buckles to trigger the deformation pattern.

The evolution and mutation of the design and functionality of the crash box can be illustrated in a roadmap as shown in fig. 6. The colour and pattern of the circles, which represent the industrial process for the products. The horizontal lines can be seen as evolution lines. The mutation is a vertical step and when one of the circles in a group is located in another group. The mutation is a larger change in functional area; rear compared to front and in the technology used to achieve the functionality.

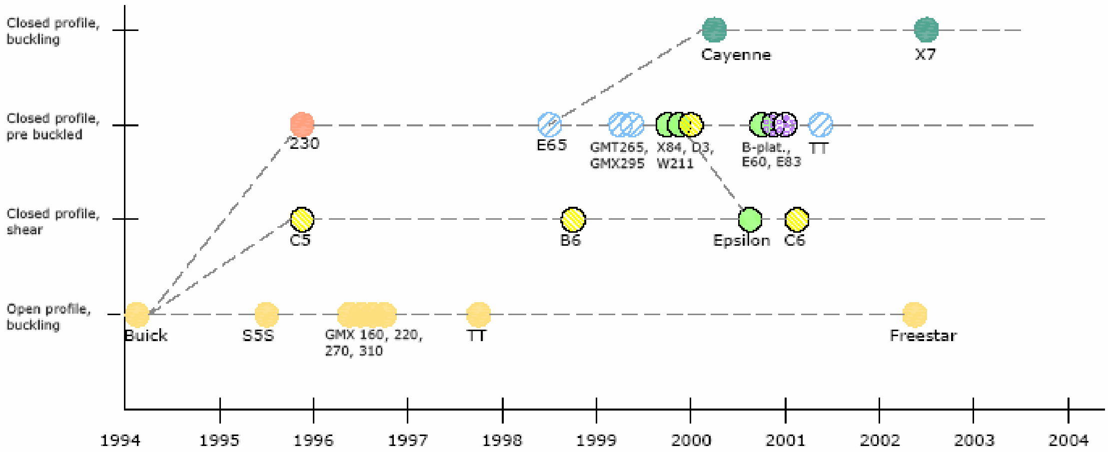

Figure 6: A historical picture of the evolution and mutation to the crash boxes from a functional view point. The figure indicates the project start time and the colour / pattern represent the industrial process.

Within the group "open profile, buckling" there has been almost no evolution of the functional aspects in the products, resulting in a steady industrial process putting out new derivatives. Comparing it to the "closed profile, pre buckled" there is an evolution in the industrial processes (change in type of circle) and this correlate to realising new product functions in another industrial process. New product functions could be part of similar industrial process, to avoid changes. If a change in an industrial processes is needed this change should happen rarely and be continuous. Hence the shift in circles should be the same or progressiv. Not as illustrated in the "closed profile, pre buckled" group, where the colour /patterns is mixed. There are also some mutation, e.g. the Epsilon, "closed profile, shear" group, using the shear principle to absorb energy, but beeing made in a different industrial process combining two good things and making a successful product.

3.2.3 The development process

The available development time for each of the projects is also illustrated in fig. 5. For the crash boxes this time is fixed to the cars development time, but it could also be vsiualised with actual development time. Illustrating this it should show a learning effect from product to product by resulting in a shorter and shorter development time for each product, fig. 4. In the interviews about development time for the crash box, it was found that the learning effect was not satisfying. The design team seems to work to much independent with limited learning effect between projects. This could also be observed in the design solutions that have evolved. This may be related to the organisation of the design team, how they share design information and where they are located.

4. Discussion

Illustrating the product family with the industrial process gives a new approach improving internal reuse. This is the first step in creating a planned portfolio, when the variation in the product is controlled by the overall strategy of the company. The experience from the crash box case gives us an opportunity to discuss some interesting topics, not only around the individual product variants, but also product platform management.

Using picture and graphical elements to illustrate what has happen, this is objective and can easily be understood by people not directly involved in the projects. In contrast to the PFMP and other methods, this illustration of the platforms can be used for products that are assembled from few components and were the variation is created in the manufacturing processes. These methods uses configuration as the primary product portfolio driver. Focusing on the industrial processes, makes it possible to illustrate several product platforms with all the product variants. The industrial platform visualisation has also its strength in being able to include time, production volume and graphical elements to visualise the product variants. This makes managing and planning the product portfolio easier. Unused production capacity for the industrial processes can easier be filled up by new product variants.

The crash boxes have been developed directly based on the customer's requirements. However their requirements have been changing over time. In the early days of the crash boxes, the aluminium light weight solution had a clear advantage over steel competitors, but this advantage as well as all advantages only last for a certain period. HAST had a rapid growing of the product family and in the early days they could charge extra for the additional product properties such as high performance combined with low weight. This rapid increase in different industrial processes leads too few product variants within each industrial process. One of the reasons for the rapid growth in different industrial processes is the organisation structure for the development teams. They were organised in several design teams working towards a set of customer's, but the culture to share information was absent. This independence between design teams may though resulted in a wider solution space compared to a centralised development process. The case, fig 5, has an appearance as a product family where the individuals are appearing in an uncontrolled sequence (sub optimising) more than a product portfolio, where the product variants are controlled more according what is best for HAST.

Some of the industrial processes have also been difficult to get up and running stable with a low failure rate. The time span this has affected the organisation has been too long and demanding. Experience has shown that launching too many industrial processes at the same time can be difficult. In a product platform perspective, it then becomes important too harvest from this knowledge, in order to lower the stress in the organisation. These organisational challenges can be illustrated in following scenarios, fig 7:

A. *One industrial process handles all the product variants instead of a range of industrial processes.* There will be a significant transfer of knowledge from product to product. The actual development time will be reduced from product to product as knowledge and skills are improved. Other areas within the organisation will also benefit from a higher repetitive number, as engineers designing the tools and fixture, the operators on the lines, the service people all benefit of a high number of repetitive actions. The product variation too the customer is though reduced compared to the initial layout, but due to reduced cost of the products he/she may accept that.
B. *The launches of new product platforms are planned so that the organisation's resources are not over-loaded, compared to a high number of simultaneous releases of new platforms.* Launching many processes at the same time put a high strain on the organisation. There are lots of new systems that need too be fixed for errors and bugs, at more or less the same time. Launching the industrial platforms in a controlled sequence ease the strain in the organisation.

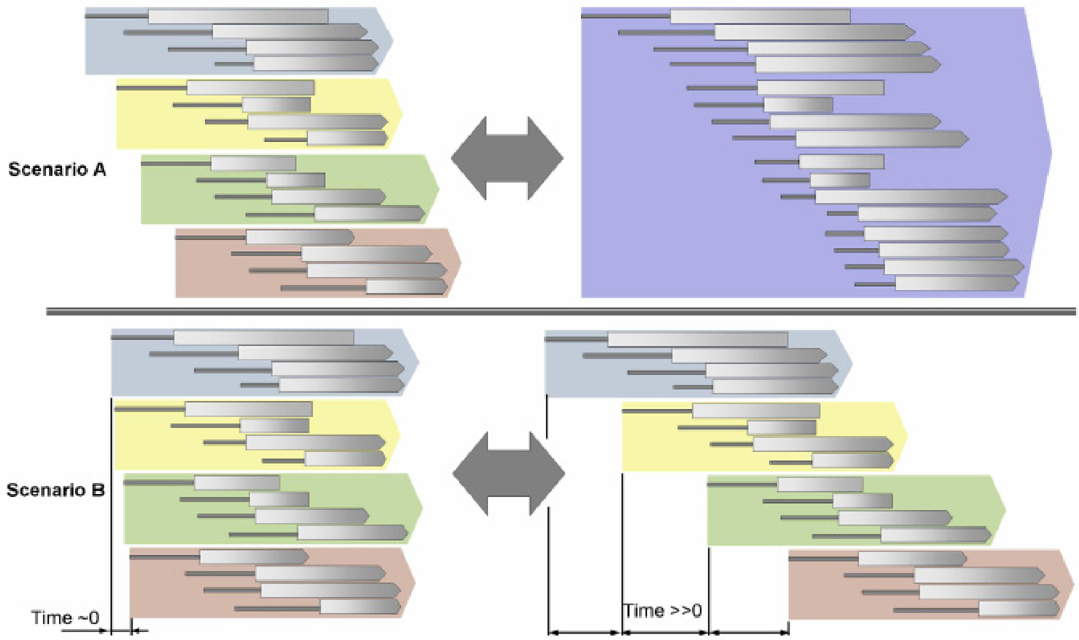

Figure 7: Possible scenarios of the historical description: Scenario A illustrate multiple industrial processes compared to one industrial process to manufacture the same products, Scenario B illustrate the time of introducing the products too the market.

These effects can be illustrated with a typical time- failure graph for starting up a new industrial project, as illustrated in fig. 8 (A)[Blanchard 2004]. This figure illustrates this:

- There may be a great number of corrective maintenance actions to achieve the reliability needed. This depend on the type of equipment, established production and equipment maturity acquired through test operations. Immediately after equipment is installed the reliability is poor before reaching a acceptable level. The constant failure rate is very often used as input during design without taking into account major start up challenges.
- The increased failure rate in the beginning is not only valid for the equipment, but also for the operators and maintenance personnel who need to get familiar with the system. Until this happen a certain number of operator-induced mistake will happen.
- Even if both the equipment and personnel operate the system well, it might not be able to run at full speed, due to the logistic supports at all levels.

Launching one industrial process follows the failure rate in fig 8 (A). If we assume that there is no learning between the product projects the failure rate will accumulate for the organisation according to fig. 8 (B). The organisation must handle each of the high failure rates of the individual projects as well as the accumulated. This accumulated failure rate can demand more resources from the organisation than available. External support or even more employees can be needed, before a steadier period is achieved. When transferring knowledge and experience between the product projects, the start up failure rate is reduced together with a slightly lower constant failure rate for each new project. The accumulated failure rate for the projects becomes lower, making it easier for company's to avoid activity peaks.

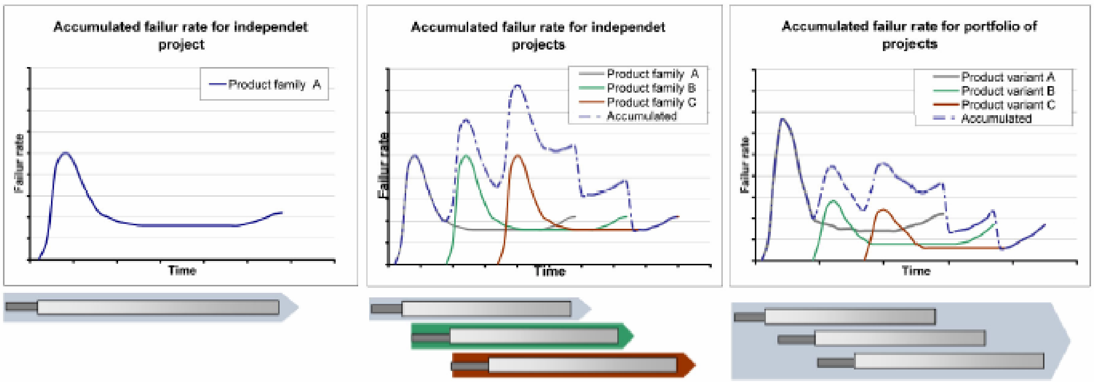

Figure 8: (A) Typical failure rate of manufacturing a product, a high failure rate in the begining, a steady period and increased wear in the end [Blanchard 2004], (B) failure rate of manufacturing multiple independent products and accumulated failure rate, (C) failure rate of multiple products that are based on the same product platform

5. Conclusion

A new model of presenting the product portfolio based on manufacturing point of view has been presented. Combining this portfolio illustration with the traditional roadmap visualises important elements in making a lean product portfolio. The model represents a starting point for discussing the main elements in the product family and how the organisation handles the task of creating product variants and new industrial processes.

The model is planned used on different product families as the first step to increase the reuse and create a lean product program. Further work will be to make a method suited for evaluating different product family design concepts for products in the same category as used in this article.

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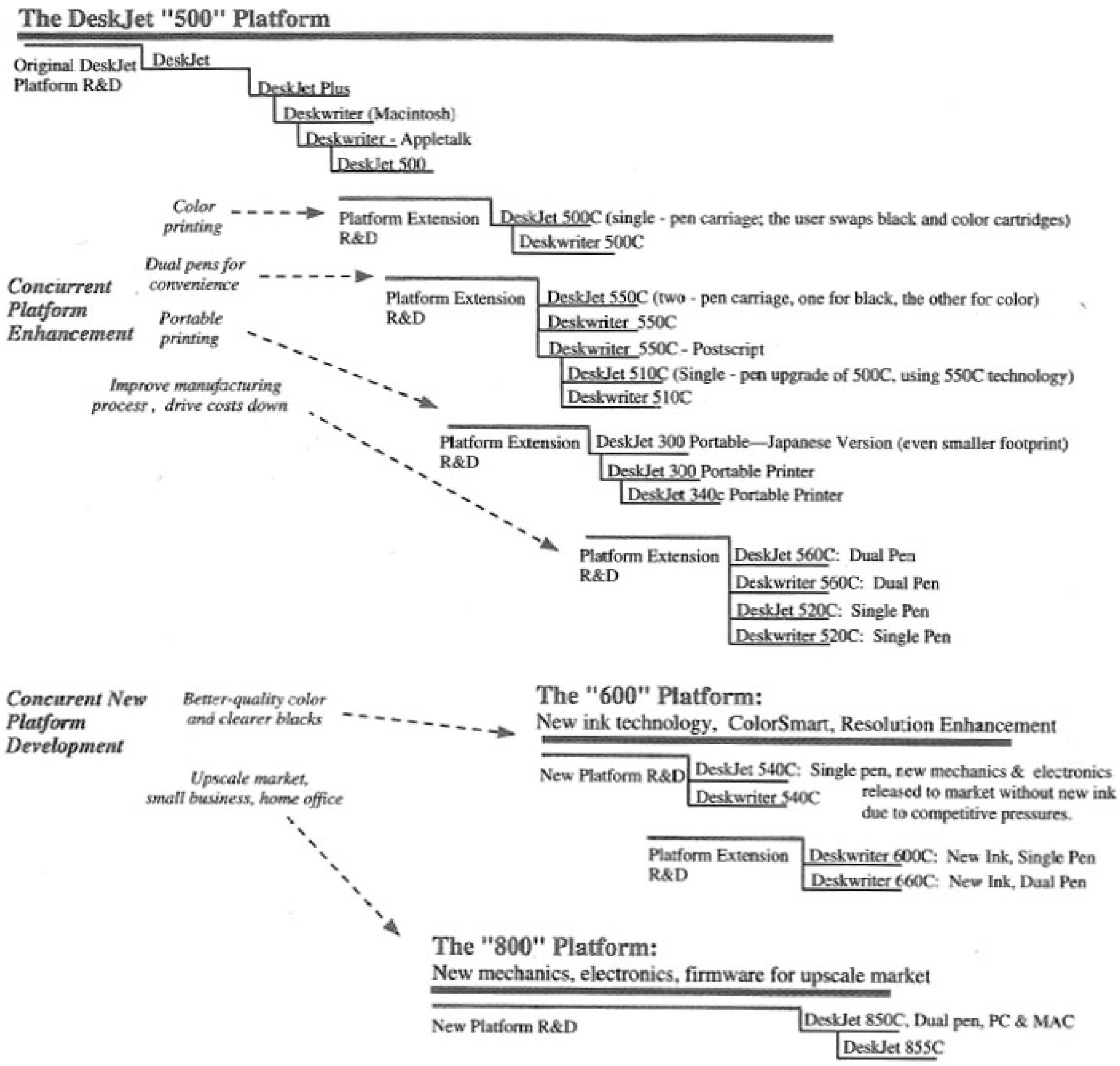
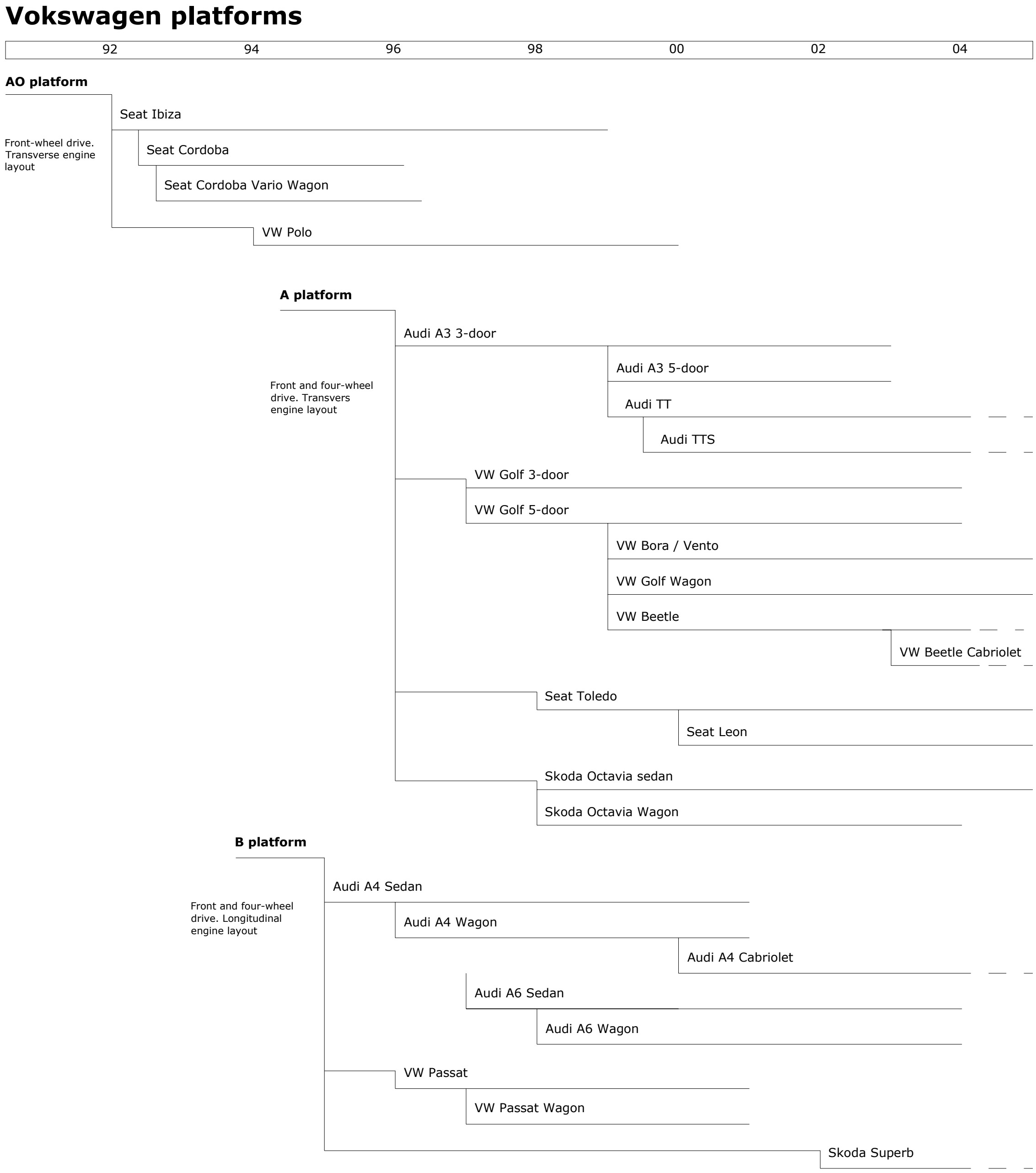
Appendix VI: Product family map for HP DeskJet



(Meyer and Lehnerd 1997)

Appendix VII: Volkswagen product platforms



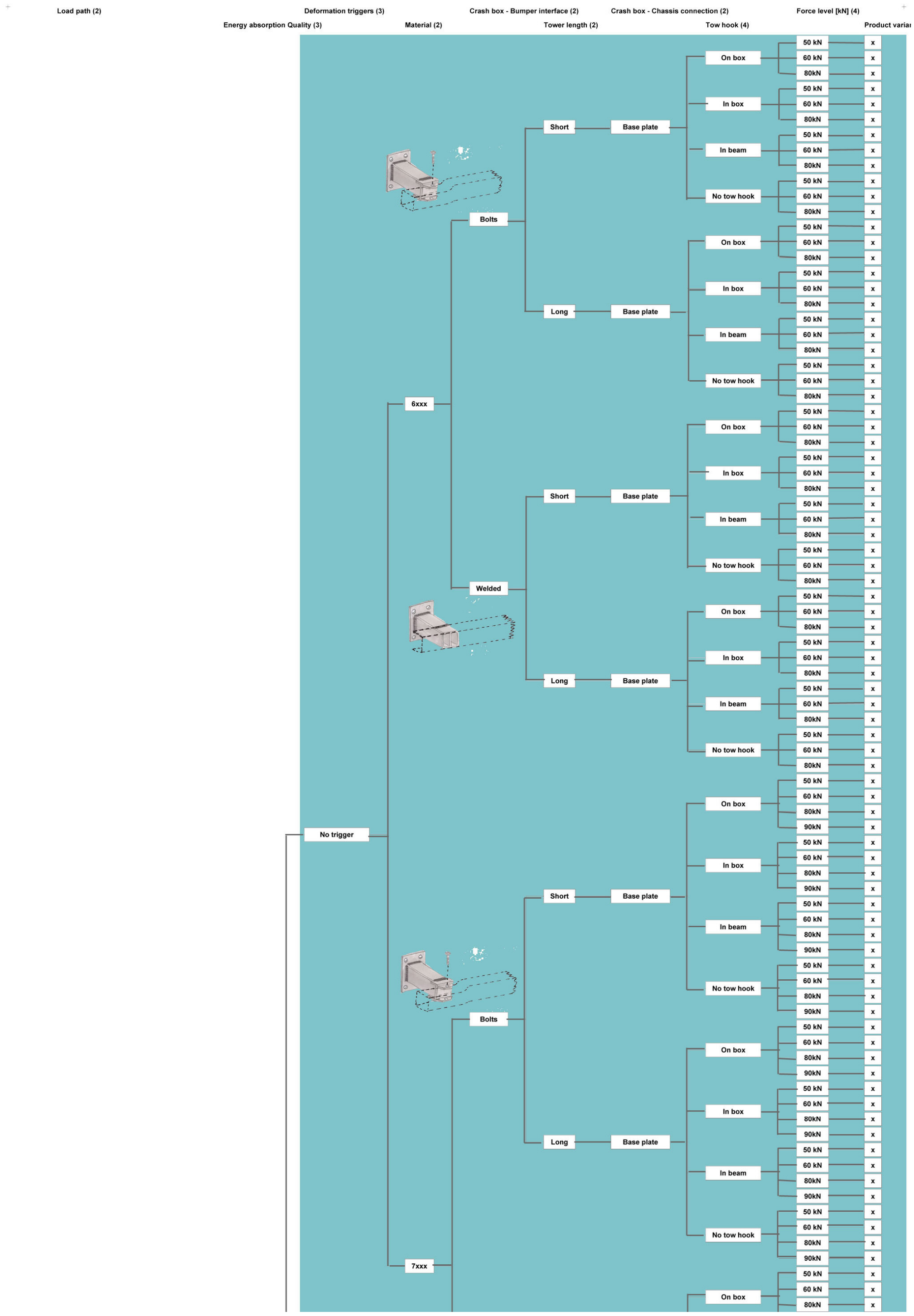
Appendix VIII: Comparison of different supply-chain structures

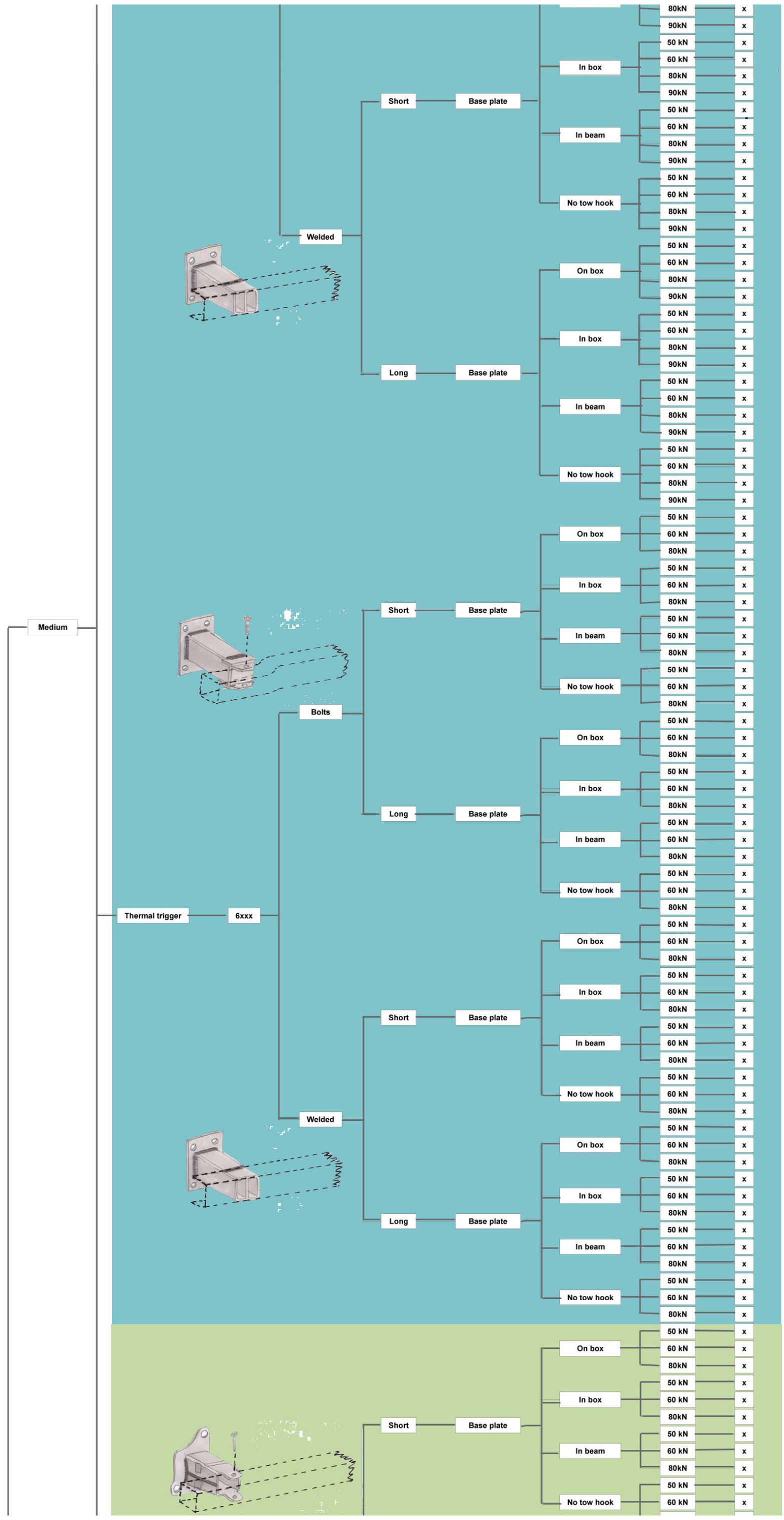
Opportunity for modularisation	Traditional supply chain	Mass customisation supply chain	Postponed supply chain
Interface compatibility effects	• Integrated vertical structure • Long development lead time	• Modular product architecture • Reduction of development lead time • Vertical coordination	• Customer decoupling points • Accurate and short customer response time
Component customisation	• Design and manufacturing focus • In-house product development • Standardised components	• Autonomous innovation in new product development • Customer focus • Design for manufacturability	• Process design • Design for postponement
Value inputs	• Economy of scale • Exploiting advantages of market mechanism	• Outsourcing • Flexibility towards specific customer's needs • Economy of scale and scope	• Reduced inventory costs and risk of obsolescence • Increased flexibility towards market needs and changes • Economy of scale and scope
Supplier-buyer interdependence	• Standardisation of operations • Consolidation of outbound logistics • Arm's-length at component levels • Supplier involvement in development not critical • Multiple sourcing	• Early supplier involvement in new product development • Strategic partnership • Supplier as a system integrator • High interdependence	• Customer relationship management • Involvement of third-party logistics providing final manufacturing and logistics • Direct deliveries to customers through merge-in-transit

(Mikkola and Skjøtt-Larsen 2004)

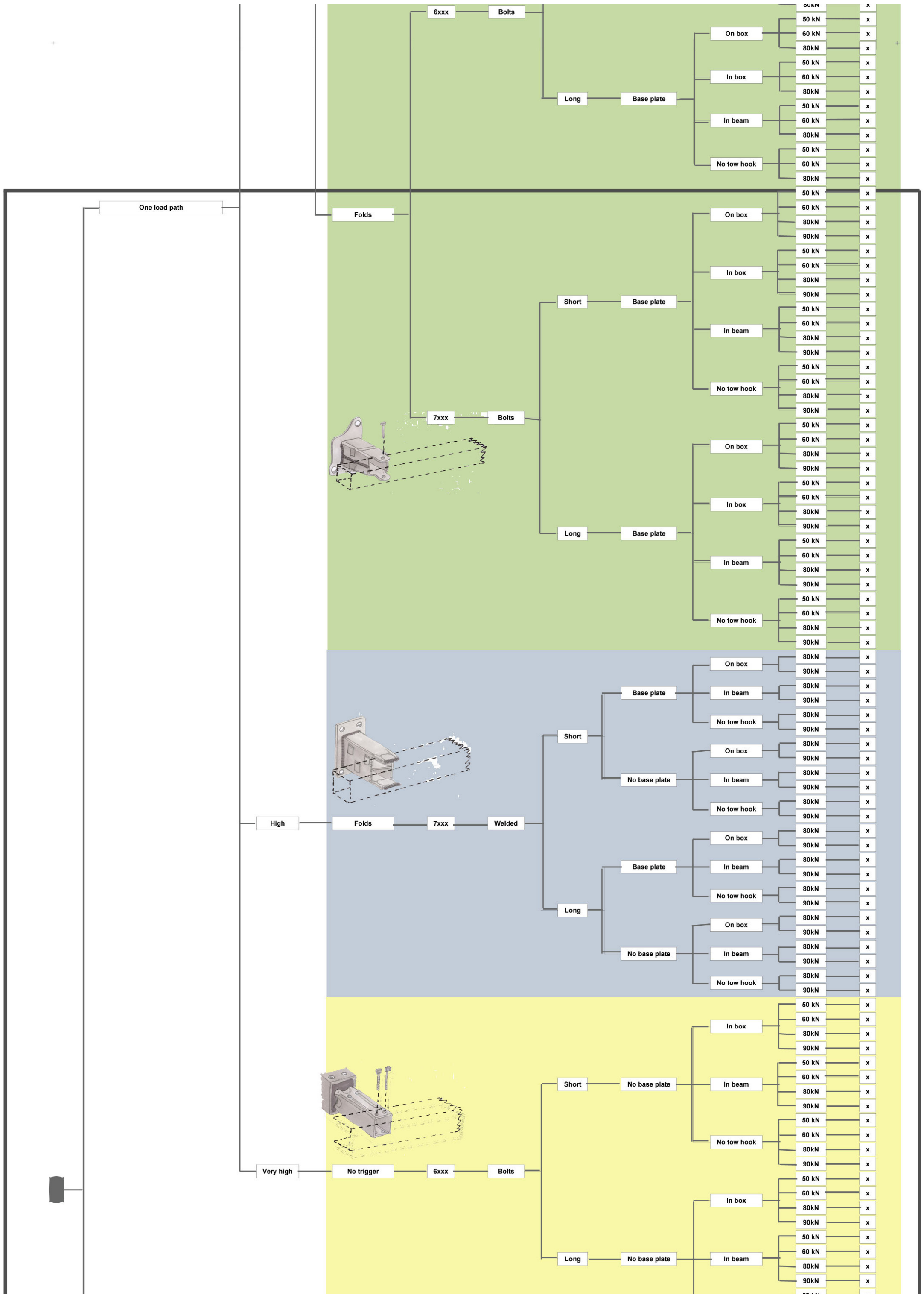
Appendix IX: Feature tree structure for the crash box product programme

Feature Tree





80kN
90kN
Short
Base plate
In box
In beam
No tow hook
Welded
Long
Base plate
On box
In box
In beam
No tow hook
Medium
Short
Base plate
On box
In box
In beam
No tow hook
Bolts
Long
Base plate
On box
In box
In beam
No tow hook
Thermal trigger
6xxx
Short
Base plate
On box
In box
In beam
No tow hook
Welded
Long
Base plate
On box
In box
In beam
No tow hook
Short
Base plate
On box
In box
In beam
No tow hook
50 kN
60 kN
80kN
90kN
x


One load path
Folds
6xxx
Bolts
Long
Base plate
On box
In box
In beam
No tow hook
50 kN
60 kN
80kN
x
7xxx
Bolts
Short
Base plate
On box
In box
In beam
No tow hook
Long
Base plate
On box
In box
In beam
No tow hook
50 kN
60 kN
80kN
90kN
x
High
Folds
7xxx
Welded
Short
Base plate
On box
In beam
No tow hook
No base plate
On box
In beam
No tow hook
Long
Base plate
On box
In beam
No tow hook
No base plate
On box
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No tow hook
80kN
90kN
x
Very high
No trigger
6xxx
Bolts
Short
No base plate
In box
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Long
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In box
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50 kN
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80kN
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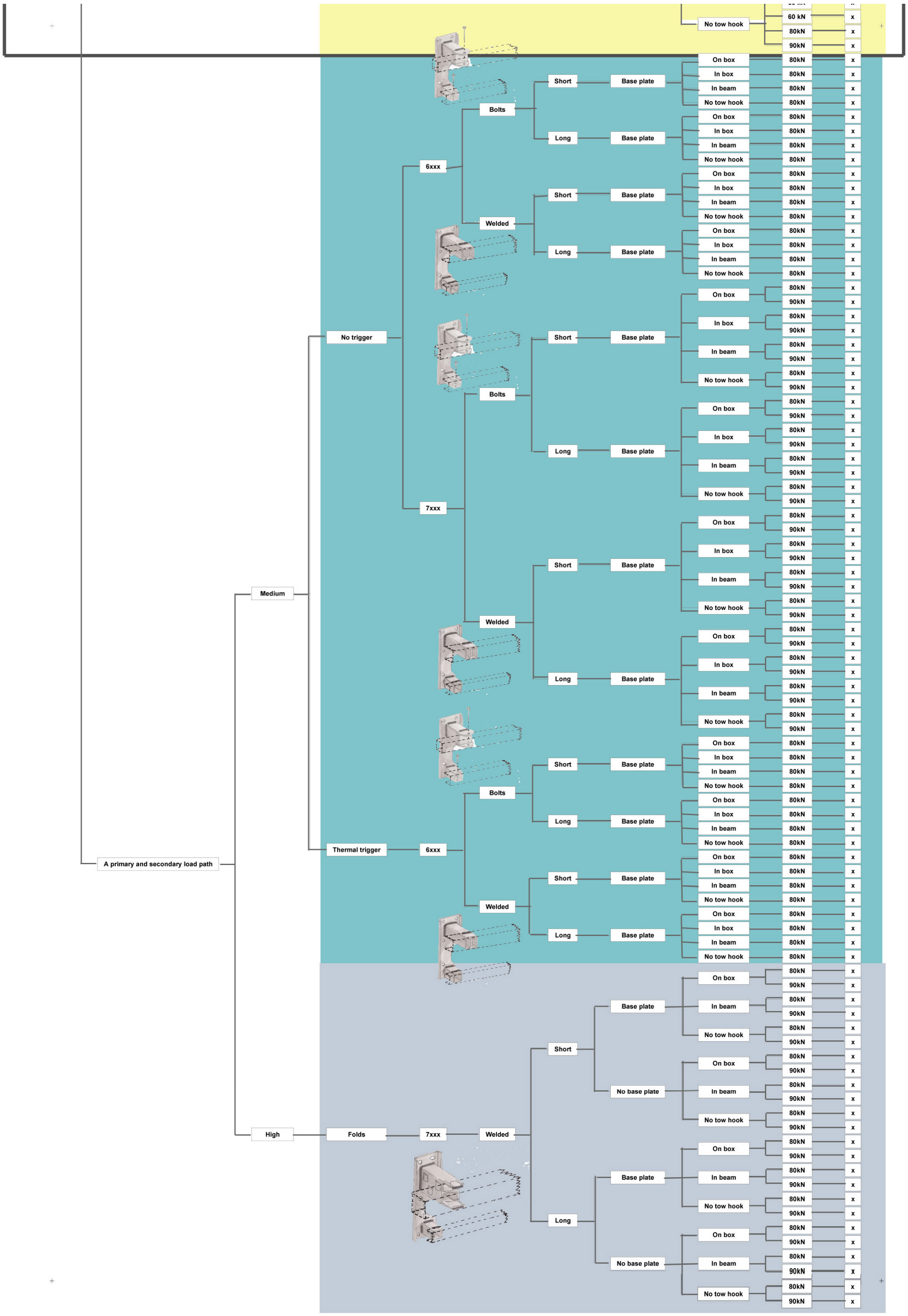
A primary and secondary load path
Medium
High
No trigger
Thermal trigger
Folds
6xxx
7xxx
Bolts
Welded
Short
Long
Base plate
No base plate
On box
In box
In beam
No tow hook
60 kN
80kN
90kN
x