INTERNATIONAL DESIGN CONFERENCE - DESIGN 2006
Dubrovnik - Croatia, May 15 - 18, 2006.

DESIGN 2006

PRODUCT FAMILY DESIGN FROM A MANUFACTURING POINT OF VIEW

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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.

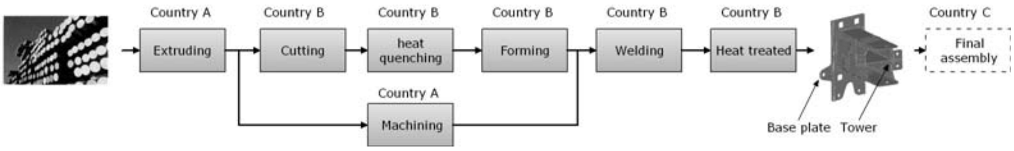

Figure 2. A typical simplified description of an industrial process

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.

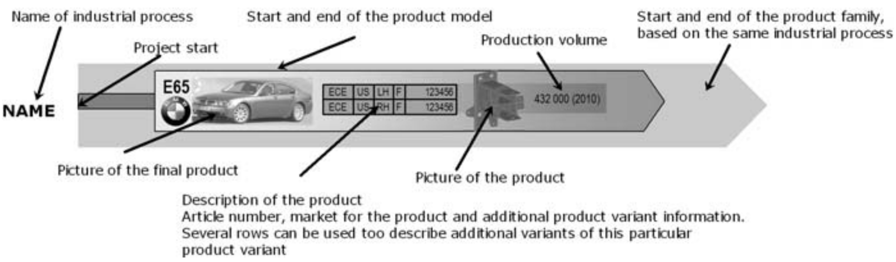

Figure 3. Notation and information in the product history description. Graphical elements ease the communication. Illustrated with one product model and two variants of this model, one for the left side and the other for the right side of the car

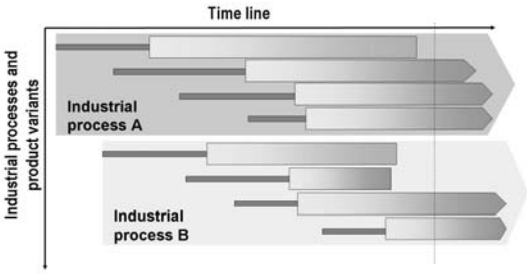

Figure 4. Illustration of two industrial processes with product variant boxes. X- axis is the time line and Y-axis is the industrial processes with product variants. Some of the product variants are out of production and this is indicated with a rectangular box and the current date is indicated with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

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.

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.

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.

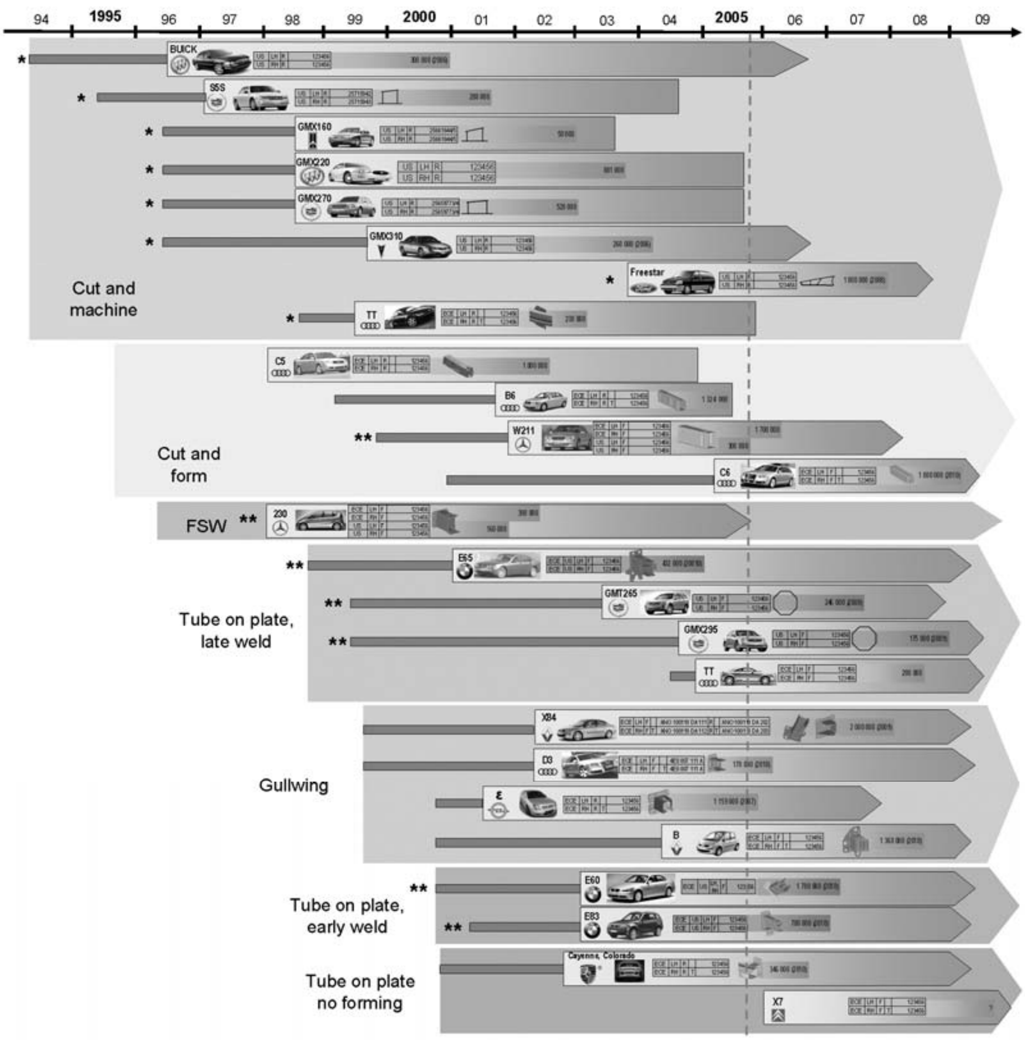

Figure 5. The description of crash boxes with all the product variants grouped by the industrial processes. Products with no * marking are design after Danner requirements. *= products are designed for CMVSS requirements, ** = both requirements are used

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.

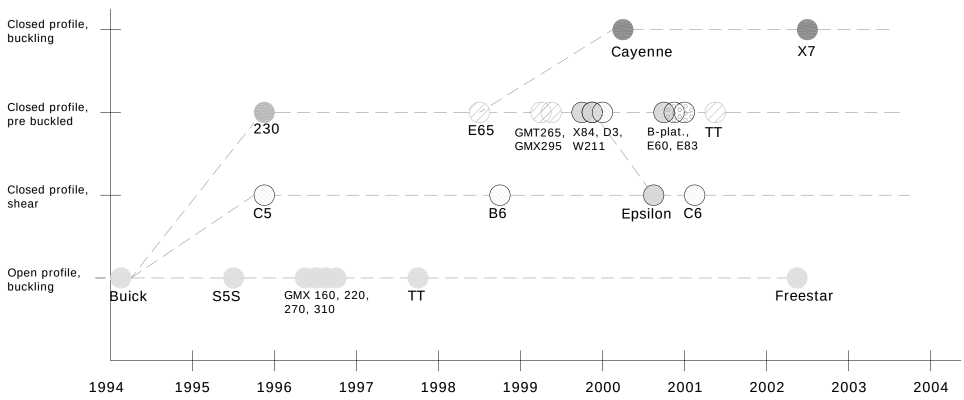

Figure 6. A historical picture of the evolution and mutation to the crash boxes from a functional view point. The figure indicates the project start time and the colour / pattern represent the industrial process

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.

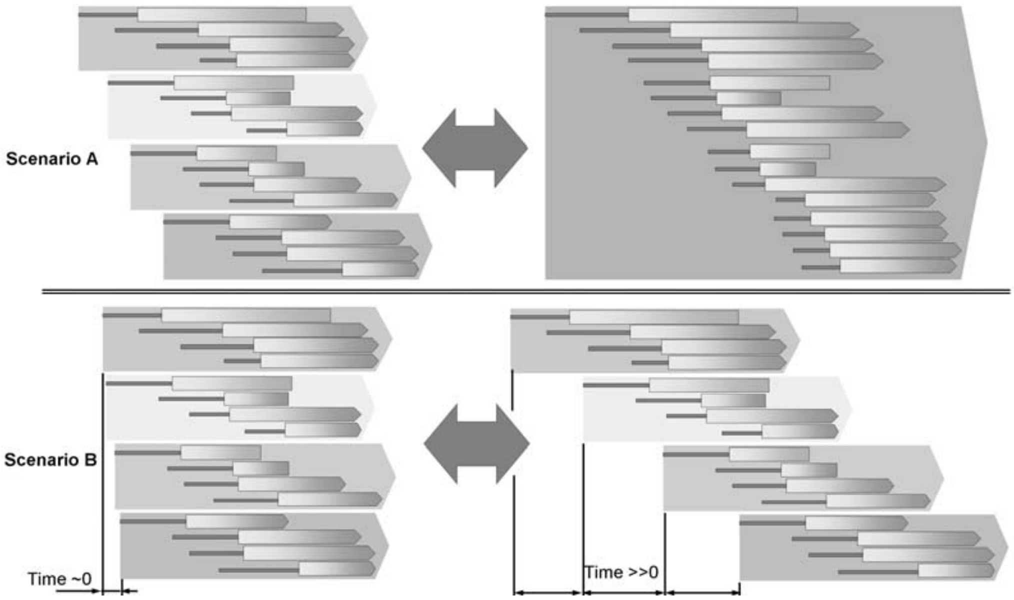

Figure 7. Possible scenarios of the historical description: Scenario A illustrate multiple industrial processes compared to one industrial process to manufacture the same products, Scenario B illustrate the time of introducing the products too the market

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.

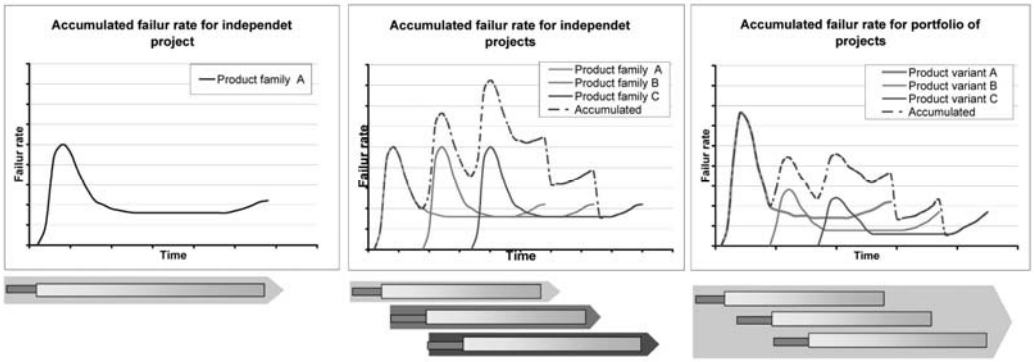

Figure 8. (A) Typical failure rate of manufacturing a product, a high failure rate in the begining, a steady period and increased wear in the end [Blanchard 2004], (B) failure rate of manufacturing multiple independent products and accumulated failure rate, (C) failure rate of multiple products that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

Reference

Blanchard B.S., "Logistics engineering and management" Pearson Education International, sixth edition, 2004

Jensen, T, and H.P. Hildre "Product platform performance in meeting with the manufacturing", Proceedings of the Design 2004, Dubrovnik, 309-316

Jiao, J. and Tseng, M.M., "Customizability analysis in design for mass customization", Computer-aided design 36, 2004, 745-757

Meyer M.H., Dalal D. "Managing platform architectures and manufacturing processes for nonassembled products". The Journal of Product Innovation Management 19, vol 4. 2002, 277-293

Meyer, M.H. and Lehnerd, A.P., "The power of product platform" The free press, 1997

Sanderson, W.S. and Uzumeri, M., "Managing product families", Irwin, 1997

Mortensen N.H., Skovgaard H.J., Skovsen F., Vølund L. " Improving business by conceptual modeling", Booklet from DTU, Department of Mechanical engineering, 2001

Robertson, David and Ulrich, Karl 1998 "Planning for product platform", Sloan Management Review; Summer 1998; 39, 4, 19-31

Yourdictionary, http://www.yourdictionary.com/ahd/i/i0116800.html 2005

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