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PRODUCT FAMILY DEVELOPMENT AND MANAGEMENT: ARCHITECTING FOR MAXIMUM PROFITABILITY

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Abstract

Every company has the business objectives of maximizing customers' satisfaction as well as its profitability. Typically, companies offer a large spectrum of variants in their products to satisfy varying customer needs. For example, a camera manufacturer may wish to offer variety such as fixed focus, auto-focus, variable zoom, different zoom ranges, SLR, APS, and digital cameras, and in different combinations, to satisfy customers with different demands (including the price that they wish to pay). The business goal, therefore, is to design a product family that meets maximum customer choices but at a minimum cost so as to maximize the profit margin. These two objectives, choice and profit margin, are not as contradictory as they seem. In this paper, we show that by using a systematic process of analyzing an existing product family's variety and re-designing it, one can indeed meet both objectives. This paper also discusses how to manage and sustain profitable product families.

Keywords: Product platforms, product families, product structuring.

1 Introduction

ABB Robotics wanted to design a new family of robot controllers satisfying its customer demands as of today and as they change for the future, as well as reducing the product cost by at least 25%. In this product development project, the product family needed to be defined in its variety (customer options like IO interfaces, electrical drives; and choices in each option like analog IO or digital IO) that meets customer demands as well as maximizes the product's profitability. In another project, ABB Instrumentation wanted to streamline its range of magnetic flow meters (to measure any fluid flow capable of carrying electro-magnetic flux) produced at three production units, in three different countries, that have little sharing of components across their products although all serve similar functional purposes. In this project too, the flow meter variety (customer options like meter size, electronic display; and choices like meters varying from 3 mm to 2.5 m in diameter) needed to be determined for maximum profitability and customer satisfaction. In both these projects, we architected the product variety to achieve maximum profit and optimum customer coverage through a systematic method containing three major steps:

1. Determine functional variety: Here the functional requirements that vary from customer to customer are determined. In this step, customers and sales personnel are interviewed to analyze the existing functional variety and the future trends.
2. Determine profitable product variety: Using statistical analysis & optimization methods profit patterns from the existing product choices are analyzed. This method is based on the principle that a particular variety offered to customers is only satisfying to them if a) it functionally meets their requirements and b) the price they wish to pay is proportional to this functional satisfaction, and also based on the fact that the

company must meet its cost targets to be profitable and remain in business. This method uses cluster algorithms to compute changes in profit margins with changes in product family. Here we also present methods to model revenues and costs as a function of variety. These models will enable designers to consider business rationale (i.e. profit per variety) while designing a product family.

3. Design for Commonality: Using results from the above two steps, design changes are determined to maximize the product family's scope of meeting customer functionality at minimum cost.

2 Related Literature

In today's competitive global markets, a product family must be flexible enough to be mass customizable [1]. To profitably sustain a product family over time requires a sound product platform approach [2,3]. This area of research is well advanced from two points-of-view:

1. Design for Variety (or, in another sense, Design for Commonality) [4,5,6,7]: here minimum component variety to satisfy maximum functional variety is the main focus. This design-focused area of research also includes the theme "Design for Modularity" [3,8,9], where modular designs are to be combined to achieve functional variety at minimum cost.
2. Common and Modular Processes [3,7,10]: Here variety in processes to manufacture the design is minimized to minimize costs. Note that the product platforms approach takes into account both these points-of-view simultaneously.

However, the research on product family design from customer demand point-of-view, and how to use these demands to design the product, and to maximize profitability of a company are still in conceptual stages. Papers in this area [11,12,13] use an approach based on functional aspects and statistical algorithms to determine attributes (e.g., weight, speed, noise) of a product family. In our research, we have expanded their methods in three ways:

1. Revenue modeling: We have formulated and tested multiple ways of calculating the effect on a company's revenues with changes in variety in a product family.
2. Costs modeling: We have formulated a link between a product family's variety and the fixed and variable costs of providing that variety.
3. Algorithms to determine design attributes: We have introduced a computational algorithm based on the idea of cluster algorithm [11], and Pareto (multi-criterion) optimization to determine the most profitable design attributes.

We use the above methods jointly to determine optimum variety that maximizes profits and yet covers key revenue generating customer demands. In this paper, we present this method in detail.

3 Designing The Product Family Architecture

We explain our design process, introduced in Section 1, with our experience and results in designing Robot Controllers and Magnetic Flow Meters.

3.1 Determining Functional Variety

Functional variety serves to satisfy various needs of customers. For example, customers choose various power ratings for electrical drives in a robot controller according to their robot's operational needs (a robot carrying large weights requires higher torque, which in turn requires a high power electrical drive). From a company's point of view, these needs also define customer-segments – groups of customers needing specific functions. For example, customer needs for robots operating in a foundry are different from those operating for welding. Such segmentation is a very important factor in architecting a product family – to design its functional variety and offer it at right price. Therefore, determining right functional variety is essential to

1. Differentiate customer segments and thereby determine market capturing product variety and its pricing: For example, magnetic flow meters need to be corrosive and abrasive resistant as per the fluid flow they need to measure. These requirements are of high importance for chemical and pharmaceutical customers (customer segments) who can pay a good price for the value they get (high quality, resistant design), but are not so important for customers in wastewater segment who need a cheaper product.
2. Design the product variety at lowest possible cost: A functional variety that can serve several customer segments, and few physical variety (parts, components, etc.) that can serve for several functional variety will always have high potential to reduce product cost. For example, Hastelloy based flow meters can serve corrosive as well as abrasive needs, thus serving both chemical and pharmaceutical customers, although it can also serve for wastewater measurement price demands require another solution.

We determine functional variety for a product family through the following steps:

1. Understand existing functional variety for the product family in business
2. Identify customer demands as of today and for future
3. Evaluate the identified variety with design, production and business logic (i.e., technical feasibilities, estimated costs and profit potential, etc.)

In this process, we interview several stakeholders of the product family – customers, sales engineers, product managers, designers, business managers and service units. For example, while re-designing for robot controllers family we found out that many customers would like to have an IO board which can read both analog and digital inputs at certain configurations.

3.2 Determining Profitable Product Variety

After determining functional variety, we determine the product variety – customer options and choices (as illustrated previously) – that can maximize a company's profit. An overview of this method is shown in Figure 1.

3.2.1 Product Variety Model

The functional variety, determined as described in the previous section, is categorized according to factors that clearly distinguish customer needs, revenue creators, and cost drivers. For example, variety in flow meters are categorized according to their sizes (in mm), materials (for corrosive resistance), regional standards (CE, US and Canadian regulatory standards), and display/electronic options, because this variety varies from customer to customer, and revenues & costs of the company can be broken down to these ***variety categories***.

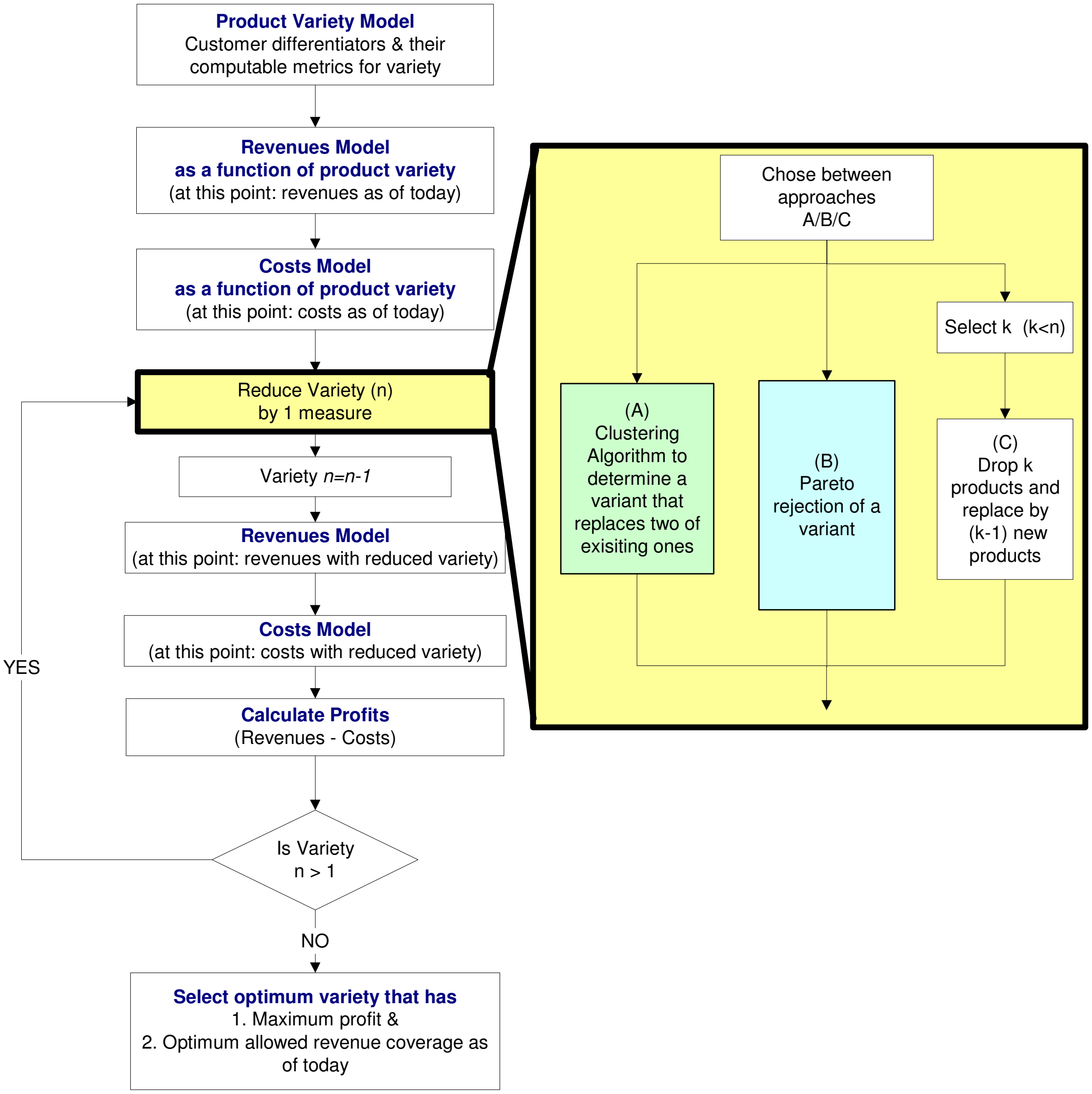


Figure 1: Method for determining profit maximizing product variety.

3.2.2 Revenues Model

Say, each *customer j* wants their ideal target τ_j but we offer him *x*. The price P_j that a customer is willing to pay for that offer could be:

$$P_j = P_{0j} - w_j \left(x - \tau_j\right)^2$$

where P_{0j} is the ideal revenue we can get, and *w* is a sensitivity factor that reflects how fast revenue drops when we change variety (e.g. price needs to be adjusted steeply low for high priority functions). Thus, if we were to offer *x* to all customers then the revenue we get is:

$$R = \sum_{\text{customers } j} \left\{P_{0j} - w_j \left(x - \tau_j\right)^2\right\} = \overline{R}_0 - \overline{W}\sigma^2$$

In other words, revenue reduces proportional to the standard deviation – or the dissatisfaction of customers for not getting exactly what they want (this model also includes customers who will not buy because of the difference). This σ is obtained from existing customer preferences and how many customers have bought existing variety at what price. Therefore, the redesigned variety's revenue potential is estimated from σ which is obtained from the product family's sales performance as of today.

3.2.3 Costs Model

Costs are also modeled according to product variety and using Activity Based Costing (ABC, [14]) principles. However, because accurate costing is time consuming and such detail is not required at this stage of analysis, we use a simplified costs model containing Fixed Costs and Variable Costs of Variety. Fixed Costs of Variety (FCV) are costs independent to the extent of variety in a product family (i.e. costs that occur even if no products are sold). These are usually building rent, machine depreciation, etc. Variable Costs of Variety (VCV) depend on extent and volume of product variety. These are usually material costs, assembly work hours, etc. We use the following steps to model Fixed Costs of Variety (FCV):

1. Determine fixed cost components of a company – Administration, Depreciation, Rent and Utilities, Office expenses, etc.
2. Determine share of those fixed costs for the product variety in consideration – this is usually done in consultation with sales engineers, product owners and management (for example, if certain products are sold directly over Internet they carry little or no sales overhead).
3. Determine how these fixed costs change if we change variety. For example, it takes large investments (building, etc.) to expand certain product variety, and only a small change in assembly process using existing machines in case of another variety (hence no added fixed costs).

We use the following steps to model Variable Costs:

1. Determine what costs vary along with volume of products produced in that variety category – material, number of machining/assembly activities, number of people, etc.
2. Fit a mathematical model of varying costs as a function of volume of variety that is produced, and the above cost drivers. In order to simplify the model, one can model according to selected (major) cost drivers rather than to fit for all of them.
3. Determine how these variable costs change if we change variety. The algorithm (Figure 1) will estimate volume of products that a company can sell with a changed variety. Given that volume and material and other cost drivers information, this costs model will estimate variable cost component.

Total cost of product variety is sum of Fixed and Variable Costs, and profit is obtained by subtracting this cost from revenues.

3.2.4 Variety Reduction

Consider the revenue distribution in Figure 2 from a flow meter variety of sizes from 1 cm to 10 cm sold in the last 3 years (an illustration only). If all this variety is to be replaced by just two, what could be those sizes? From the revenue distribution, one can visualize two clusters – one at 3,4 & 5 cm, and the other at 7, 8, 9 & 10 cm. Using cluster analysis, weighted with revenues, these two sizes could be computed as 4.1 & 8.2 cm. The customer dissatisfaction (σ) with these two sizes can be computed from the number of customers & revenues from the known data. Such clusters are sequentially determined from the known data of 10 levels up to single choice as shown in Figure 2. Using the σ, the number of customers at each new cluster is estimated.

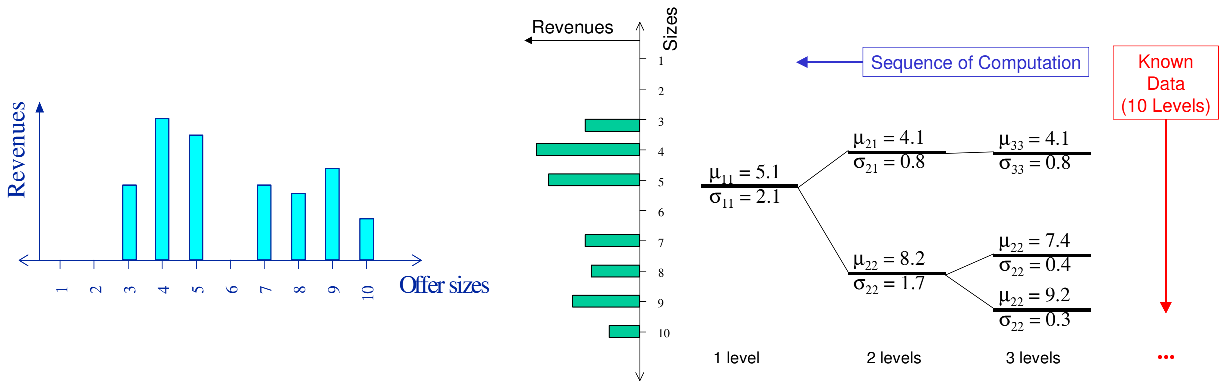


Figure 2: Illustration of revenues in a product variety category (left), and computation of new variety values given the revenue distribution (right).

Using the revenues and costs model, and given new variety values & number of customers from cluster algorithm, we determine changed revenues and costs at each level. Figure 3 shows results in case of variety in flow meter build & casing types (actual revenue and profit values have been edited to preserve confidentiality of our client).

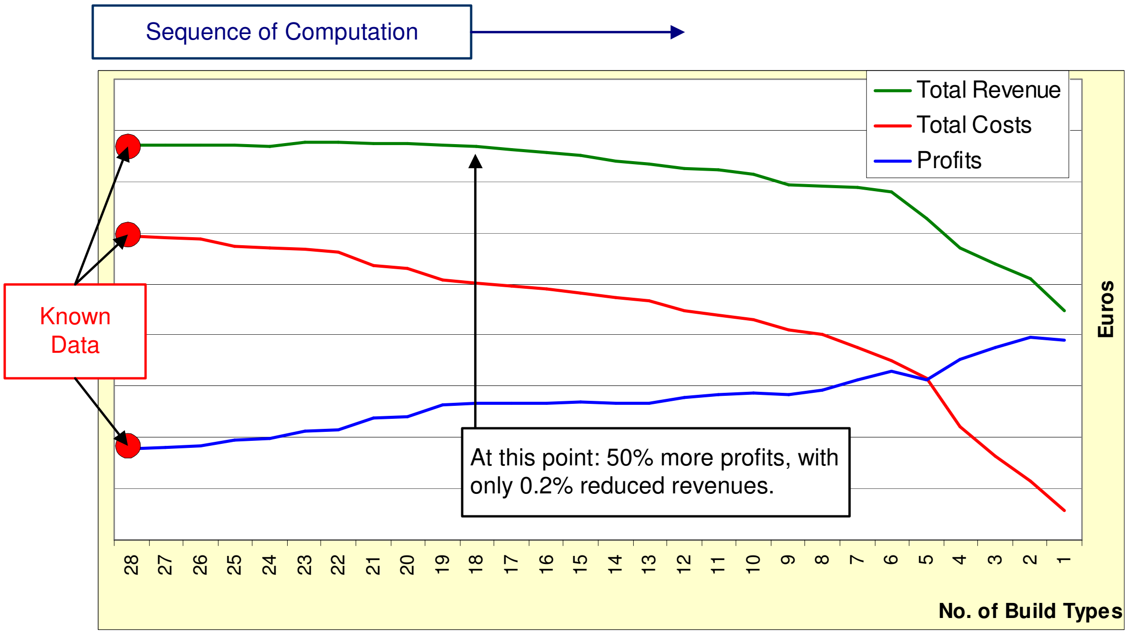


Figure 3: Using the revenue, cost and cluster algorithms, we found that 18 types of build & casing designs will result in 50% more profit, without compromising existing customer revenues, as of today's profit with a variety of 28 types. Our method also determines design values (like sizes) for these 18 types.

At each step in the iteration (see Figure 1), the cluster algorithm computes variety from n to $(n-1)$ levels by replacing two of the weakest candidates (those that have lowest revenues and farthest from rest of variety) with a substitute $x_j^{(n-1)}$ using the formula:

$$x_j^{(n-1)} = \frac{\sum_{i=1}^{N} w_{i,j}^{(n)} \cdot x_i^{(n)} + \sum_{i=1}^{N} w_{i,j+1}^{(n)} \cdot x_i^{(n)}}{\sum_{i=1}^{N} w_{i,j}^{(n)} + \sum_{i=1}^{N} w_{i,j+1}^{(n)}}$$

where the w are revenue proportional weights. Note that the distance scale represents customer differentiation. For example, wastewater segment usually requires large flow meters compared to pharmaceutical customers who need small and precise ones. Here size can be used as a differentiator. In other cases (e.g., non-numeric scale such as color as a customer preference), the differentiation scale is arrived through results from customer interviews (priorities, overlapping needs, etc.).

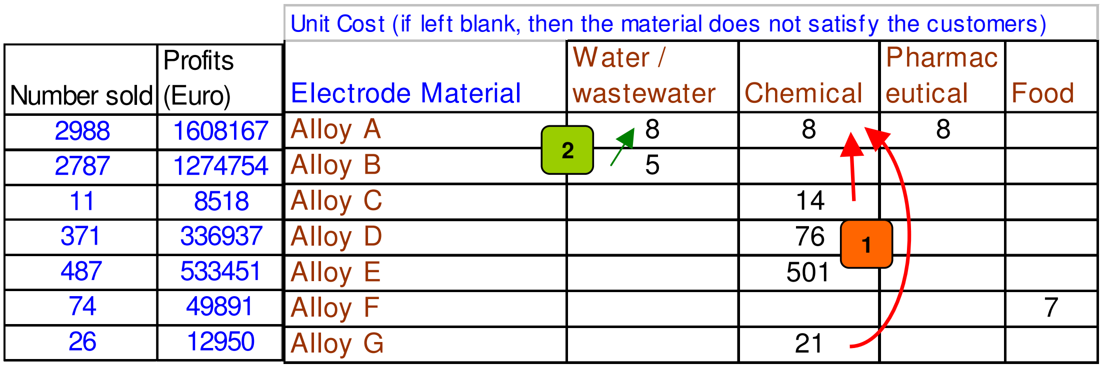
We also use two other algorithms for sequential reduction of variety: Pareto Rejection and K-Cluster approach – with or without manual overriding of variety values. In Pareto Rejection, the weakest variety values – those that have lowest revenues and are farthest from the rest of variety – are rejected using multi-criterion optimization (a farthest loner represents an exclusive customer preference, and low revenues means not many customers). Here revenue and the distance are the criteria. In K-cluster approach one can specify the number of clusters to extract from the known data. Detailed discussion of this algorithm is out of scope of this paper. Often business logic proclaims the new variety and how many of them to be introduced in a product family (e.g., new customer demands for new business opportunities). In such cases, the values found by algorithms need to be overwritten manually. In those cases, the σs will be recomputed, and revenues and costs are estimated in view of new business opportunities. According to various business contexts, we also use various revenue formulae:

1. Revenue with one offer ($R_{1\text{offer}}$) as value between minimum ($R_{2\min}$) and maximum ($R_{2\max}$) of revenues with two offers: $R_{1\,\text{offer}} = R_{2\max} + R_{2\min} \frac{\sigma_{2\max}^2 + \sigma_{2\min}^2}{\sigma_1^2}$. This model is most often used because it predicts reasonable drop in revenues with reduced variety. The results in Figure 3 use this formula.
2. Revenue with one offer as a proportion of sum of revenues with two offers: $R_{1\,\text{offer}} = (R_1 + R_2)\frac{\left(\sigma_1^2 - (\sigma_{21}^2 + \sigma_{22}^2)\right)}{\sigma_1^2}$. This model is used when revenue drops will be high or low, often influenced by market or other external factors (a multiplier as a weight can be introduced), according to the variety in consideration.
3. Revenue with one offer as sum of revenues with two offers (no loss of revenue): $R_{1\,\text{offer}} = R_{2,1} + R_{2,2}$. This model is used when reduced variety is likely to keep or even increase revenues (usually by meeting customer choices better).

Because the design process is an iterative process, the results from these algorithms must be crosschecked with relevant people as described in Section 3.1. For example, the design of IO board for robot controllers (introduced Section 3.1) resulted in a variety reduction of 40% with this algorithm in its initial iteration. During the cross verification, designers could realize a better revenue potential if they could create an IO board combining three existing designs. Such new substitute was technically possible. We immediately verified market attraction for such new design through sales channels and customer contacts. We received a very positive response from our customers. Based on this feedback, we have repeated the algorithm now using the additive revenue formula (third one above), and manually overwriting the new variety values for the new IO board. The end result showed even higher potential for profit increase because of cost reduction (the new design turned out to be 20% cheaper) and increased customer reach even though variety has been dropped by 40%.

3.3 Design For Commonality

The analysis method described so far derives business logic (revenues and costs per variety) and key design decisions (what variety values to change, and to which values) using the product variety performance as of today. These results are used to realize the product design using the concepts of Design for Commonality [4,5,6,7]. Here, the primary goal is to increase commonality in physical components to meet various customer needs, thereby reducing costs due to physical variety. Supplementing this research, we have developed a method to further bring in business logic in decision making during the design process. In this method, we have mapped physical variety to the functional variety, and along with the business results (profit & volume) from that variety as shown in Figure 4.



		Unit Cost (if left blank, then the material does not satisfy the customers)				
Number sold	Profits (Euro)	Electrode Material	Water / wastewater	Chemical	Pharmaceutical	Food
2988	1608167	Alloy A	8	8	8	
2787	1274754	Alloy B	5			
11	8518	Alloy C		14		
371	336937	Alloy D		76		
487	533451	Alloy E		501		
74	49891	Alloy F				7
26	12950	Alloy G		21		

Figure 4: Illustration of decision-making using business logic (profits & volume) and design for commonality reasoning.

Figure 4 shows various alloys satisfying requirements in four different customer segments. Each alloy has a purpose, and meets specific customer demands in its corresponding customer segment. In this figure we have simplified these differences to convey how the design process works. Using this matrix, we realized that Alloys C & G could be replaced by Alloy A (see item 1), because from our analysis the costs saving from variety reduction was more than the loss of profit (as not all customers will be satisfied with the replacement). Moreover, we found that Alloy A can be better served for Alloy B (item 2), and made cheaper because of increased volume in manufacturing. Currently we are developing this method further using DFMA [15] principles.

4 Sustaining Optimum Product Families

Because customer demands are dynamic, a product family evolves over time. We need to add products, accessories and features to meet the needs of new markets. As we belong to an industry where product life cycles span from 5 up to 40 years, we cannot discontinue production, service and support of old products. Thus our product portfolio invariably grows over time. Therefore, the efficient management of product families over time is a major challenge. In ABB, we are addressing this issue through frequent application of platforms related design methods such as the method presented here, and with information tools and organizational change. The latter two are infrastructure and organizational development. Here we describe overview of these approaches and challenges we face.

4.1 IT Systems for Managing Variety

Managing variety in a product family is an enormous information management problem. This is because, product variety generates choices at customer level with rules to determine feasible mix of these choices in various options (e.g., a high voltage transformer requires withstanding cables and expensive insulating accessories), components & parts at manufacturing level also with rules for feasible & efficient manufacturing (e.g. high voltage cables need more time to cure), and product support & service information specific to the variety. This information is (should be) realized during the design process, where all factors such as manufacturability are considered. An efficient product variety management has to deal with this information from its identification, representation, storage, and usage for various activities such as product configuration, manufacturing, service, and product development. We are currently working on an integrated system that connects sales configurators, PDM and ERP systems to improve information management for product variety.

4.2 Organizational Change

Implementing an efficient IT system to manage information is not enough for successful variety management. People – sales engineers, designers, manufactures, product managers, and service engineers – must share & understand priorities and common decisions to sustain profitable product variety. For example, product variety could not be managed well if a new product family shares very little with existing products. Often variety is added to satisfy special customer needs without checking on the long-term costs for a company. Such practices could only be changed with systematic change in organizational culture. In one of our product families, where product development is distributed in three countries and production in seven distributed locations, we are enforcing designers to share common components, and logistics to have common suppliers. This is a challenging task but an essential step for efficient management of product families, and keep them profitable.

5 Conclusions

Maximizing profitability of a product family while reducing variety, yet maintaining customer satisfaction & market share is possible. Using the analysis method presented in this paper designers and management can achieve these objectives. This was proven in two successful applications within ABB. Once optimized variety needs to be managed in order sustain its profitability. This needs to be achieved by continuous improvement – applying analysis methods such as described here, as well as enhancing information infrastructure and organizational behavior.

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