Product line development with customer interaction

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Abstract

While customizing their products, manufacturers attempt to fulfill specific requirements of the customers within the constraints dictated by the manufacturing (design, planning and production) environment, and by the economical necessity of earning profit. This paper offers a generic framework that captures more technical features of this problem than the marketing models: in addition to customer welfare and profit maximization considerations, engineering aspects are made operational, too. Driven by the interaction between customer preferences and the reallocation of manufacturing resources, viable product families emerge from a variety of technically feasible product alternatives.

Keywords: optimization, product development.

1. Introduction

In order to decrease the development, manufacturing and marketing costs of products, manufacturers usually prefer to develop several, related product versions in parallel. Treating such a group of product variants, the so called *product line* as a single unit is advantageous at all stages of the products' life cycle. However, unqualified commitment towards a group of products may produce adverse effects: in the short range, it may be cost effective to apply a single, well-established technical solution or to focus just at a specific need of the customers — but such an attachment may be disastrous when new technologies or requirements appear. On the other hand, keeping many product variants alive may be too expensive *within* (because of offering capabilities and interfaces not actually exploited) and too cheap *outside* since the customer may purchase a minimal product that meets no more than his present needs.

Section 2. draws a wide-angle view of production and marketing research on product line development, with an outlook to the evolutionary aspects of these questions. Section 3. offers a new, generic approach to closing the loop of engineering and economical decisions and introduces our product positioning model. Finally, we outline how to get manufacturing advice from the results, conclusions are drawn and open problems exposed.

2. Related work

The positioning of product lines is on the crossroads of engineering and economical research, however, neither the practitioners nor the academic circles pay due attention to the work of the other party. In order to bridge this gap, below the views of both communities are summarized, with special emphasis on their findings that urge for novel approaches.

2.1. Analytical and heuristic methods

From the management and marketing science point of view, product positioning aims to determine which combination of products should be offered to the customers, and on what prices, so as to maximize the total profit of the firm. Classical economical theory postulates that the full satisfaction of demand for variety can not be supplied because of increasing production costs [10]. Intuitive explanations and formal analytical approaches agree on the reasons for the mutual segmentation of offer and demand: upper segments of the market should be prevented from switching to lower priced products by providing less than ideal products for lower segments [24].

Others who refrain from exact solutions develop detailed cost and selection models and combine each customer's strive for his maximum *welfare* with the producers' intent to select a subset of the technically feasible product offer and set the prices so that the producer could earn maximal *profit* from the line. This setting leads to non-linear, mixed integer mathematical programming formulations [5, 6] and the application of heuristic optimization methods. Elsewhere, products in the line are generated by combining the promising attribute levels of partially defined products [17]. Relevant *perceptual attributes* of the products are selected for guiding the sequential elimination of product candidates in [15].

2.2. Empirical and descriptive research

Customization — in contrast with standardization — should begin at downstream activities, close to the marketplace, and may then spread upstream, towards fundamental design [9]. However, the renewal and succession of product families should be built on the *core capabilities* of the firm [16]. The interactions of modularity in products, processes, information structures and the organizations themselves should be discussed in terms of nearly decomposable systems while a "modular creation environment" emerges [19].

Performance analysis has shown that companies that invested parallel in process and organizational improvements have been able to shift the tradeoff between cost and product variety; this way "variety can be free to companies" [14]. Plants that decided to produce only a few products may be sacrifying new product flexibility and leaving themselves open to volume fluctuations [23].

Customization approaches have been classified along the types of the producer – customer interaction [7]: while the *collaborative customizers* conduct a dialog with the customer to articulate his needs and make dedicated products on the fly, the *adaptive customizers* provide a lesser number of products, each designed in such a way that the user can alter them — so it is not the producer but the product that interacts with the customer.

2.3. Evolutionary approaches

In this new line of research, product selection is deemed to be too difficult to be treated as an optimization problem. They call for dynamic and path-dependent models that allow for randomness, where success depends on cycles of *reorientation and convergence* and where the internal environment reflects the selection pressures from outside [3]. Strategies of localized adaptation and system-wide coordination have to be evaluated in a long-range time dimension: learning may teach outdated lessons and decrease the ability to compete with the *new* rivals. The interaction of positioning and pricing decisions may lead to situations where no stable solution exists: firms compete towards central positions to gain market share by under-cutting their competitors' prices. However, as the customers' needs are getting less homogeneous, stable *positioning patterns* of several competitors may emerge [2].

The *local search* nature of innovation has been attributed to the limiting role of *organizational routines* that are bound to generate similar responses to similar stimuli: organizations search for novel solutions close to their established technological base [22]. Since the accumulation of competitive advantage can be self-reinforcing, non-linear effects are likely to occur and lessons of chaos theory may be relevant [11]:

while long term planning is essentially impossible and dramatic changes may occur unexpectedly, short term forecasting *is* possible, and "the best strategies might achieve goals indirectly and even appear counter-intuitive". The most important skills are in anticipating the *shape* of the future, like intelligence operations do [20]. On the road towards evolving products, the processing side of product–driven, dynamic, reconfigurable manufacturing systems — one of the first demonstrations of the Biological Manufacturing Concept — has been shown in [27].

2.4. A production engineering perspective

The need for manufacturing technology that "costs the least for single production" and for consumer-oriented design was asserted a decade ago in [29]. Having analyzed the closed loop in social impacts of production, [18] warns that profit should be the satisfaction of the whole community through the optimal use of its resources.

Intricate relations of delivery satisfaction and efficient production have been explored by [1]. At early stages of product development, preference biased towards available tools and components leads to decisions with small *committed costs* at the expense of the development of original designs [21].

The challenges of a mass customization oriented product family architecture have been exposed first in [25]: our attempts here are aimed at adding operational power and exploring the economical side of a similar problem setting. Further, closely related items are discussed with the directions of our further work.

3. Modular product positioning

While the above mentioned product positioning models look at the feasible products as indivisible entities with fixed costs, our, novel approach of *modular product positioning* is concerned with a model of two structural layers. As usual, the customers select from among the available products (this is the *outer layer*). On the other hand, the manufacturer alters either the actual product offer (without technical changes) or introduces new products or processes. We assume that these technical changes effect similar components within several products in parallel: this way a modular structure of the products will be created or renewed. The modules (both physical ones and processes) make the *inner layer* of the model. Additional dynamics of our model, missing from earlier ones, comes from the interaction of the two layers.

The other novelty of our approach is that — in accordance with the lessons of evolutionary approaches — we do not want to stop at a single, "best" solution but aim at getting several good-enough product line variants to be used in a framework for experimentation with product development alternatives and paths.

The practical use of such a model could be illustrated with a scenario as follows: Having introduced a *product platform* (a product line, and its manufacturing environment), it may turn out that some of the product variants are far more preferred as predicted, while others — although they are equally sound in technical terms — are not favored by the customers. Within the limits of the same platform, how should one modify the products, processes, costs and prices?

Some of the straightforward answers are confined solely to the economical dimensions of the problem: Change advertising policy to call more attention for the products; declare preference towards specific product variants with guaranteeing some bonus; introduce option-packages with special advantages. Further suggestions, driven by economical considerations, have a true manufacturing dimension as well: Freeze in some product attributes, prune the alternatives: this may result in simplified design and more efficient procedures. Extend the high end of the product line to attract further buyers; extend the line downwards in order to increase the use of resources and to ensure larger total production volume. (The latter may be the wrong choice if it deteriorates the customer image of the brand, and, in both cases, the new products may cannibalize the well-established, cost-efficient products.)

Certainly, the innovative answers are those driven by the engineering core of the problem: Decrease actual cost to give more freedom in positioning and pricing. Redesign the products, increase the level of modularity. Rearrange the operations in such a way that intermediate products may be shared in a larger extent. Recognize the situation when it is better to cancel the improvement of the present line; then start to develop a new product platform or stop the manufacturing of the product line.

3.1. Products, producers and customers

Our basic assumptions concerning the *product* are as follows: (1) it is a durable, physical product that fulfills some well-articulated requirements of the customers; (2) it can be delivered in several variants of construction and/or technological parameters that influence both the production cost and the product's value for the customer (its so-called reservation price); (3) manufacturing of the products uses shared resources. In addition, (4) the product is purchased at a single action, with the option of no buying at all, and (5) usage, maintenance and disposal aspects could be judged at the time of purchase. In other words, this model could not be applied to products that are either (1) frequently bought (short term effects of advertising and variety seeking of the customer are not considered); or (2) purchased by a sequence of events, by adding/replacing some features and/or modules. Products aimed at novel, not articulated customer needs could not be modeled this way, either.

Each product is described as a vector of its $(attribute, value)$ pairs. The description is "flat": the modular structure belongs to the semantic level. The attributes are either technical ones (i.e., construction or technology related), or describe the functional profile of the product from the customers point of view. The attributes are either from discrete, ordered scales or nominal values (such as identifiers in catalogs). The scales are of two kinds: those with a sense of monotone change over their range, and those with an optimal value for the customer. Infeasible combinations of attribute values are handled by setting a very high cost value to the product variant.

The *producer* intends to maximize its profit (the sum of prices minus costs) on the line as a whole. Competition with other manufacturers is captured by giving the customers the option of not to buy from these products: however, the foreign products have fixed parameters and prices, i.e., mutual retaliation answering competitive actions is not considered here.

Costs are assumed to be *close* to proportional both to the functional qualities and to the technical content of the product (but there is no need to be strictly additive). Cost per unit should be a decreasing function of production volume; this comes from the smaller share per product of initial investments (from research to advertising) and from the learning effects in production. A zero volume production may have a non-zero cost at keeping a product option alive. Further details of the actual cost calculation scheme are considered as exogenous factors: however, the assumptions above are enough to make the offering of subsets more profitable than offering the maximal, technically feasible variety of products.

The *customers* are represented by a number of customer groups. Each group has its demand towards the products in the line. The buying behavior and power of each group are represented by the *reservation price* (the maximal acceptable price, or "true value") for each particular product. Members in each group decide uniformly about what to buy (or not to buy). The groups are considered as fixed in number and in characteristics and these are known by the producer.

The reservation prices are supposed to be close to proportional to the product's functional qualities, added up with weights that may change from group to group. For each attribute, the valuations could be either (1) sigmoids, with different slopes and horizontal segments (e.g., at an efficiency-like attribute each customer prefers the higher values, but he may be willing to offer not more than 5% increase of the reservation price for 10% improvement of the attribute value that may be produced with 15% increase in actual manufacturing costs; in addition, the minimal acceptable and highest distinguished levels may be different from group to group); (2) bell-shapes, with maximal reservation price at some ideal value; and, (3) unstructured. The reservation price may show second-order effects: some combinations of the features may be more (or less) valued than the sum of the part-worths.

Each customer group strives to find its maximal welfare: it buys the product with maximal difference between reservation price and market price. If all these differences are negative, no product will be bought by that customer. Considering a given offer of products, fixed market prices and reservation prices, the customers' decision is deterministic. However, when the set of product variants or their prices change, this may re-arrange product selection — as a consequence, cost and profit at producers, as well as the welfare of the customers are altered, too.

3.2. The product positioning heuristic

As motivated earlier, our aim is to find a variety of close to optimal solutions to product positioning (pricing included). The solutions will be analyzed and serve as pieces of advice to be weighted by engineering judgment in (re)setting product positions.

Product positioning could be formulated as an optimization problem whose exact solutions are hopeless to find but in the smallest cases; hence, the use of a heuristic approach is indeed inevitable.

The number of customer groups is N, that of the products is M. The 0-th product represents the no–buy option. Input data are as follows ($i = 1, \ldots, N,\ j = 0, \ldots, M$):

- c_j cost of manufacturing the j-th product
- o_j 1, if the j-th product is ours, 0 otherwise
- $v_{i,j}$ reservation price of the the j-th product for the i-th customer group
- w_i size of the i-th customer group.

For the no-buy option $c_0 = 0$, $v_{i,0} = 0$. Although the costs may be made dependent on the actual selection values, this feature has been omitted from the formalization here.

The output data sets have one more index to refer to the R product line variants (PLVs) $k = 1, \ldots, R$:

- $p_{j,k}$ price of the j-th product in the k-th PLV
- $s_{i,j,k}$ 1, if the i-th consumer group selects the j-th product in the k-th PLV, 0 otherwise.

Further characteristics of each PLV can be calculated from these output data: the total volume of, and the profit earned by each product. Each PLV has to obey the following inequalities for all indices: $c_j \leq p_{j,k}$, i.e., each product has to be profitable for the producer; $p_{j,k} \leq v_{i,j}\ whenever\ s_{i,j,k} = 1$, i.e., the selected product has to be of higher reservation price than its price. Finally, the selected product has to be that which yields the maximal welfare for the customer: $if\ s_{i,j,k} = 1\ then\ (v_{i,j} - p_{j,k}) = \max_{j'} (v_{i,j'} - p_{j',k})$.

At starting the search for a PLV, prices are set equal to costs for our products and the known, fixed prices of the foreign products. The search consists of alternating steps by the Producer Agent (PA), the Consumer Agent (CA) (the use of a single CA for making all the customers' decisions in parallel means that the customers' decisions are independent from each other), and the Search Control Agent (SA):

while more PLVs needed **do**
begin
  PA sets new prices of some products;
  CA finds the maximal welfare selection of the costumers;
  PA modifies the costs according to volumes needed;
  if good enough PLV found **then** SA saves it;
  SA modifies the search strategy of PA;
end;

The PA uses four kinds of steps (k below stands for any state of the search):

1. Raise price of product j to the selection threshold: increase $p_{j,k}$ up to the maximal value where all customers with $s_{i,j,k} = 1$ still remain at their selection. This step is a greedy profit increasing action.

2. Raise price of product j to the threshold that forces c ($c = 1, 2, \ldots$) customer(s) to select some other product(s). This price rise may increase profit by increased price - cost differences, and by concentrating to fewer products, some with decreasing costs. On the other hand, this step may decrease profit if some customers are forced not to buy or to buy from other producers.

3. Raise price of product j randomly, within a range that results in discarding c ($c = 0, 1, 2$) customers. This allows more price change paths; some of them will go into regions not reachable by paths made solely of previous kinds of steps.

4. Decrease price of product j randomly, within a range that attracts c ($c = 0, 1$) more customer(s). This step is to pass local optima.

The strategy parameters of PA tell to which product to apply these steps and how to mix them; these details will be reported in a forthcoming paper.

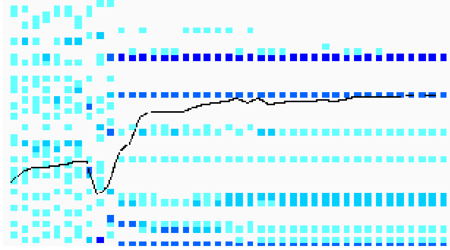

Fig. 1: The product line formation path: darker dots are products selected by more consumers, the thin curve indicates the profit produced by the PLVs

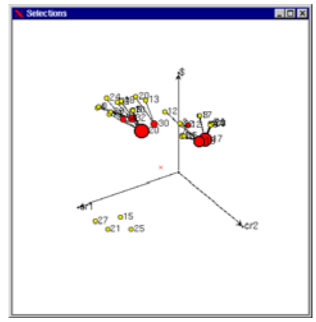

Fig. 2: Product selection: the horizontal axes are for two requirement coordinates, the upward axis shows the reservation prices (smaller circles), and the prices of the products (size proportional with the selection frequency). Some customers do no buy, most (but not all) purchase products that are worse than their preference point

A simpler search with greedy price increase has been reported in [6]. However, that search gave *single*, sub-optimal PLVs on large-scale, random problem cases that have been generated with the cost and reservation price assumptions as outlined here. In contrast, for the same random cases of up to 100 products and 100 customers, with the above search method we have reached, within a few minutes, a *variety of PLVs*, made of different products, each in the 5% range from the best–ever PLV.

3.3. Manufacturing consequences

As for the first experiments with PLVs of real products, a catalog of engineering microscopes was considered. The modules were of two kinds: sets of objectives and eyepieces, described with the magnifications of the lenses, the field of view of the eyepiece and the working distance of the objective. Customer requirements were specified with the magnification and working distance of the microscope made of these modules. The use of this data was hindered by two problems: first, from the market price quoted in the catalog there was no way back to get *costs* of the modules and the products themselves, second, a similar problem with the customers' reservation prices. In addition, the dependencies of product capabilities and customer requirements were *separable* in the sense that the working distance of the microscope depended on the parameters of the objective lens only. Other candidates for requirements (such as depth of view) have shown similar separable behavior.

To overcome these difficulties an artificial problem set was created with two dimensions of technical capabilities (C_1 and C_2) and of customer requirements (R_1 and R_2). R_1 was the example of a requirement whose levels can be generated by the two kinds of modules with *multiplicating effects*, such as the overall magnification of the microscope. R_2 gave the example of a parameter where best values could be got by pairing modules that both belonged to the middle range. Since the customers prefered higher values of both R_1 and R_2, the capabilities C_1 and C_2 were in conflict.

Having settled costs and reservation prices as discussed above, several different PLVs could be generated within a 10% interval of the maximal profit ever achieved; this indicated that one should try the various engineering improvements that may further change the costs of the products.

For the analysis of the set of the PLVs no uniform method could be offered, since the actual engineering content of the abstract model has to be considered. A generic analysis scheme should be based on the following concepts: (1) different PLVs that earn similar profit should be seen as *neutral manufacturing alternatives*; (2) product variants (modules) included in several PLVs with high profit should be seen as *key product variants (modules)*, they should be foci of efforts towards manufacturing improvements. Similarly, one could find the *irrelevant product variants and modules*. The *inline* and *own* values of the products (modules) indicate the profit-earning capacity of the line as a whole and the specific product (module).

In specific settings, one could check more specific hypotheses: e.g., if the interplay of several technical capabilities C_j yields a single customer requirement, then a product offer with the free combination of the C_j values may be unnecessary; in such a case the PLVs could be used to find those subsets of values for C_js that are just enough to offer enough variants in a more cost-efficient way.

However, due to the nonlinear nature of the models, the analysis, manufacturing improvement and repositioning steps may not be used for building up long scenarios of innovations: after each step human judgment has to check the credibility of the results and tell what to explore next.

In conclusion, we claim that the generic product positioning tool introduced here is a necessary, innermost element of a not yet existing, complex environment of experimenting with the interplay of manufacturing and economical effects. Based on real data, this tool will serve as a decision making aid in working out product line alternatives and investigating the innovation paths of products.

4. Directions of further work

In the future, connections should be worked out to well-established manufacturing models: Products of frequent demand should be handled as partially defined, *open structures* [13]. The model of direct and indirect *cost drivers and carriers* should be made more specific as in [12] and [4]; perhaps with control aspects [26]. *Life cycle issues* should be considered: e.g., the option content has to be tuned to match fashion effects that are most important after market entry, when innovative customers are gathering around a new product. Later in the life-cycle, the *customer decoupling point* should move to earlier stages of production [28]. Sustainable production would prefer long- or even everlasting products designed to allow the replacement of the weakest modules over again.

The economical side should be refined, too: First of all, the sensibility on reservation prices should be analyzed. As the customers' choices transform the product line, the decisions of the manufacturer reshape the structure of the customer groups. These mutual relations call for nonlinear techniques, such as the so-called "active walks" [8]. When offered at a low enough price, the customer may be willing to buy a product with a feature not *yet* needed, in spite of expectations that technical progress may later decrease the costs (and prices) of products with that feature. In order to arrive at the right decisions, the present value of uncertain, future expenses should be estimated with methods of evaluating real options.

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