Product Architecture Definition Based Upon Customer Demands

by

Janet Yu

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Signature of Author: ______________________
Department of Mechanical Engineering
May 17, 1999

Certified by: ______________________
Kevin N. Otto
Assistant Professor of Mechanical Engineering
Thesis Supervisor

Accepted by: ______________________
Ain A. Sonin
Chairman, Department Committee on Graduate Students

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ABSTRACT

Product architecture can have a large impact on the performance, cost, and profitability of a product. In particular, well-researched architecture design can be leveraged to maximum advantage when applied to a set of multiple products that share common elements. We introduce the idea of product portfolio architecture as the strategy with which products in a portfolio share or do not share features and define the three types of portfolio architecture: fixed, platform, and adjustable. These different architectures each optimally satisfy a different amount and type of customer variety, which we describe with the distribution of customer target values across the population and the distribution of target values for individual customer segments across their range of different product usages. These distributions indicate what level of variety should be provided to the market and how much that variety can be segmented and fulfilled by different products. This analysis of customer demands can help determine a successful product portfolio, portfolio architecture, and product architecture. Having compiled a list of suggested architectures for each feature, we look at methods for prioritizing them by impact on customer satisfaction. These results can then be weighed against the cost of offering that level of variety to design a portfolio suited to the market needs and evaluated for cost concerns.

Thesis Supervisor: Kevin N. Otto
Title: Assistant Professor

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Chapter 1: Introduction

Planning the architecture of a product is one of the most critical tasks facing a design team at the preliminary design phase. Deciding which approach to use when implementing a mechanical system has profound impacts on risk, performance, and cost [13, 19]. The majority of research in architecture and product platforming has been driven by the cost side of the equation, or 'how can I decrease the cost of providing variety?' However, this fails to address the issue of 'what level of variety *should* I offer given that I have different architecture options?' In this thesis we present a market-based analysis to help determine what architecture is appropriate for products in a portfolio. By analyzing customer needs across the population both at a single point in time and over different usages, we determine how market variation should be accommodated through the architecture of the portfolio and each individual product while taking advantage of resource reuse and established capabilities.

Overview

In this thesis, we present a method of incorporating data gathered on customer needs into the formulation of a product portfolio and its architecture. We start in Chapter 2 by defining the terminology which describes the core ideas upon which this research rests. In Chapter 3, we examine the benefits and costs of providing variety and introduce the tools we use to understand a customer population. The process by which we take customer need data and design a portfolio is described in detail in Chapters 4 and 5. Other methods of constructing a product portfolio and architecture are also described. Many of these approaches are not mutually exclusive but complementary to ours as they address the other factors that influence the development of multiple products. We illustrate our method with two examples, a small-scale exploratory study on instant-film cameras in Chapter 6, followed by a large-scale validation study also on instant cameras in Chapter 7.

Case Study: Polaroid

The Polaroid Corporation generously provided the testbed for this work, allowing us to study their Electronic Instant Camera (EIC) project which was under development during the period of this research. This project was part of a larger movement throughout the company to restructure itself and its product development processes to focus on its market segments. By studying

Polaroid, we sought to validate our method and provide Polaroid with a view of how it could plan portfolios and multiple-product projects suited to its wide target market.

Chapter 2: Architecture

First, we establish the terminology that will be used throughout this thesis to discuss the design of multiple products, the underlying structure of these products, and how these structures relate to another, namely product and portfolio architecture.

Product Architecture

Depending on the target customer population, as well as other factors such as ease of manufacturing and simplicity of design, a product architecture may be configured in various ways. For any given product, Ulrich [24] has defined *product architecture* as the strategy by which function is mapped to form. There are two main categories of product architecture, *integral* and *modular*, which are defined by (a) the relationship between functions and components, and (b) the interaction between components. An integral architecture implies complex mapping between components and functions and a high level of incidental interaction between components. A modular architecture exhibits one-to-one mapping between functions and components and only necessary interactions between components. For instance, a bike light with integral architecture might have an injection molded shell that simultaneously acts as a protective casing for the batteries and lamp, provides a mount for attachment to the bicycle, and holds the entire assembly together with snaps. A more modular design would fulfill the same functions with a plastic shell, a mounting pad, and screws. Since almost no products are perfectly modular, i.e. demonstrate completely uncoupled relationships between functions and components and have no unnecessary interactions between components, but do present some aspects of modularity, architecture should be seen more as a continuum, with integral and modular as its two extremes.

Product Portfolio Architecture

Although there are advantages to modularity when applied to a single product such as ease of design and facilitation of production, especially with outsourced components, modularity can be leveraged to much greater benefit when implemented in a set of multiple products that draw on common resources. We seek to examine this issue of appropriate product architecture when applied to several products at once. To this end, we will refer to the set of products a company offers a target market as a product *portfolio* and, further, introduce the term *product portfolio architecture* to describe the way in which members of a portfolio meet market variety by sharing or not sharing features. As a product consists of many features, a portfolio of products can demonstrate a combination of different portfolio architectures. In the remainder of this thesis, we will concentrate on defining portfolio architecture for an individual feature at a time. As we consider a single feature at a time across a set of products, we find there are three main categories of portfolio architecture: *fixed*, *platform*, and *adjustable* (Figure 1). The difference between these portfolio architectures is in how they offer variety to the market.

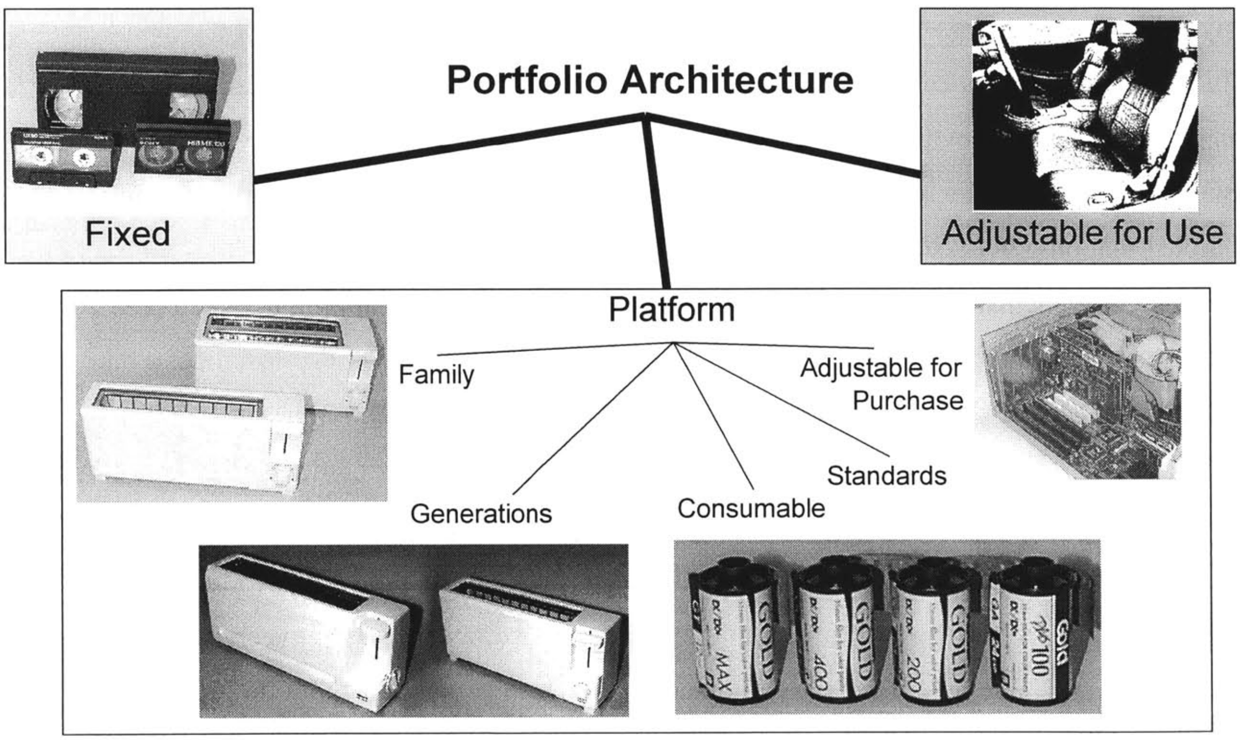

Figure 1: Various Types of Portfolio Architecture.

Fixed Portfolio Architecture

A set of products exhibiting *fixed* portfolio architecture for a specific feature offers a single option across the entire set. For example, Henry Ford's famously limited original line of automobiles demonstrated a fixed portfolio architecture for color in that black was the only option offered to customers. Offering one feature option may be an advantageous decision when there is limited variety in customer demands, a firm has a monopoly, or multiple options are prohibitively expensive to offer.

Platform Portfolio Architecture

On the other hand, a set of products with *platform* portfolio architecture for a specific feature offers variety through multiple options across the set. Usually this implies each product variant in the portfolio exhibits some form of modular product architecture. One of the main advantages of modular product architecture lies in the ability to remove or replace modules without affecting the rest of the design, thereby creating different products with minimal investment of time and resources. A product portfolio can capitalize on this advantage in two ways: at one time or over time.

A *platform family* consists of several simultaneously existing variants offering different feature options. Offering these options may be as simple as varying color or as deeply embedded as a change in core technologies. Polaroid's family of photographic slide scanners, for instance, offer three different level of scan resolution (Figure 2).

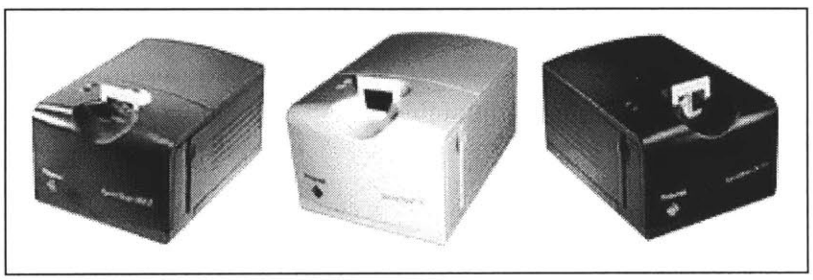

Figure 2: A Platform Family of Polaroid Scanners with Varying Levels of Resolution

We also define *platform generations* as products of the same architecture that succeed each other in time. For example, product lines that involve technologies that evolve rapidly benefit from the use of platform generations by isolating the modules that change. There are additional forms of platform portfolio architecture, including: *consumable platforms*, where the platform is disposable; *adjustable for purchase platforms*, where the variants can be custom configured; and *standard platforms*, where multiple vendors agree on and supply the platform. Many have studied the ways in which platforms have been used to provide variety cost-effectively [19, 22]. Their analyses of specific cases have demonstrated the multiple ways in which product platforms have allowed companies to reduce costs, taking advantage of modularity, commonality, and standardization.

Adjustable Portfolio Architecture

Lastly, an *adjustable* portfolio architecture offers multiple options through a single design which can be customized by the user. The customer can change the value of an adjustable feature at any time, unlike a fixed or platform feature. Household blenders with one (fixed) or multiple (adjustable) settings for motor speed demonstrate the difference between products with fixed and adjustable features (Figure 3). Adjustable automobile seats also enable several different feature values for leg room to accommodate drivers of different heights (Figure 1).

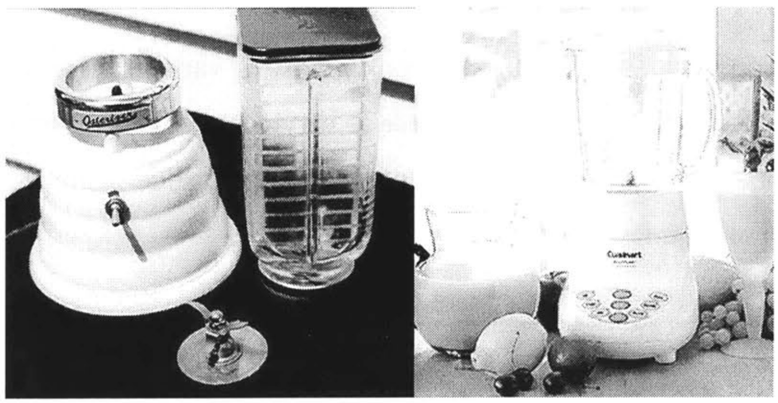

Figure 3: Fixed and Adjustable Speed Household Blenders

Chapter 3: Providing Variety

The study of architecture and portfolio planning exists primarily to handle the problem of variety. Variety as perceived by the customer exists in the array of products feature options available to them. Manufacturers on the other hand grapple with the variety of products, assemblies, and components they must produce and distribute. The advantages of architecture lay in maximizing variety to the customer, in other words the benefit of variety, while minimizing the cost of variety, i.e. variety to the manufacturer. We will discuss related work in this field and then the framework we use for evaluating both these types of variety.

Related Work

Increasing research into the area of variety has brought to the fore the advantages of product platforming and offered detailed success stories [22]. For example, the Sony Walkman platforms enabled Sony to dominate the market with rapidly developed products, tailored to the different needs of regional markets and unexploited customer segments. Mass production has lowered the asking price for multitudes of products previously created by less efficient methods and raised customers' expectations of quality for money spent. However, they nonetheless demand products tailored to their specific needs [21]. Burgeoning study in how to provide customized products at low cost has focused on the roles of product architecture, commonality, and reuse. However, the issue of what level of variety is appropriate for specific companies to offer to their target markets remains largely unanswered. This problem consists in itself of two complex problems, how to anticipate the costs of offering variety and how to evaluate the benefits. We will first discuss relevant existing work in this field before describing our own approach.

The majority of study on product architecture and commonality in an engineering context has been focused on estimating and decreasing the cost of providing variety. Henderson and Clark [13] showed that rearrangement of assembly processes and the product architecture to accommodate revised assembly can dramatically decrease cost. Cost reduction may also be brought about through delayed differentiation between products in a closely-related family and estimating the actual cost benefits of rearranging manufacturing processes through calibrated metrics, as explored by Martin and Ishii [18].

Function-based techniques have also previously been developed and used to evaluate the design of multiple products [8, 18, 23], as well as market-oriented methods for evaluating small differences between products. Function decomposition is useful from a design perspective in determining what amount of commonality between products is technologically possible and for exploring the design space for feasible additions to the portfolio. Krishnan examined the decisions to build successive product generations off a platform, given a certain amount of market demand for each product, and analyzed the system as a network optimization problem [15]. Previous market-oriented methods have focused on products for which the majority of the embodiment has already been determined [20].

One approach explored by Elgard is to implement variety as a method of dealing with market uncertainty instead of market breadth. The ability to offer a wider array of products, as built into the design of a product line, can be optimized by gauging how uncertain the desire for that added variety is [6]. Variety can be built in at any step of the value chain of a product line, which can be generalized as the sequence of design, fabrication, assembly, and distribution. At the initial phase, variety exists in the product concepts themselves. Different products are conceived as different product ideas with individual markets, embodiments, and manufacturing plans. At the design stage, reuse of the knowledge needed to design a product to design an entire portfolio reduces the expenditure of a company's resources. This knowledge commonality could be the core technology used in the products or the same general design scaled to different sizes but demanding distinct components. Variety may be introduced in the assembly stage by building a set of products from a common set of manufactured components but using different subsets in assembly to create distinct products, such as a line of automobiles with different upholstery or sound system options.

Where variety is built into this value chain results in varying levels of individual product optimization and portfolio flexibility. In general, the more a set of products has in common, the easier it is to adapt the production system of one constituent product to another's. The desire to optimize each individual product in a portfolio for performance and cost drives them to earlier divergence along the process flow, in other words introducing variety at the manufacturing stage rather than the assembly stage. On the other hand, flexibility and quick switchover to a different product mix pushes divergence to the latest possible introduction of variety into the process flow.

For instance, a toy manufacturer may decide to use paint to color plastic trucks rather than using different pigments during the injection molding process in case they find that yellow trucks become more desirable than the blue ones originally produced and suggested by market research. Thus, the level of uncertainty for a particular feature can help determine whether and how that feature should be designed into the product platform and at what point in the value chain that feature is set.

Looking at Variety

Since the benefits of variety lie in satisfying the varied customer population, we aim to create a model of the market that captures heterogeneous preferences. Using mean ideal points for the customer would clearly lead to tailoring products for the possibly non-existent 'average' customer, thus we proffer a method for designing products for the panorama of actual customers.

We propose here to produce a model of the market in terms of customer needs and then allow that model to determine up the portfolio architecture. The procedure is outlined in Figure 4. The first step in constructing the model is to identify the needs of the proposed customer population. The initial list of needs can be generated in a variety of ways: interviews, focus groups, or questionnaires [25, 26]. What we seek is a comprehensive list of the qualities sought by consumers when evaluating the product. We survey a statistically significant number of customers for the relative importance of each need using standard questionnaire methods. Taking the mean of the importance gives us an indication of the most important needs.

This assessment of the market is an on-going process to maintain a current view of customer needs. In addition to the methods described in this paper, new techniques are being developed to decrease the cost and time required to gather customer need data frequently, such as use of advanced simulation tools and the Internet [5], making this methodology available to smaller firms. Additional work exists on the evolution of rapidly changing technologies and how to predict their effect on future customer needs, such as technology S-curves [7] and lead user analysis [27]. Krishnan relates this need for flexibility in technology-driven fields to product architecture [15]

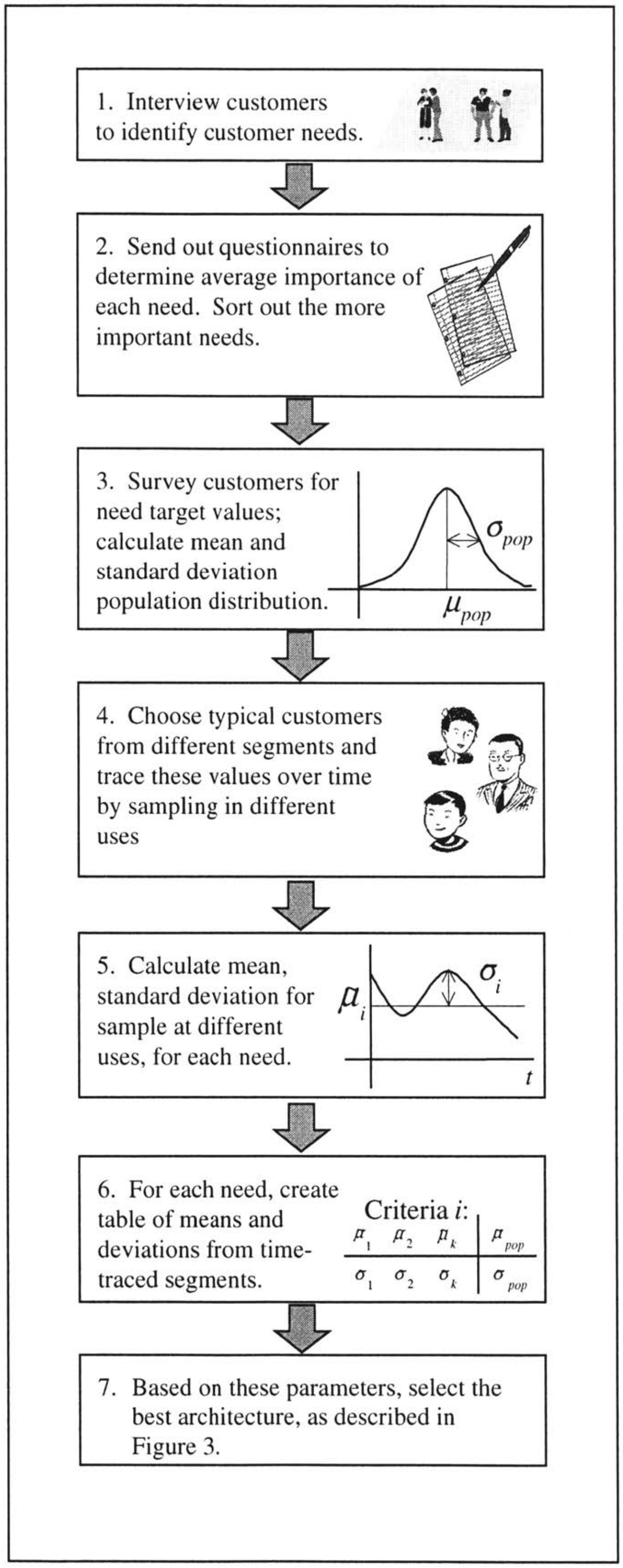

Figure 4: Market-Based Architecture Selection Process.

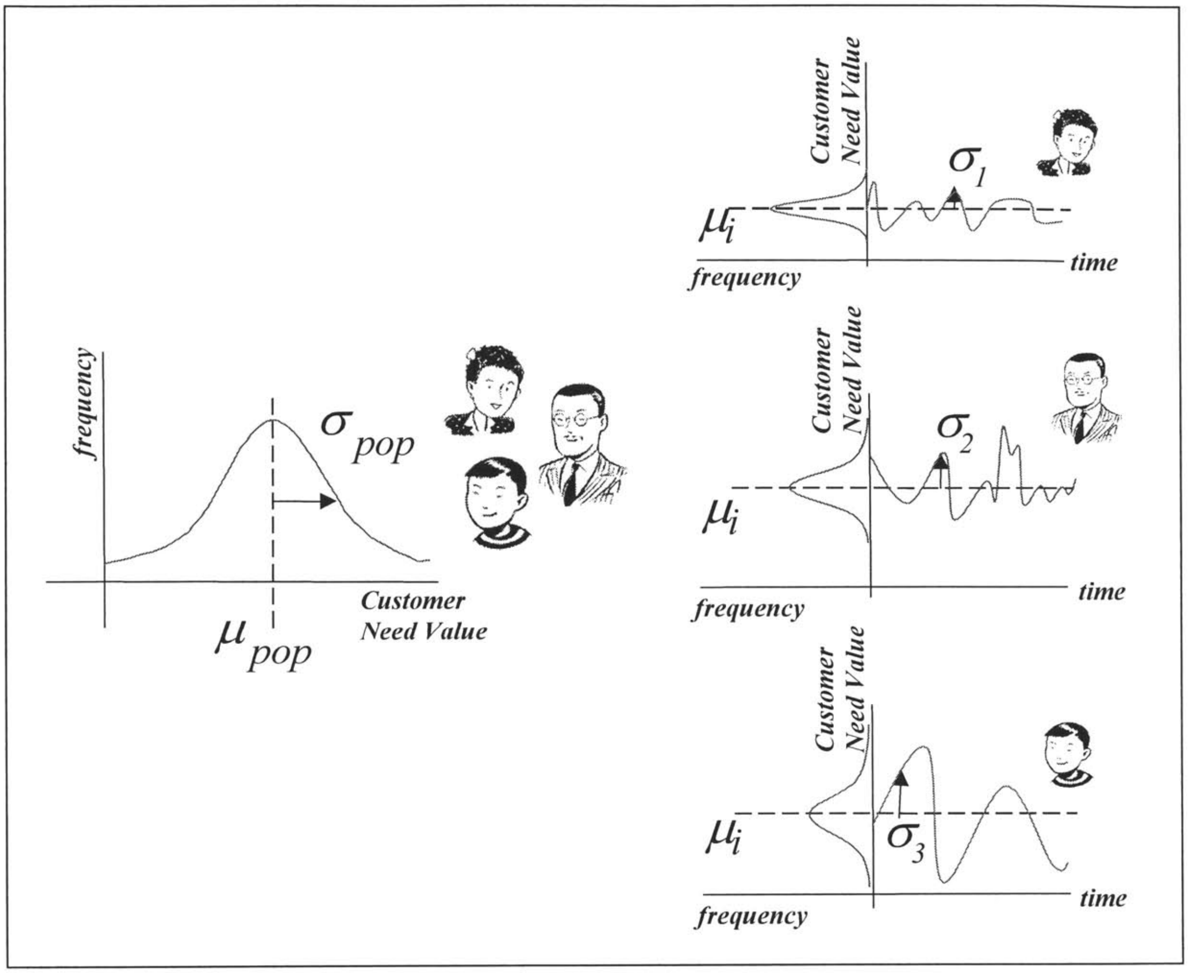

Figure 5: Population Distribution and Usage Distributions

Customer Variety

After identifying these important needs, we compose a snapshot view of the entire target market population by polling them again for target values for each important need. With this information, we arrive at a *population distribution* of values desired for each need, which can be described by the mean, μ_{pop}, and standard deviation, σ_{pop} (Figure 5). Polled in this manner, each customer is forced to give a single-point evaluation of their needs for the product, though their needs may not be fully described by one point. This single-point may be the average of the range of their needs, or the maximum value when a certain level of need must be satisfied though required rarely during use, such as the maximum transmission distance for a cordless telephone. Thus, this snapshot view provides us only with a picture of the market at one point in time, which is the conventional way quantitative market research has looked at customer need variety [3]. Furthermore, usually only the mean value of these distributions is passed on to and used by product development teams when they are creating product specifications and not the wealth of information contained in the entire distribution [25].

Usage Variety

Furthermore, we also seek to understand how desired target values change for different product uses, since some product architecture types exist to support variety amongst different usages. A customer uses a product for many activities that can vary over time. For instance, a user's target values for an automobile when he is commuting may be very different from when he is using it for recreation, high gas mileage and small size for commuting, four-wheel drive and large trunk capacity for recreation. To capture this, we construct a *usage distribution.* We accomplish this by following the use of a single product in different usage settings, collecting the target values for each customer need in different circumstances. This need signal can be aggregated to form a distribution that can also be described by a mean μ_u, and a standard deviation σ_u (Figure 5).

The difficulty lies in that this is a new and unconventional way of gathering customer needs. Thus, analysis of pre-existing data according to this methodology is difficult as assumptions must be made to extract usage-varying needs. We attempt to address this issue in our case study at Polaroid, but hope that this work will influence some market research in the future to focus on usage variety as well as population variety.

Cost of Variety

Assumptions

In this thesis, we choose not to include analysis of development and manufacturing cost, but rather look at how the market would point to a desired type of architecture regardless of cost. To do this, we make two assumptions. We first assume that, although the design of complex single products can be simplified through the implementation of modular architecture, integral architectures are more cost-effective than modular architectures when offering a single option. For instance, creating integral complex injection molded parts with multiple functions reduces inventory, material, and assembly costs. Second, we assume that ease of design, smaller part inventory, and other concerns make modular architecture a less costly approach to offering multiple options. Volume has a large effect on the validity of these cost assumptions as well. Since the primary advantage of commonality is the reuse of development resources, product platforming decreases fixed costs. However, the compromises made to enable sharing between products reduces the opportunities to optimize each product individually, thus increasing variable cost. At a sufficiently high sales volume, the increase in variable costs outweighs the savings in fixed costs, and products become more integral. Nonetheless, these assumptions are generally applicable and allow us to address the market-oriented focus of this paper.

Developing Cost Models

Given enough information, preliminary cost models can be built to determine how much and what types of variety a firm can afford to offer. This process requires the input of people with significant design experience to lay out the general design of the products in the portfolio and form good estimates of the resources needed for the development and production of the initial product and later products that share some of those resources. On the other hand, spending too much time on design just to evaluate costs prevents this from being an efficient front-end evaluation tool, subverting the initial purpose of estimating the cost of development before actually carrying that process out.

Chapter 4: Portfolio and Architecture Selection Methodology

Now that we have established the tools with which we will examine the market, population and usage distributions, we will present the process by which we collect these distributions and analyze them to arrive at a set of architecture recommendations. In later chapters we will illustrate this process with actual case studies.

Range of Application

The method we will outline suggests usefulness primarily to the redesign of existing types of products, since it requires understanding of the product by the surveyed population. However, this by no means limits its application to mature products. It is only required that customers are able to evaluate and express their needs. Customers may in fact have a good understanding of their demands from similar previous products, allowing them to provide useful information on the design of significantly new products. Furthermore, the implementation of new architectures can benefit even seemingly mature products and revolutionize an industry [13].

Customer Need Data

Collection Methods

To determine a product architecture, the first step is collecting data to represent the two different types of customer need distributions. Questionnaires asking prospective customers to specify the importance of each need attacks this task directly. Indirect approaches include conjoint analysis, where the value customers place on individual features is derived from their preferences for products offering different feature combinations [20].

Ideal Points, Utility Values, and Scaled Target Values

Different studies have chosen to measure customer needs in several different ways, each with their own strengths and weaknesses. Usually, the manner in which the customer preference space is to be modeled and analyzed drives the form of customer need data collected. Ideal point, or target value, modeling represents each customer's or segment's ideal product as a multi-dimensional point and thus the customer space as a collection of these points amongst which a company may position its product [4]. This presentation of preferences is intuitive for product developers to understand, but does not capture tradeoffs between attributes when straying from ideal points. Vector representation, an expression of the customer's ideal product attribute values with vectors, enhances ideal point representation by adding the ability to represent a 'more is better' preference, such as for the speed of a computer processor for which there is no upper bound for acceptable values [11]. This vector is really only a special case of the ideal point model as it is essentially the same as an ideal point at positive or negative infinity [14]. Others have incorporated uncertainty by constructing probabilistic representations of ideal points to forecast product acceptance [16, 17].

We choose to collect target values directly by polling customers for ideal attribute values scaled against price, their "stated preferences", instead of by deriving them from comparisons of ideal point representations of attributes and price. Conjoint analysis assumes consumers assign each attribute a "utility value" and the total of these indicates their likelihood of purchase. These utility values, or "revealed preferences", for each product attribute are generated by running a linear regression on either total worths assigned by customers to different product options, which offer different feature combinations and are usually represented by models or drawings and descriptions, or relative rankings of the different product options when accompanied by prices [3]. There are no infinite preference vectors for any attributes when using conjoint analysis or scaled attribute values, since presumably a high enough price makes any option undesirable. Conjoint analysis ensures this by assuming that the highest and lowest values for each attribute lie outside the range of acceptability. Of course, one of the downsides of this approach is that, given a low enough price, every attribute appears desirable. The outcome of a conjoint might encourage a firm to offer a combination of low-preference options because they are inexpensive to manufacture while neglecting important though complex features. Because customers are only choosing between preset options, they cannot describe their ideal product which may be significantly different from their preferred product from the offered set. It may be difficult to reveal the consequence of some less obvious needs when overshadowed by extremely important ones.

We operate with scaled ideal points because it is a more reliable method though it requires more effort and is more demanding of prospective customers being polled. Conjoint can conceivably be performed with sales figures and descriptions of different products, whereas the collection of "stated preferences" requires questionnaires or interviews. To evaluate individual attributes, subjects must have a more astute understanding of how they make their purchase decisions than in a conjoint study, but no product models are needed to gather data and there is no attempt to derive "revealed preferences" from aggregate feature preferences.

Decreasing preference for attributes away from ideal points is modeled as a normally distributed likelihood of product satisfaction. This is based on the assumption that scaled ideal points for different customers in a segment are distributed normally, for each attribute, around the ideal point centroid. Other distributions that fit the data set better may also be applied for slightly different values of expected value and variance. Further work in this area can investigate the validity of employing the normal or other models.

Scaled Target Values

To map out the customer space, we survey customers for scaled target values on a shortlist of the most important needs. We presume these are equally important needs, and therefore ideal target values for each attribute have equivalent utility values. One approach is to ask participants to choose from different options for an attribute value, such as the size of an instant camera, given a specified price increase for each increase in attribute utility, in this case a decrease in size. We present here a direct questionnaire approach, where the options are labeled one through five, one being the least costly and five being the most [12]. This type of question is repeated for each of the important needs. To obtain the market distribution at one point in time, we calculate the mean target value, $\mu_{pop,i}$, and standard deviation, $\sigma_{pop,i}$, on the desired target value for each customer need i from customer responses to these questions. This provides us with our population distribution of desired target values, a representation of the customer population at a fixed moment in time.

To construct a usage distribution of desired target values for each need, we choose customers from different market segments. Market segments are identified, for example, by clustering responses to the first survey. We now identify representatives from each segment and track their desired values through different circumstances. Different usage patterns also indicate customers belong to distinct market segments. Tracking desired values over sufficiently long periods of time in order to measure the customers' response over all possible usage scenarios is generally impractical. Therefore, we simulate sampling over time by asking each customer k to conceive of different circumstances in which they use the product. At each of these different circumstances j, we sample the customer's target values, V_{ijk}. We also record for each of these circumstances a rating, P_{jk}, of how much of the total product usage time these circumstances would apply. This number is directly proportional to the probability that the customer will be using the product in such a situation at any given time. Therefore, the higher P_{jk} is, the more effect the sample taken in situation j, V_{ijk}, should have on the customer need model. We take this into account by determining a normalized mean value of criterion i for customer k, $\tilde{\mu}_{ik}$. Here, the tilde over $\tilde{\mu}_{ik}$ indicates normalization for different P_{jk}.

$$\tilde{\mu}_{ik} = \frac{\sum_j V_{ijk} P_{jk}}{\sum_j P_{jk}} \tag{1}$$

Eq. (1) is intended to normalize the impact of situation j; other normalizations might include how important the situation is to the customer. For example, a user of a toaster might not toast 4 slices very often, but having that capability may be important nonetheless. This approach is easily implemented as different weights P_{jk}. Also, as always, one should examine the distributions to ensure they are normal; *e.g.*, bimodal distributions would imply two values that a customer may use at different times. For example, a customer may sometimes use a 2-slice and other times use a 4-slice toaster; this does not mean one should average the data to select a 2.5-slice toaster.

We must also alter the basic equation for standard deviation based on a sample, σ, to take into account the probability of usage in a given scenario, similar to Eq. (1). The standard deviation is typically defined as

$$\sigma = \sqrt{\frac{\sum_j (V_j - \mu)^2}{N-1}}, \tag{2}$$

where V_j is the value in sample j, μ is the mean value across all samples j, and N is the total number of samples taken. We need a variant form of this equation that takes into account the different P_{jk} values. We do this by treating each value V_{ijk} as having P_{jk} number of samples with the same need value. Hence, N, the total number of samples in Equation 2, is replaced in

Equation 3 with the sum of P_{jk} for all scenarios j. This results in a standard deviation normalized across samples of differing importance that approximates the deviation of an actual usage-distributed sampling of the customer's target values for need i.

$$\tilde{\sigma}_{ik} = \sqrt{\frac{\sum_j \left[P_{jk}\left(V_{ijk} - \tilde{\mu}_{ik}\right)^2\right]}{\sum_j P_{jk} - 1}} \qquad (3)$$

This set of information is complete to determine a product architecture for a population and its variety of uses over time. We compile into a table (Table 1) these data, mean and standard deviation, $\tilde{\mu}_{ik}$ and $\tilde{\sigma}_{ik}$, for each customer k traced, and mean and standard deviation for the entire population, $\mu_{pop,i}$ and $\sigma_{pop,i}$. We use these data to then compare distributions to determine the best product architecture for the market, using a procedure described in the next section. Other distributions besides the normal model can also be fitted to this customer need data and provide evaluations of expected value and variance. These values could then be utilized in the same manner as the ones derived here from an assumed normal distribution.

Utility Values

In lieu of scaled target values, we can use utility values to calculate means and standard deviations for the population and each segment as well. First, standard deviations would have to be normalized by dividing over the range of values available for each attribute. Since our model assumes a uniform utility for each attribute, we would then scale the normalized standard deviation for each segment and attribute according to the utility value of that attribute and compare these scaled and normalized values when choosing an architecture.

Choosing an Architecture

The benefit of defining product portfolio architecture and its different types lies in the relationship between these types and the distributions of customer criteria. Certain portfolio architectures are better suited to support certain customer distributions.

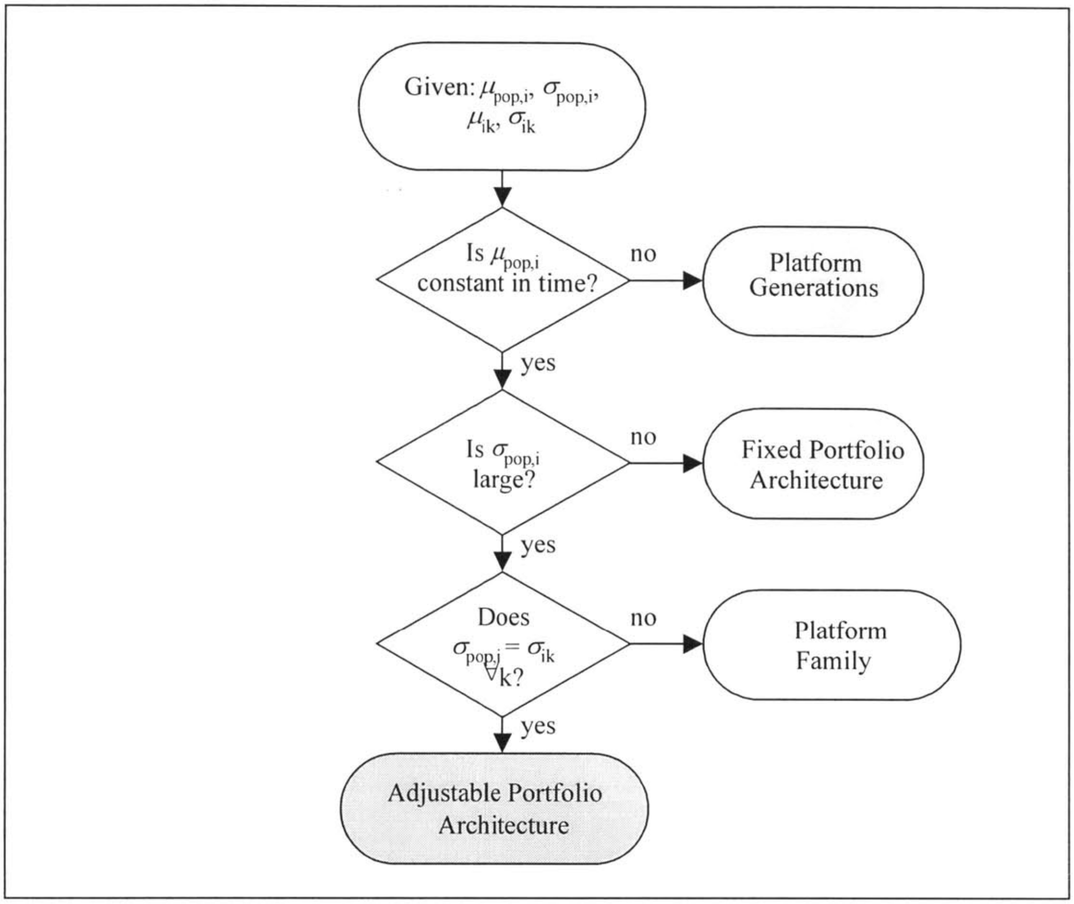

Figure 6: Architecture Selection Flowchart

We propose a guideline for architecture selection based upon the distribution of target values for customer needs, as summed up in our flowchart (Figure 6). To illustrate this method, we use the example of the Krups Toastronic Toaster. First, we determine if the population distribution for a need is fixed with respect to time, in other words, whether or not μ_{pop} is stable over successive market studies. If it is not, and given the cost assumptions made in Chapter 3, we recommend implementing *platform generations* to handle such time-variable needs. The features that satisfy that need will benefit from being isolated into a module, since it can then be modified easily without seriously altering the rest of the design.

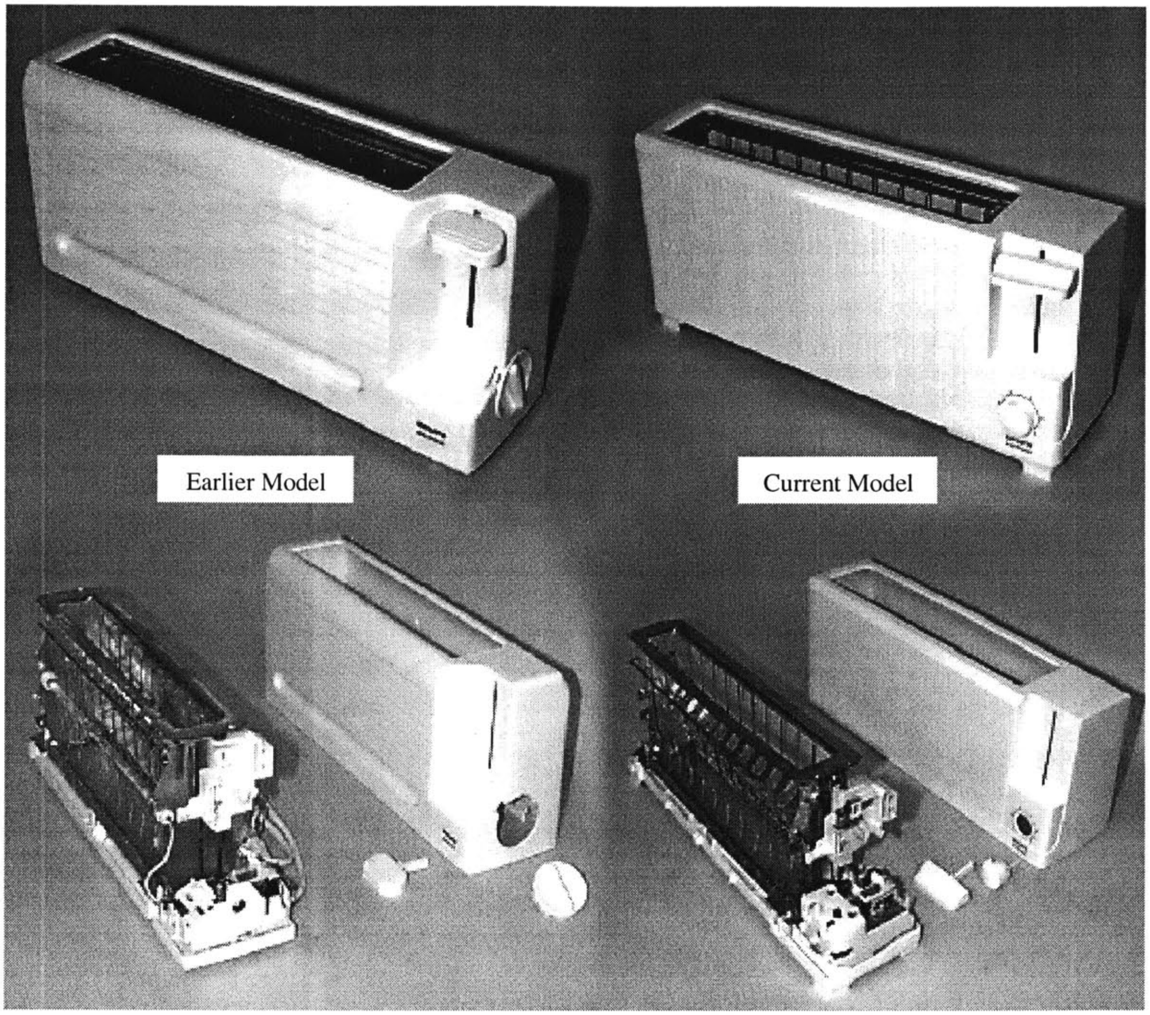

Figure 7: Krups Toastronic Toaster, Current and Earlier Model, where most of the functional inner modules are identical.

For example, because styles change constantly and each manufacturer wishes customers to perceive its product as the newest and thus most desirable item in the market, appearance is often best disassociated from the rest of the product. The Krups toaster, for example, achieves this by isolating the functional components from the stylish plastic shell. Figure 7 shows the nearly identical underlying platforms from two generations of toasters. Thus, the manufacturer is able to sell a toaster with a new look while only having to redesign and retool the shell, toasting lever, and time knob. Another clear example of a time-variable need that should be isolated is computer CPU speed. As technology advances, customer expectations for CPU speed rise. Thus, computers are now being structured with interchangeable processors, allowing basic design to remain the same while staying competitive by providing state-of-the-art processing speed. Technology-based and cosmetic concerns typify those time-varying customer needs best served by platform generational portfolio architectures.

Next, we consider the opposite case, when the population distribution is constant with respect to time. Here we must first decide whether a *fixed portfolio architecture* can encompass all the variation in the market for a single customer need. If the variation is sufficiently small ($\sigma_{pop,i}$ is small), then all customers will find a single fixed product satisfactory because the need value provided by its features does not differ greatly from their target need values.

If the breadth in the market cannot be answered with a single fixed need value ($\sigma_{pop,i}$ is large), we must endeavor to provide multiple values to capture more of the market. There are two effective methods to provide many values for a given need, *platform families* and *adjustability*. Platform families have variants which each provide different fixed target values and thus provide consumers with a finite range of options at the time of purchase. Adjustable products, on the other hand, have features whose values can be changed *at any point* by the customer. Adjustability is often more difficult and expensive to provide, but allows the product to fulfill a range of need values after purchase.

Adjustable product architectures should be constructed around needs whose distributions demonstrate *ergodicity* [2]. Ergodicity, in our context, refers to the condition when the need distribution across the population at a single point in time is equal to the distribution of every customer over time. Hence, ergodicity in a customer need model implies that the entire variation seen in the population distribution is encapsulated in each customer and the variation can be observed in his or her needs over time. Thus, an adjustable feature satisfying the target need best captures both time and population variety. For example, the seat adjustment on an automobile must provide the range in leg room required by the entire population. This same amount of variety must also be available from the product at any point in time after purchase, as different drivers may want to adjust the seat to their own needs. Leg room is an ergodic requirement and is best served with an adjustment. In the case of the toaster, ergodicity is demonstrated in the distribution of toasting time target values. Depending on the type of bread, whether it starts off fresh or frozen, and personal preferences, a toaster customer requires a variety of toasting times for different usage conditions. Similarly, what the toasting population desires at any given time also constitutes a wide toasting time distribution. These distributions are roughly the same. Toasting time is an ergodic requirement. The adjustability of toasting time on most toasters accommodates both these types of variety.

When the population and time distributions of customer need target values are different, the standard deviation of the time distribution will necessarily be smaller. This is based on the assumption that the population survey is sufficiently comprehensive that it captures all the need variation that exists in all different usage situations. Thus, the standard deviation of a single customer's use over time, σ_{ik}, will not exceed the deviation of the entire population, σ_{pop}. When the time-based deviation is significantly smaller, we see that the product traced in the time distribution only sees a segment of the need values expressed by the population distribution. Full adjustability is not required. If deviation within the time distribution is sufficiently small, we can cover the population breadth with a *family of platform products*, with each variant catering to a market segment. For example, the size of portable stereos is often a concern that matters more to some and less to others. Thus, manufacturers provide bulky and more lightweight versions of stereos with essentially the same features. Customers for whom stereo size is a concern are willing to pay more for a smaller product. Toast capacity is also a need that benefits from offering several fixed options. By and large there are two-toast customers and four-toast customers, presumably determined by eating habits, household size, economics, etc. Modularization of toast capacity (Figure 8) allows manufacturers to market to different customer segments without being forced to develop and manufacture two completely different products. In this case, comparison of the population and time distributions will yield curves with differing means and standard deviations.

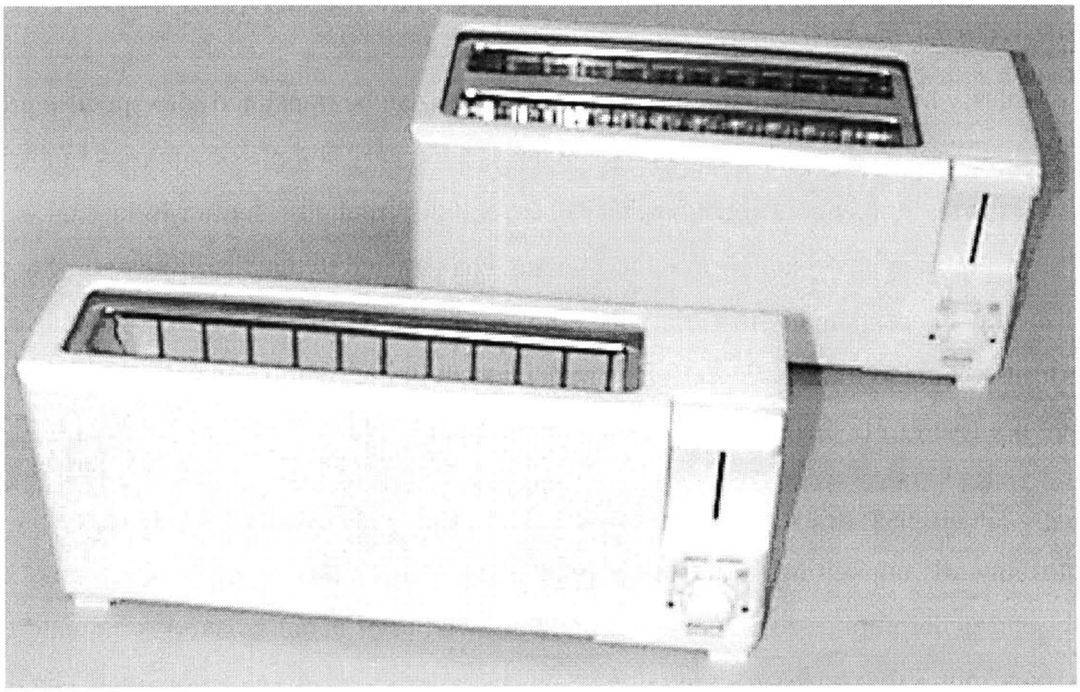

Figure 8: Two-Slice and Four-Slice Krups Toastronic Toasters that use identical internal functional modules.

Rather than just comparing means and standard deviations of the population with the market segments as suggested here, statistical tests could be used, such as the t-test for comparing means and the f-test for comparing standard deviations. This provides a confidence level that the standard deviations or means are indeed different. This basically converts the subjective judgement over the standard deviations described here into a subjective judgement over the acceptable level of risk.

The method for selecting an architecture is therefore based upon a comparison of the market population mean and standard deviation with the usage means and standard deviations for each market segment. Judgment is clearly required to assess when standard deviations are sufficiently different and require a unique variant solution; this judgment also naturally includes consideration of the difficulty in providing an additional variant. Nonetheless, pointing out how much the variety is requested by the difference in means and standard deviations helps in the portfolio decision making.

Need-to-Attribute Mapping

We've primarily looked at attribute-specific needs which can be translated into specifications in a fairly straightforward manner, however some needs have very complex mappings to attribute space. One attribute may contribute partially to several different customer criteria, making it difficult to determine how much importance should be allocated to that attribute and how variety along it should be compared with variety for other attributes. Furthermore, many of these needs are not orthogonal and independent. It is beneficial to filter out redundant needs, but likewise important not to entirely disregard needs that are only partially correlated with others.

Setting specifications based on needs is the source of many pitfalls to development teams. Without frequently consulting the customer population, teams may overemphasize some attributes and underemphasize others based on their own biases about what adds value to the product. Attributes that have profound impact on customer satisfaction can be overlooked entirely due to the focused but narrowed vision of the designers. It is important, as with all development processes, that the development team maintains a firm grasp on what the customer finds important. The House of Quality provides a way of organizing these relationships [9]. Another way is to represent the product as a function structure, a diagram detailing the individual subfunctions of a product and the transport of material, energy, and signal flows between them, and map the customer needs to those flows and subfunctions. Specifications can then be set on all the flows in the system. Complex theories on how to quantitatively evaluate need to attribute relationships have been posited in the fields of marketing, psychology, and economics [10]. Application of these theories would greatly benefit this work by allowing the architecture decision process to be applied to features which do not map directly to evoked needs.

Chapter 5: Managing Portfolio Size

We established in the preceding chapter how to choose an architecture appropriate to the distribution of customer preferences. This established, we now move on to the challenge of choosing between those architecture recommendations to construct an actual portfolio of products a company can offer to their market.

Many Attributes, Many Products

Depending on the number of attributes studied and the outcome of the architecture selection process for each attribute (e.g. two-option platform, adjustable, fixed), the resulting portfolio may be of unmanageable size. For instance, a set of five attributes with distributions that point to a two-option platform family architecture for each becomes a portfolio architecture capable of 2^5 or 32 products! This product proliferation is to be expected, and not seen as a failure of the method, as it is designed to generate all the product permutations suitable for the target market assuming no limits on manufacturing capability. However, this possible portfolio size must be balanced against the cost of offering this level of variety. We recommend a couple of different methods for arranging these architecture options hierarchically based on benefits to the customer population. Ideally, a firm would be able to measure the monetary benefit of widening the portfolio and compare it to the cost. However, since this work does not focus on the cost estimation aspect of portfolio design and the complexity can vary greatly from firm to firm, we arrange an ordered list of portfolio recommendations with which a firm can decide what level of variety is appropriate for it.

Winnowing Down to Manageable Portfolios

Minimizing standard deviation

One way of ranking variety for one attribute over variety for another is in terms of how much each decision decreases the standard deviation of target values within the population targeted by each product. Since the adjustable feature makes available the whole range of target values, this method only applies to fixed and platform architectures where there is distance between the customer's ideal point and the product's position. Other metrics based on ideal points and adjustment intervals must be developed to determine level of satisfaction with adjustable features.

By implementing a three-option platform family, such as three different maximum output rates for a portfolio of copiers, the average distance between a customer's ideal point to the closest product in the portfolio decreases. Splitting the population up into three subsets based on proximity to one of the three options, we can then re-evaluate the variance supported by each product, by calculating standard deviation for each of the three subgroups. As described in Chapter 4, we interpret proximity of ideal points to product position as increased probability of satisfaction. This interpretation of standard deviation as dissatisfaction applies for both the population and usage distributions. When the variance for a population distribution subset is high, the average distance between products and customer's usage-averaged target values is large, meaning a decreased probability of satisfaction, even when each customer is perfectly represented by a single target value. This dissatisfaction is even greater when each customer prefers varying target values for different uses. A larger variance in usage target value distributions means the product does not meet the customer's expectations during most uses. However, since we are only prioritizing platform architectures here, we can assume the usage distributions all have small variance. Thus, by looking at just the population distribution for each attribute, we can evaluate the benefit of a platform family architecture for any single attribute by comparing standard deviations among the subgroups formed when the entire population is divided based on proximity to the feature values offered by the platform family.

Figure 9 illustrates the portfolio advocated by this method for a given population distribution of customer target values in a two-attribute space. The one-dimensional distributions are shown for each attribute. The dashed lines indicate the suggested feature values for each attribute when implementing a two-option platform family architecture. The X's denote the recommended positions for a two-product portfolio. Because of the large spread of the upper-left cluster, the standard deviation along Attribute 1 is much larger than that along Attribute 2. Thus, we choose to provide variety along that dimension to decrease the maximum variance within product subgroups. These suggested products assume the average value for Attribute 2 since the portfolio endeavors to capture all of the market by taking average values within the subgroups formed around each product. If the firm could offer more products economically, it might assume to offer four products represented by the circles in Figure 9. However, we see that one of these would be a waste of resources since there is no market for it. This method of examining attributes one-dimensionally gives us a better view of sharing feature options, but can also generate unnecessary feature combinations. Excess variants can be determined by splitting the market amongst the products in a proposed portfolio and calculating market share. By segmenting the customer space into four groups based on proximity to these four product locations, we would find that one of the products has no market share and should be removed. Nonetheless, this method has led us, in this case, to create a three-product portfolio that takes advantage of sharing between the products and fits the distribution of customer demands. At the end of this analysis, we are left to make the decision between offering two and three products in the portfolio. This may be determined by setting a maximum standard deviation value. If the maximum standard deviation within the two subgroups formed around the products indicated by the X's exceeds this threshold, we would choose to offer the three already described.

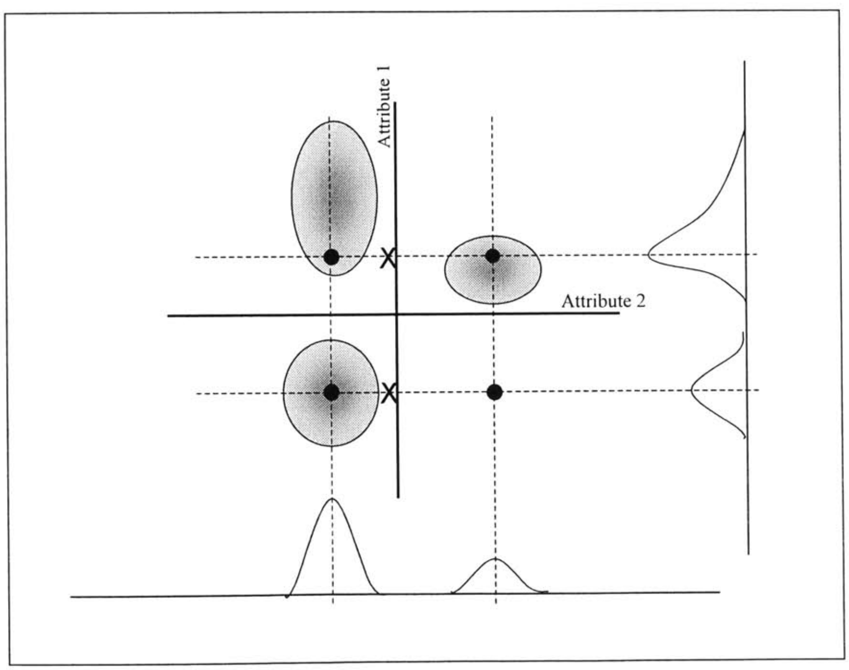

Figure 9: Different methods suggest different portfolios for a given distribution of target values.

Related Methods

Factor Analysis/Principal Components

Factor analysis is another method of resolving what feature combinations to offer by creating a new set of independent dimensions along which to map customer preferences [3]. Since a set of important product needs may be redundant or some of the needs may result from a common underlying need, and are thus positively or negatively correlated, that need may be overemphasized when looking just at initial need importance data. Factor analysis counteracts this by finding correlations in customer data and re-mapping the customer need data to new independent dimensions, often referred to as principal components. This results in a better understanding of core customer needs and trade-offs. However, it also somewhat obscures the problem for the development team since, even if customers are aligned along a set of principal components, the development team still needs to translate those components back into dimensions they can apply to designing the product family. The method is useful here in reducing redundant needs, but does not greatly benefit portfolio design as it adds an extra step into the process. Even if a principal component, correlated 70% with one attribute and 60% with another, very clearly suggests, through the analysis described above, that it should be architected in a fixed manner, the designers still must make 100% of both those attributes common to the portfolio, not just 70% of one and 60% of the second. In other words, using principal components doesn't clarify how to share design elements between customer-focused designs.

Straight Cluster-Oriented Design

Disregarding the advantages gained by commonality and depending solely on market data, portfolios can be determined by choosing those product options that lay closest to market clusters. Thus, a two-product portfolio for the customer distribution presented in Figure 7 might consist of a product each aligned to the ideal point centroid of the two larger customer clusters. This is the form of market information often passed to design teams and directly targets customer demands, however it does not provide a framework for the sharing of features and components amongst multiple products.

Chapter 6: Exploratory Study

Project Background

After formulating this method for designing a portfolio architecture, we set out to verify a portion of it with a small-scale experimental trial on the case of an instant film camera. We completed the data collection and architecture analysis without coming to conclusions on final portfolio design. Though the prospective customers polled were indeed a subset of the target customer population, consisting mostly of students, faculty, and university staff, they were by no means assumed to be representative of the entire instant camera market. The results would reflect the group polled and allow us to test the methodology for serious obstacles. However, we had no intention of comparing our results to expected market outcomes since there was no effort to match the sample to the entire customer population.

Methods

We examined an instant film camera as an example of comparing population and time distributions to determine product architecture. We first interviewed potential customers to determine their needs, polled them for the relative importance of those needs, and determined from these data the seven needs that were most important to their evaluation of the product: picture quality, compactness, convenient focusing, ability to adjust to lighting environment, ruggedness, large film pack capacity, and stylish appearance.

Next, we had each customer reply to a survey on these features as shown in Figure 10. We asked for desired target values as compared to a \$15 price increase or decrease with the associated gain or loss in performance. Various reference values were provided on each customer need, such as "Walkman" or "shoebox" on the "Size" need. Measuring needs in this manner provides us with target values scaled against price which is preferable to ideal point and vector representations, as discussed earlier in Chapter 4.

Criteria	**$15 less**		**Current Price**		**$15 more**
Size	Shoebox **1**	 **2**	Camera **3**	 **4**	Walkman **5**
Light Adjustment	only in daylight **1**	 **2**	3 Settings **3**	 **4**	Automatic **5**
Focusing	Fixed **1**	 **2**	3 Settings **3**	 **4**	Automatic **5**
Ruggedness	Survives 1 Drop **1**	 **2**	5 Drops **3**	 **4**	10 Drops **5**
Picture Quality	Fuzzy **1**	 **2**	Current **3**	 **4**	35mm **5**
Film Pack Capacity	5 Exposures **1**	 **2**	10 Exposures **3**	 **4**	20 Exposures **5**
Style	15 years out of date **1**	 **2**	Current **3**	 **4**	Wicked Cool **5**

Figure 10: Questionnaire on Instant Film Camera Performance.

The means and standard deviations for each need target value, derived from the customer surveys, are shown in the "Population" column of Table 1. As discussed above, the values in Table 1 do not necessarily represent the entire instant film camera market population, but rather are sufficient to illustrate the methodology we have described. The survey was also completed by customers we tracked in time for each of the different scenarios they felt were important to their use and purchase of the camera. These usage scenarios included such applications as identification photos, family snapshots, documentation, et cetera. The normalized mean and standard deviation values for the customers traced across different uses are also shown in Table 1 in the "Segment" columns. The segments denote different types of customers with different usage patterns, such as industrial users with less of a need for automatic adjustments and a need for larger film pack capacity, commercial high-volume users, and household users.

Results

The information in Table 1 was used in conjunction with the flowchart depicted in Figure 6 to determine which architecting option should be used for each need. This is shown through graphs of the observed distributions. Figures 11 and 12 show the normal distributions corresponding to two of the customer needs shown in Table 1, "focusing" and "film pack capacity" (or size).

Table 1: Population and Time Distributions of Instant Camera Needs.

	Population		Segment A		Segment B		Segment C	
	mean	std dev	mean	std dev	mean	std dev	mean	std dev
Size	4.333	0.816	3.533	0.516	3.700	0.949	3.800	0.632
Light Adjustment	3.667	0.724	2.533	1.187	4.600	0.843	3.300	0.483
Focusing	3.933	0.961	3.000	0.000	4.600	0.843	3.900	0.876
Ruggedness	3.533	0.990	3.333	0.488	3.000	0.000	2.800	1.033
Picture Quality	4.267	0.704	3.267	0.458	3.800	0.422	3.700	0.949
Film Pack Size	3.800	0.862	4.800	0.414	3.000	0.471	3.500	0.527
Style	2.923	1.188	3.000	0.000	2.700	0.675	3.800	1.317

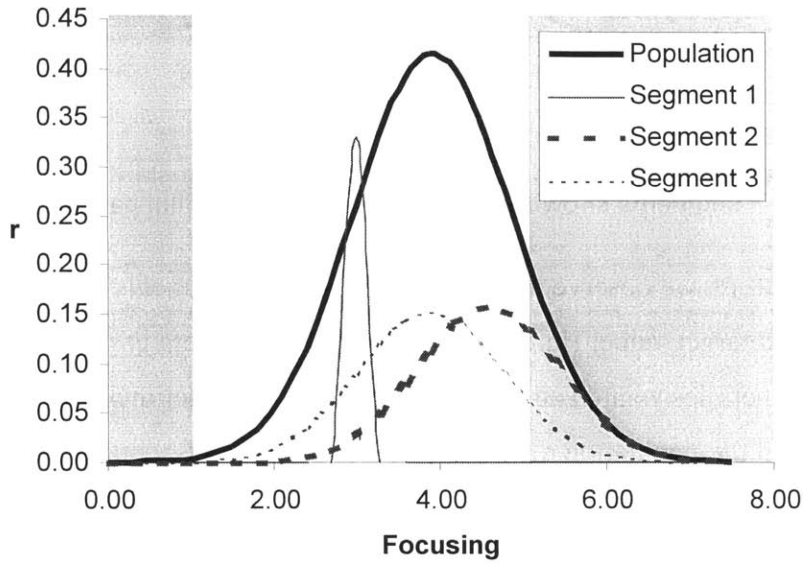

Figure 11: Usage distributions for focusing need for three instant-film-camera customer segments showing a need for both a fixed and an adjustable focus feature.

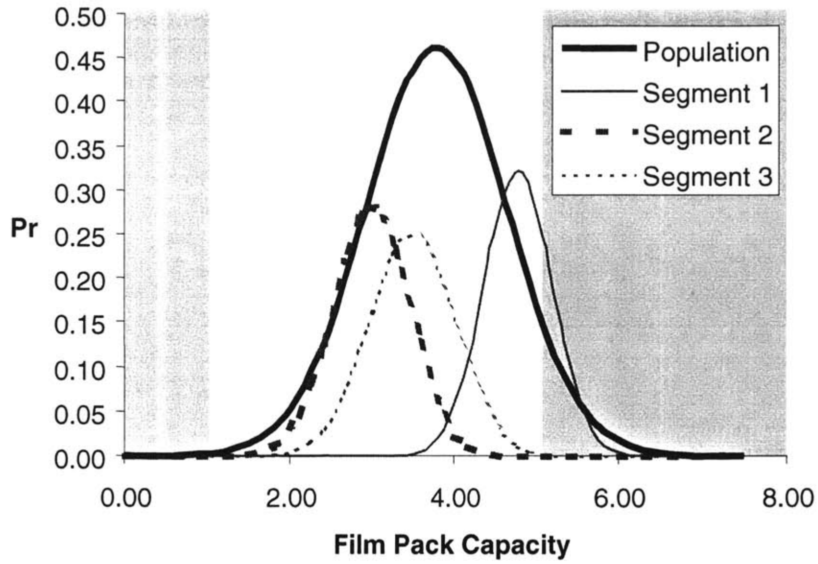

Figure 12: Usage distributions for film pack capacity for three instant-film-camera customer segments showing a need for different size film packs.

For the focusing feature, we observe that one of the customer segments had no measurable difference in desired target value. Here, a single fixed-focus camera is sufficient. On the other hand, the others sometimes wanted autofocus capability, and sometimes not. Their usage distribution matched the population distribution. These customers would like a camera that has auto-focus capability but do not need it all the time. Thus, using the guideline illustrated in Figure 6, these two different usage distributions would indicate that having two models in the product family would be best for the customer population, one inexpensive fixed-focus and one more expensive autofocus.

On the other hand, for the film pack capacity feature, we observe that all three of the customers had measurable differences in desired target value, and all three distributions were narrower than the population distribution. According to the method outlined in Figure 6, these different usage distributions would indicate that a modular architecture with three different film pack sizes would be most appealing to the customer population.

Table 2: Architecture Recommendations for Instant-Film Camera Features

Customer Need	Architecture Choice
Size	Integral
Light Adjustment	Fixed and adjustable
Focusing	Fixed and autofocus
Ruggedness	2 model modular
Picture Quality	Integral
Film Pack Capacity	3 model modular
Style	2 model modular

Similar recommendations for architecting the other features are shown in Table 2. Again, the transformation of the information of Table 1 and Figures 11 and 12 to the results of Table 2 requires judgement. For example, the camera size data would indicate that some customers want a small camera some of the time and do not care at other times. But since an adjustable-size camera is not feasible, a single size camera or possibly two models, one standard and one compact, is best for the market. For the light-adjustment feature, customers' need values showed distinct but large-variance distributions. This would indicate the need for an architecture with an inexpensive fixed model and a model which can adjust to different lighting conditions.

The data for camera ruggedness showed customers only wanted a rugged camera at times, and some customers more often than others. This would suggest a modular architecture with a standard and a rugged model. The usage distribution of each customer's target values for picture quality was about equivalent to the population distribution. This indicates the implementation of either an adjustable or fixed feature, depending on the amount of variation. For instant film, this would indicate a fixed architecture on this feature, as it is difficult to offer adjusting levels of quality. For other photographic tools such as digital cameras, providing flexibility in picture resolution is considerably less challenging and can then be implemented as an adjustment (dpi resolution selection). Finally, for the style feature, the data exhibit two distinct time distributions, one for a person who does not care about style, and one who does at times. Therefore, a modular architecture supporting two models is indicated, one inexpensive and not concerned about style, and another model with rapidly changing stylish features.

Chapter 7: Polaroid Case Study

Background

After completing the exploratory study, we decided to run an extended study on comprehensive market data. Once again, we examined the case of an instant film camera, this time in conjunction with the Polaroid Corporation. Although application of the method we have described above was hindered by incomplete data, we made reasonable assumptions and reached conclusions that agreed with our observations of the photographic industry, providing some level of validation for our model.

Segmentation

Polaroid was restructuring their consumer products division to form a three-segment market focus: inexpensive, children/teen-oriented products, their core customer market, and the advanced digital market. Management saw the youth-oriented products as an opening to a potentially high-volume market and the digital products as a potentially high-profit product line, especially as their core market shrank with the increasing convenience of film developing. They were very interested in figuring out how much to grow their portfolio as they expanded into these markets without stretching their resources too thin.

Digital Segment

In particular, Polaroid was making its foray into the consumer digital world with the EIC (Electronic Instant Camera), a product that produced both an electronic and instant image. By offering this hybrid product, they sought to appeal to the new digital market by offering a combination of product features different from all other existing products, while leveraging internal capabilities . However in the fast-moving world of digital cameras, it was also important to maintain the ability to quickly adapt to unpredictable customer needs and rapidly changing technologies.

EIC Strategy

The new flagship product for the digital segment was the new Electronic Instant Camera (EIC), which was in development during the course of this research project. The EIC offered both the advantages of digital imaging, which was revolutionizing the photographic industry at the time, and instant film images which gave customers an immediate physical artifact. Both images were generated simultaneously through parallel image capture paths in the camera. By offering this hybrid camera, they sought to establish their own niche in this rapidly developing field. The digital camera industry was and is in a period of rapid change. As technology develops, customers expect more and more performance. Several aspects of the digital camera technology were also advancing at once: electronic image capture, digital memory, processor speed, and image displays, just to name a few. Furthermore, as a result, consumers were reluctant to invest a large amount of money in a product that might only have half the performance for the best product on the market next year. And unlike the case with personal computers, where this consumer reticence to invest in what would soon be last year's technology had already manifested itself, a large portion of potential digital camera customers weren't yet certain about the product's worth and how to take advantage of what it offered over conventional film cameras.

Thus, Polaroid saw a modestly-priced hybrid product, such as the EIC, as a bridge between their traditional instant-film products and the new burgeoning world of digital imaging. Consumers could use the EIC as they did previous products while exploring the possibilities of digital photography. The firm also hoped to develop another source of film sales, whose high margins were the main source of profit.

EIC Platform

Because of the aforementioned rapid changes in camera technology and the ambiguity of customer needs, the EIC was conceived as the first of a platform of hybrid camera products. This platform, actually a set of common 'modules', was not only to encompass future generations of similar cameras with higher image-resolution and larger displays, but also cameras with significantly different feature sets. The modules were foreseen to last for five years before the entire system would be redesigned. An Electronic Still Camera (ESC) would capture digital images but not produce instant film photographs, while a Photographic Instant Camera (PIC) would offer the converse, an instant photo and no digital. Further down the line also lay the prospect of an Electronic Instant Printer (EIP) which combined an electronic camera and instant-film printer in one portable camera unit. With this device, a customer could take digital photographs, preview them on the LCD display, and print out selected ones on instant film. This was foreseen as highly attractive to a significant portion of the digital photography market, and Polaroid sought to capitalize on it by leveraging the platform developed for the EIC to support the rapid deployment of the EIP once the compact film-printing technology had been developed.

Although Polaroid already had a number of digital cameras in their portfolio, EIC was to be a new venture for them. A line of expensive, high-performance digital cameras (the PDC series) was primarily targeted at the commercial/industrial market. Inexpensive, lower-performance digital cameras were outsourced from outside vendors, offered modest performance through established technologies, and competed in a crowded price-driven market. The EIC marked Polaroid's entrance into a faster-changing higher-yield market than the OEM cameras that was also a significantly larger market than the one targeted by their PDC line.

Reasons for Platforming

A platform of products would enable shorter time to market for future products, which was seen as a necessary change to enable Polaroid to compete in this fast-paced field, and less risk as the cost of development, production machinery and tooling, and inventory would be spread across a number of different products.

Other internal factors also drove the decision to platform. Older non-digital instant cameras demanded redesign both because the styling was outdated and because some outsourced components were becoming obsolete. By replacing these with the PIC, they would decrease the cost of a development effort they needed to engage in anyway by sharing platform resources with EIC.

Another motivation for the platform movement was the transition in Polaroid's overall financial model. For decades, Polaroid had relied on the sale of its high-margin instant film to generate profit. Cameras produced virtually no profit and in some cases were sold at a loss. As film sales per camera declined over the years, the demand to produce and sell profitable hardware rose. Thus, platforming was introduced as a way of decreasing cost without narrowing the product line.

Platforming History at Polaroid

This was applied from the very start to a consumer camera product set developed in the early 1990s. A group of compact cameras with varying features was specified based on learnings from previous market offerings, and a first product variant developed based on a platform that could support all the prospective products. Unfortunately, the first product performed poorly in the market, and the entire platform was resultingly scrapped. The EIC platform was Polaroid's first platform since that last attempt.

In fact, platforms were not something new to Polaroid. Their film products were all based on a number of common film media. The development of a new instant film is an extremely time- and capital-intensive endeavour. Therefore, each new film had been developed into several different size and film pack formats that could be used by customers with different film and camera needs. Similarly, each type of film pack could be seen as the consumable platform upon which all the cameras that used that pack were based.

One of the primary reasons platforming had not been introduced into previous camera developments was the need to keep variable costs down. With volumes in the millions, Polaroid's most popular cameras could not afford to carry even an extra ounce of plastic. Although shared development decreases the initial cost of a product, the compromises made to accommodate the sharing of components and assemblies generally increase variable cost. Thus the decision to platform is highly dependent on the sales volume. Since they had also been producing simple, low-cost instant-film cameras for years, development costs were relatively low. Design rules had been established, and manufacturing processes were understood. Designing these products off a common platform would not have decreased their fixed cost significantly. Furthermore, since Polaroid had a virtual monopoly on instant film, there was considerably less concern about introducing products to market before the competition. Thus, Polaroid had little motivation to design any of its previous camera products on a platform.

On the other hand, EIC costs were foreseen to be highly front-loaded, quite possibly their most expensive consumer camera development to date. The use of technology new to the consumer hardware division (though not new to other divisions of Polaroid) also presented an immediate increase in development time as engineers would need to learn about and how to use these components.

Cost Of Variety

Degree of Modularity

As one principal engineer said, modularity can exist at many levels. There is in fact a hierarchy of modularity, at the concept level, the architecture level, and the component level. Where you implement modularity for a particular aspect of the product family depends on what flexibility you need, the technological constraints, and the anticipated sales volume of the products. For instance, full component-level modularity for the EIC, i.e. separating functions to have one-to-one mapping with components, would have sacrificed too much in performance by making the product too large, too slow, too expensive. However, this did not mean the development team forsook modularity entirely. By setting up the architecture properly, a different feature set can be accomplished with minimal redesign, such as the additional design of a few new components.

Changing Technologies

The rapid pace at which image sensors were evolving and the large impact the quality of the sensor has on the quality of the image demanded extreme care from the development team when they chose their path for the image sensor in the EIC platform. The primary type of sensor used in digital photography is the charged-couple device (CCD), which had been common in the video camera market for years. Other types of sensors were being developed, such as the CMOS, but they weren't anticipated to challenge CCDs in terms of resolution and price for at least several years. Resolution of these devices is measured by the number of pixels per image. The general minimum level of resolution offered in a general-use digital camera was VGA resolution (640 x 480 pixels, 3.1×10^5 total), the same level of resolution as a computer monitor. This level of resolution was sufficient for users who only viewed their images on computer screens. However, as digital cameras expanded their market to replace traditional cameras and photo-quality printers became more accessible, camera makers could not remain competitive without higher-resolution cameras. Megapixel (1×10^6 pixels) CCDs were now available industrially and to consumers in high-end digital cameras. Two megapixel CCDs were anticipated in digital cameras from competition in less than two years. Polaroid had an advantage in that they maintained an internal CCD design group, and the close relationship enabled them to design expensive and long lead-time electronics such as the microcontroller with the demands of the next CCD in mind. The lower prices for high-quality CCDs gave them a strong position with their PDC line of cameras whose customers placed a high level of import on resolution with relation to cost, but the consumer-oriented EIC camera's market required a more competitive price-point. Being able to anticipate requirements for upcoming higher-resolution CCDs, such as processing speed, would support faster and cheaper development of next generation cameras.

In contrast, the technology of LCDs, which enabled customers to preview their images right after taking them and were a necessary competitive feature for high-end digital cameras, was fairly slow-moving compared to the rapid advances in CCDs, however it nonetheless demanded changes every year for products to keep up with competition. The expense of keeping up with LCD technology was increased by the dearth of acceptable vendors. Laptop-size LCDs dominated the industry with the greatest volume and hence also enjoyed the greatest variety and fiercest competition among manufacturers, keeping prices down. The small LCD industry was dominated by a handful of manufacturers who, acting together as an oligopoly, maintained high prices. A couple new overseas suppliers had started offering much more attractively priced displays, however the need for reliability and the high price of failure, prevented any major companies from pursuing these possibilities. Polaroid was likewise reluctant to trade reliability for lower price. Other features affected by LCD choice included weight and size, as the high energy consumption of higher-quality active-matrix LCDs required larger battery packs, and the electronics that supported the LCD. LCDs were available with either analog or digital inputs. Commitment to one option precluded switching to the other for the next generation without significantly redesigning the electronics.

The advances in digital storage were by far the most extreme of all the changing technologies being incorporated into the EIC. With the cost of memory dropping at a rate of , it was clear that the electronics layout had to support swappable or expandable memory. Fortunately, a number of new storage formats addressed this issue and freed the host from being capacity-specific. Thus, the electronics did not have to change, nor even the mechanical interface with the storage unit, to accommodate increased memory. In fact, the price of memory was dropping at such a furious rate, there was debate over how late in the supply chain memory cards could be bundled with the camera and how to package the camera to facilitate this.

Cost Models

Once a set of products within the portfolio was agreed upon, tools were created to evaluate the cost advantage of building these products off a common platform rather than individually. For the EIC, this was the subject of a Leaders for Manufacturing (LFM) thesis. To make this estimate without actually designing the products both individually and as supported by the platform, a number of assumptions about the design of the products and the cost of production had to be made. One of the major assumptions was that differences between unique and platform designs would not affect customer satisfaction and hence sales. Thus, individual product sales figures were estimated with accepted market research techniques and applied to both cases.

The outcome of this analysis was that use of the common modules amongst the products represented a significant savings in development costs, but a more modest savings in recurring cost. The total savings on initial investment, comprised of product and manufacturing development, capital outlay for tooling and machinery, and filling up the supply chain, was 42.5% of initial cost if the products had been designed uniquely. On the other hand, using a platform approach only resulted in a 10.8% savings in annual costs, which cover materials, inventory, labor, and manufacturing overhead.

Methods

As with the initial exploratory study, customer needs were measured to help plan the design for a portfolio of products. Embarking on a market research study can be a tricky operation. Researchers must take great care to specify the target customer population correctly, choose an unbiased statistically significant sample of that population, or at least recognize unavoidable biases, and formulate questions that probe for the desired information. However, the large scale of a study on the consumer photographic market prevented us from acquiring original data in the format we would have preferred, i.e. scaled target values for an independently generated list of important customer needs. Although Polaroid had a sizeable historical record of market data produced from their own studies, most of it focused on customers' acceptance of products already designed. None of their pre-existing data gave us a view of the entire consumer photographic market through its general product needs.

Thus we turned to third-party market research data. With over 4500 respondents with regional, economic, ethnic, and age distributions matched to that of the entire North American population, this data set, acquired from the Photographic Marketing Association (PMA), had the advantage of volume and being a minimally biased sample population [1]. Furthermore, this survey, administered in January and February of 1997, provided relatively recent data. It directly queried respondents about customer needs, asking them for the importance of 36 primary product attributes, on a scale of 1, not important, to 7, extremely important, when they chose the camera/camcorder product they currently used most.

Table 3: Total Distribution of Attribute Importance Values

Importance Value	Count	Percentage of Total
1	21811	29.0
2	5912	7.9
3	8517	11.3
4	9537	12.7
5	12500	16.7
6	8161	10.9
7	8659	11.5

This sort of importance data had a number of inherent problems that we attempted to correct. The primary issue was how to compare one person's importance evaluation of 'autofocus capability' as a 3, or somewhat important, to another's. The significantly higher incidence of certain importance values, such as 1 and 5, over others (Table 3) indicated the need to mitigate a perhaps psychologically-motivated preference for those numbers. Furthermore, since the scale respondents use to choose importance values can vary significantly from one person to another, scaling these importance values to each other on a linear or logarithmic scale might result in highly unreliable results. Therefore, we decided to distill the importance value data to relative attribute rankings. For each respondent, we ranked all the attributes in order of their importance values and reassigned them a number based on that rank, as demonstrated in Table 4. Further analysis of the data was performed on these attribute rankings rather than the importance values. We also culled non-camera related attributes, such as 'uses same tape as VCR', from the set to prevent confusion.

Table 4: Adjustment of Importance Values to Attribute Rankings

Attribute	Importance Value	Attribute Ranking
Value For Money Spent	7	1
Autofocus Capability	5	10
Built-In Flash	3	27
Built-In Zoom Lens/No Need For Interchangeable Lens	5	10
Can Take A Higher Quality Picture	5	10
Easy To See Viewfinder	5	10
Easy/Quick Film Loading	5	10
Fashionable Color/Stylish Design	2	32.5
Lightweight	3	27
Low Price	6	3.5
Manufacturer/Brand Name	5	10
Many Accessories Available	4	19
Portable Size	5	10
Recommended By Salesperson	2	32.5
Rugged Construction	4	19
Stable To Hold	4	19
Smaller Than 35mm Camera	4	19
Quick Focusing	5	10
Red-Eye Reduction Feature	5	10
Can Take Panoramic Pictures	1	35.5
Weatherproof	4	19
Data-Imprinting/Date Back	2	32.5
Simple Operation/Easy To Use	6	3.5
Large Data Display Panel	4	19
Large Operating Buttons/Knobs	4	19
Picture Quality	6	3.5
Instant Developing Of Prints	2	32.5
Uses Same Tape As VCR (Camcorder)	6	3.5
Color LCD View Screen (Camcorder And Digital Camera)	4	19
Color Viewfinder (Camcorder)	4	19
Offer Index Print	3	27
Offer Variety Of Print Sizes	3	27
Able To Load Images Into Computer	1	35.5
Able To Print Information On The Back Of Prints	3	27
Able To Change Film In The Middle Of A Roll	3	27
Prints Stored In The Back Of The Camera	3	27

The next issue to tackle was interpreting usage information from the PMA data set. Another unfortunate result of using pre-existing data was the inability to gather the customer need usage distribution data as we presented in our methodology. Instead, we made the assumption that a number of distinct customer groups with similar usage patterns exist and that each respondent ranks attributes according to their average importance across different usages. Thus, we should be able to separate the entire population into subgroups with different and distinct usage patterns by segmenting based on all their attribute rankings. To do this, we ran a cluster analysis on the attribute rankings with a statistics program, JMP, and looked at the level of differentiation to determine how many subgroups was appropriate.

The clustering was based on attribute rankings for a total of 24 attributes. Twelve attributes were removed from the original list of 36 because they were either specific to camcorders or were universally deemed unimportant by the sampled population (indicated by an average attribute ranking of 18 or higher from every subgroup). This reduced our sample population to 674 respondents since cluster analysis required a full set of responses for all 24 attributes. JMP offers a number of options when performing a cluster analysis. We used a hierarchical method, though this is not usually recommended for data sets as large as this one, but allowed us to choose the number of clusters to work with based on the spread of attribute rankings within the clusters. Each respondent's set of rankings for the 24 attributes is interpreted as a point in 24-dimensional space, and hierarchical cluster analysis is performed by repeatedly grouping two points or clusters together based on proximity until all the points have been joined into one cluster. We used Ward's method which interprets proximity as the ANOVA sum of squares across all 24 dimensions. Therefore, at each step the pairing that would result in the smallest sum of squares within the cluster formed by that pair is made. We choose the appropriate number of clusters by looking for a sharp rise in this sum of squares distance. If the highest sum of squares within a cluster rises significantly from one step to another, e.g. when going from seven clusters to six, that implies the two groups joined together at that step may not belong to the same cluster but to two distinct groups. For our data set, a sharp rise occurred at the third to last step, indicating four clusters in our population. We used this grouping of our sample population into four segments to determine a portfolio plan.

Although we believe the assumptions we made to form these usage subgroups are valid, the resulting variance in each cluster cannot be assumed to equal our concept of a usage distribution. Besides random noise, differences in customer need values or, in our case, attribute rankings can be attributed to two major sources. The first is population variation, the difference from one person to another in how they evaluate the product, and the second usage variation, the different needs a customer has when using the product in different situations. Following customers in different scenarios allows us to separate population variation from usage variation. However, this option was not available to us for this study. Thus, we make the assumption that customer variation within each cluster is a narrower reflection of usage variation within the cluster. Ideally, usage distributions would be compiled independently of the population distribution. A representative subset of the sample population would be surveyed for their scaled target values for different uses of the camera. These individuals would then be grouped into segments based on cluster analysis of the usage means and deviations for all important needs.

Also available to us from the PMA survey were the importance values of needs for each respondent's next camera purchase. We used this data to determine which needs were changing with time. To compare it to the data for current camera purchase criteria, we transformed this set to attribute rankings as well. We chose a threshold of 3 for change in attribute ranking to determine whether or not the demand for that attribute was time-sensitive.

Although we could have targeted the instant-film camera market specifically by only using data from respondents who ranked the 'instant developing of prints' attribute highly, we chose not to for two reasons. Despite the generally negative opinions many consumers have of instant film and instant-film cameras, Polaroid's market research has found that many consumers rate the benefits of instant photography much more favorably when they are not described specifically as 'instant'. Thus, focussing on just the subgroup that ranked instant prints highly would result in only addressing a portion of Polaroid's target market. Furthermore, Polaroid's portfolio, though largely composed of instant-film products, was not entirely so, and would become increasingly less so as they extended their reach into digital imaging. Lastly, using just the subset of respondents that both rated the 'instant developing of prints' attribute highly and gave a full set of responses to all 24 primary attributes would've narrowed the sample down to a statistically unreliable size. Only 26 respondents out of the total 4642 completed responses for all 24 attributes and rated instant prints their sixth most important attribute or better. Despite its small size, we also recognize that this is an important customer group to Polaroid and duly pay it special attention later in forming our conclusions on appropriate portfolio architectures.

Results

After converting the importance values to attribute rankings for both current and future camera purchases, we then compared the relative rankings (see Table 5). The assumption of replacing scaled target values with attribute rankings is least detrimental in this time-based analysis of product purchase criteria to determine if a platform generations architecture should be implemented. Assuming the average amount of money consumers spend on cameras stays the same, the average attribute ranking would remain constant if the scaled target value were to stay constant with time. Of the 24 attributes we used to segment the population, only one, 'manufacturer/brand name', differed more than 3 ranks between current and future camera purchase average attribute rankings. Besides that, only four other criteria changed more than 2 places in attribute rankings: 'simple operation/easy to use'(-), 'many accessories available'(-), 'fashionable color/stylish design'(-), and 'able to load images into computer'(+). This suggests the use of a platform generations approach in defining the architecture for at least the 'manufacturer/brand name' attribute and perhaps also the latter four. We can approach this result on the brand name in two ways, depending on the interpretation of brand name and cost of variety. First, we can decide that since the relative importance of this need is decreasing and some aspect of the manufacturer's name is immutable, this can be ignored and left as a fixed architecture feature. A company with a strong name would probably choose this path. On the other hand, a company with a weak brand name may wish to take advantage of the relative ease and low cost of modularizing a product's brand name and phase out the changes as this became less important over the years. Of course, this assumes the only cost of modularizing the name is in changing the physical product and neglects the other costs of offering this level of variety, such as inventory-carrying costs and the expense of marketing and distributing a new name. If the costs were prohibitively high, the company could choose the fixed architectural option.

Table 5: Current and Next Camera Purchase Criteria and Mean Relative Rankings

	Current Camera Criteria	Mean Rank	Future Camera Criteria	Mean Rank
1	Picture Quality	6.1	Picture Quality	7.1
2	Can Take A Higher Quality Picture	8.5	Can Take A Higher Quality Picture	8.3
3	Simple Operation/Easy To Use	8.5	Value For Money Spent	8.5
4	Easy To See Viewfinder	9.8	Easy To See Viewfinder	10.7
5	Value For Money Spent	10.1	Autofocus Capability	10.7
6	Built-In Flash	10.5	Simple Operation/Easy To Use	11.4
7	Easy/Quick Film Loading	10.9	Easy/Quick Film Loading	11.9
8	Autofocus Capability	11.1	Built-In Flash	12.3
9	Quick Focusing	11.4	Quick Focusing	12.8
10	Portable Size	11.8	Built-In Zoom Lens/No Need For Interchangeable Lens	12.9
11	Stable To Hold	11.9	Portable Size	13.0
12	Manufacturer/Brand Name	12.4	Low Price	13.2
13	Rugged Construction	12.9	Stable To Hold	13.4
14	Low Price	12.9	Rugged Construction	13.6
15	Built-In Zoom Lens/No Need For Interchangeable Lens	14.3	Red-Eye Reduction Feature	14.6
16	Lightweight	14.5	Lightweight	15.4
17	Red-Eye Reduction Feature	14.9	Manufacturer/Brand Name	15.5
18	Many Accessories Available	16.6	Weatherproof	16.2
19	Weatherproof	18.2	Many Accessories Available	19.3
20	Large Operating Buttons/Knobs	19.1	Large Operating Buttons/Knobs	21.0
21	Large Data Display Panel	20.1	Large Data Display Panel	21.2
22	Instant Developing Of Prints	22.9	Able To Load Images Into Computer	23.8
23	Fashionable Color/Stylish Design	22.9	Instant Developing Of Prints	24.8
24	Able To Load Images Into Computer	26.5	Fashionable Color/Stylish Design	25.5

The other features whose distributions point to a platform generations architecture also need to be weighed against feasibility and cost on a case by case basis. Multiple options for 'simple operation', for instance, may be considerably more difficult to implement than multiple options for 'fashionable color/stylish design'. In fact, this is evident in the proliferation of products in Polaroid's portfolio in which styling is the only distinguishing feature between otherwise identical products. Also to be considered is how much simplifying use of a camera adds to the variable cost. We assume that this is a need that satisfies customers when exactly matching and exceeding their target value. In other words, a camera cannot be too simple to use in terms of the customer's satisfaction. Since the importance of this need decreases with time according to our data and the cost lays mostly in the development of a simple to use design, using a platform generations architecture may not represent much benefit to the consumer. Modularizing this feature would only be advantageous if it resulted in a lower price to the consumer, which we consider unlikely since this feature is mostly determined by design effort rather than components and materials. On the other hand, the costs associated with the ability to load images onto a computer may be significant enough to justify the design and implementation of multiple options.

After establishing the time-varying attributes, we next determine fixed architecture attributes based on the standard deviations of the attribute rankings across the sample population. We choose a threshold for standard deviation of 6 attribute rankings. This threshold represents how much variance in customer needs can be captured by a single product. If the variance exceeds this level, a platform family or adjustable approach must be implemented to satisfy all the customers. We allow a larger range of variation, represented by a higher standard deviation threshold, here to be satisfied by a single product than we did earlier, when comparing current and future camera purchases and using a difference of 3 attribute rankings. The time-based variation reflects changes in customer needs between the average date customer's current cameras were purchased and the date of the survey. Since a significant portion of the population had purchased cameras/camcorders in the 12 months before the survey, approximately 27%, the variation between their current and future attribute rankings was based on less than a year of difference. Since the majority of camera models last significantly longer than a year before they are replaced by newer models, we would expect the level of time-based variance in the survey to be lower than the actual variance that must be accommodated between one generation of cameras and the next.

The attributes that suggest a fixed portfolio architecture by satisfying this criteria are 'picture quality', 'easy to see viewfinder', 'easy/quick film loading', 'stable to hold', 'can take a higher quality picture', and 'rugged construction'. Indeed, with the lowest standard deviation across the population, 'picture quality' was deemed universally important, except by Segment 4. This segment, characterized by a much higher ranking of 'instant developing of prints' than the other segments, also valued picture quality significantly less, more than one standard deviation from the population mean (Figure 13). Thus, although the low deviation would indicate a single-option feature appropriate throughout the portfolio, examining the data more closely reveals that perhaps a two-option platform family approach more advantageous, especially as this addresses the specific needs of a core Polaroid market, the segment that values instant photography highly. Likewise, Segment 4 differs greatly from the population mean and other segments for the 'stable to hold', 'can take a higher quality picture', and 'rugged construction' attributes, implying that these too should implement 2-option family architectures. The agreement of suggested architectures between 'picture quality' and 'can take a higher quality picture' confirms the significance of the data. Furthermore, this also explains the general predominance of a single level of picture quality, as embodied by 35mm film. The majority of the industry offers quality at this single level (with a smaller amount variety provided by different qualities of camera), whereas Polaroid offers multiple film quality formats, such as Spectra and 600-series film, to accommodate the wider variance in their particular target market.

Table 6: Average Attribute Rankings and Standard Deviations for Segment and Total Population

	Segment 1		Segment 2		Segment 3		Segment 4		Population	
Sample Size	315		102		216		41		2419	
Product Attribute	μ	σ	μ	σ	μ	σ	μ	σ	μ	σ
Value For Money Spent	8.2	5.6	6.7	5.4	11	7	10	8.3	10	7.3
Autofocus Capability	11	7.3	22	7.5	10	7.4	16	9.2	11	7.8
Built-In Flash	11	9.1	23	8	10	8.1	14	9.3	10	8.5
Built-In Zoom Lens/No Need For Interchangeable Lens	15	9.6	26	5.8	9.7	7.5	17	9.4	14	9.3
Can Take A Higher Quality Picture	9.2	5.9	4.5	3.8	7.9	4.8	15	8.7	8.5	5.7
Easy To See Viewfinder	11	5.7	8.8	5.2	11	5.7	15	6	9.8	5.4
Easy/Quick Film Loading	12	5.9	12	6.5	11	5.6	15	6.3	11	5.6
Fashionable Color/Stylish Design	24	7.3	24	6.6	25	7	20	7.4	23	6.6
Lightweight	14	6.9	16	6.6	16	8.2	16	7.9	15	7
Low Price	12	6	12	5.2	16	6.3	16	6	13	6.2
Manufacturer/Brand Name	13	7.1	7.9	4.8	16	6.7	17	6.1	12	6.8
Many Accessories Available	19	6.2	7.6	4.3	21	6.3	21	6.3	17	7.5
Portable Size	11	6.3	11	5.7	13	6.7	20	6.5	12	6.7
Rugged Construction	13	5.4	8.4	4	16	6.6	19	6.2	13	5.9
Stable To Hold	11	5.2	8	4.1	14	5.9	19	5.8	12	5.7
Quick Focusing	12	6.5	15	7.6	10	4.9	17	6.5	11	6.3
Red-Eye Reduction Feature	17	8.4	20	7.3	12	6.9	19	6.9	15	7.9
Weatherproof	19	7.7	19	6.8	18	7.7	18	7.8	18	7.1
Simple Operation/Easy To Use	7.9	4.9	14	7.8	7.9	4.8	15	7.5	8.5	6
Large Data Display Panel	24	5.6	24	4.8	18	6	16	6.9	20	6.6
Large Operating Buttons/Knobs	23	5.9	21	6.4	17	6.1	14	6.3	19	6.8
Picture Quality	5.7	4	3.3	1.9	6.5	4.8	13	8.6	6.1	4.8
Instant Developing Of Prints	24	8.4	25	5.7	28	5.8	17	9.2	23	8
Able To Load Images Into Computer	28	4.9	26	4.7	30	3.7	22	8.4	27	5.2

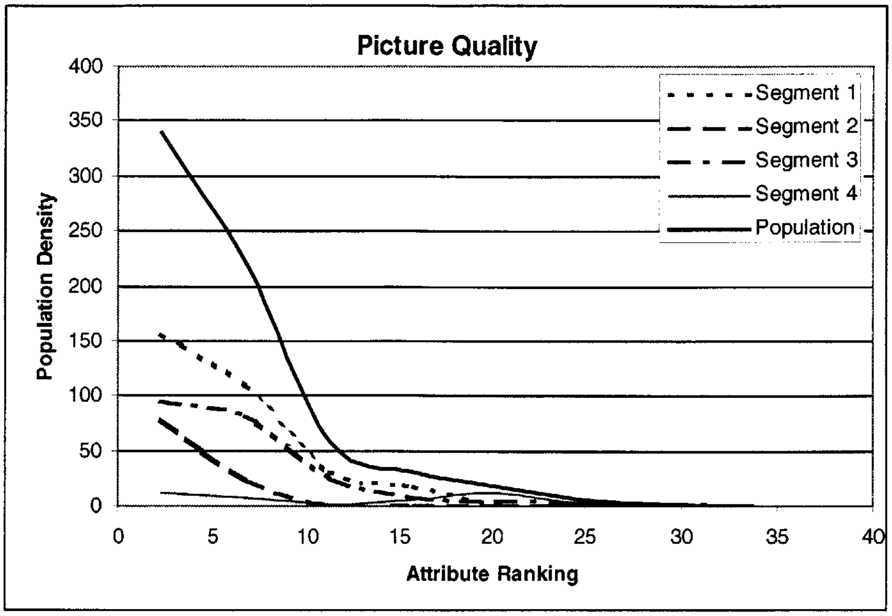

Figure 13: Usage distributions for picture quality indicate a need for two qualities of film.

We then explore the variance of the individual segment's usage distributions. As stated above, we assume these to reflect but underestimate the true usage distribution variances. Examination of Figure 14 reveals the suggestion of a two-model platform family architecture for 'autofocus capability'. Fairly straightforward to implement, this would consist of autofocus cameras and manual focus versions. The wide variance of Segment 4's usage distribution points to a third offering for this feature, an adjustable model. However, since this is both difficult to implement and suggested only by the smallest segment, we recommend a two-model platform family to satisfy the majority of the market's demands. This conclusion is confirmed by the continued existence of both feature options in the photographic industry's offerings. Similarly, the narrow usage distributions for the 'built-in flash' criteria (Figure 15) support the design of a two-option family, one with an internal flash to satisfy Segments 1 and 3 which consider the attribute important and one without the flash for Segment 2. Once again, the wide variance within Segment 4 implies the need for an adjustable model, which might be realized by incorporating a small internal flash with the ability to attach a larger external strobe.

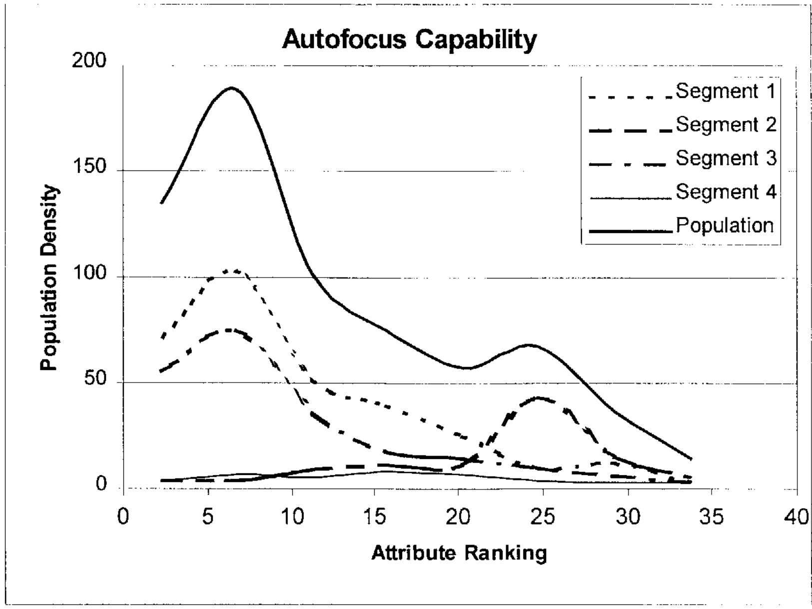

Figure 14: A wide population distribution and narrower usage distributions suggest a two-model platform family architecture for autofocus capability.

Distributions of rankings for other attributes, however, demonstrate the need for a truly adjustable option to satisfy the wide variation across the market and within each usage segment. Such a set of customer distributions is shown for the 'weatherproof' feature in Figure 16. The wide population distribution and the overlapping segment distributions with high degrees of variance argues for the adjustable levels of weather resistance. Since these rankings signify the attributes' importances relative to one another, we interpret the high level of intra-segment variation as customers varying willingness to trade off other attributes for resistance to severe weather. At times the 'weatherproof' attribute rates over all but a few other attributes. At others, customers find most other attributes more important. One way of implementing an adjustable architecture that takes advantage of this insight into customer needs is an external case or enclosure. The customer could adjust the product to her liking by using the case when weather resistance was important and doing without when other attributes such as 'portable size' and 'lightweight' were of greater import.

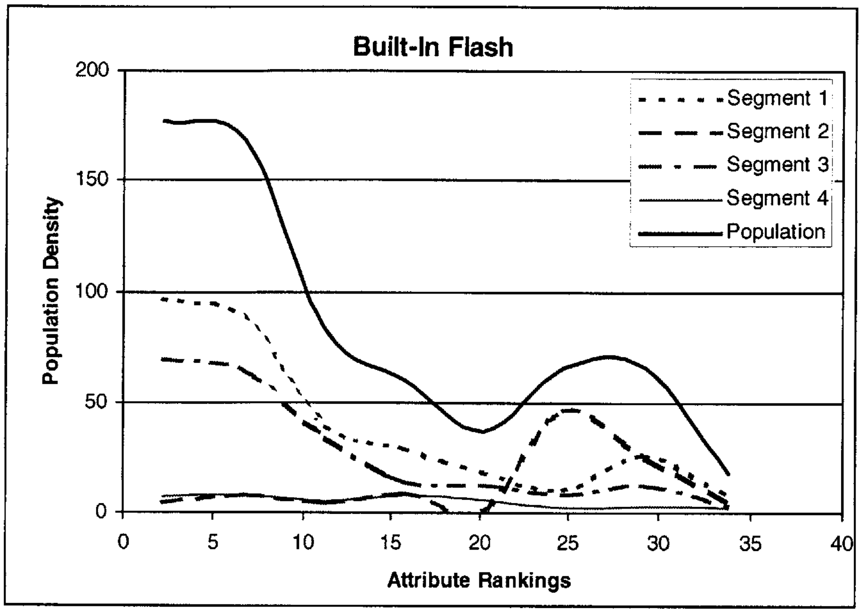

Figure 15: Population and usage distributions indicate the need for cameras with and without built-in flash.

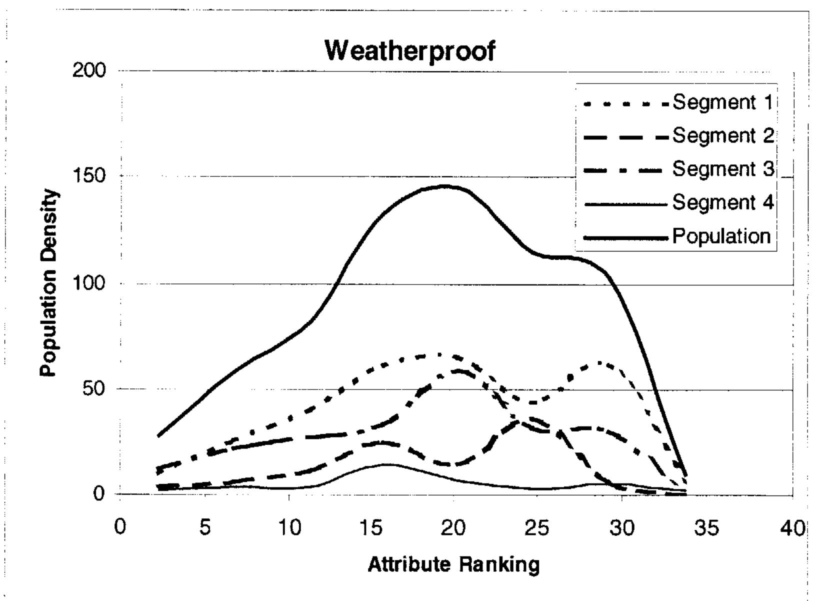

Figure 16: An adjustable architecture is recommended for the weather resistance feature of the portfolio.

We've summarized the portfolio recommendations for all 24 product attributes in Table 7. Usage and population distribution graphs in Appendix A reveal some correlations between distributions not apparent in just the statistics. As anticipated, this analysis generated a portfolio of infeasible size—147456 individual products! Now we tackle the issue of choosing between architectures based on their fitness to the customer space. For instance, if Polaroid can afford to provide and support four different products, should those products include autofocus and manual focus models and/or offer two different levels of picture quality?

Table 7: Product Portfolio Architecture Recommendations

Customer Need	Feature Architecture
Value For Money Spent	Adjustable
Autofocus Capability	Two-Option Platform Family
Built-In Flash	Two-Option Family And Adjustable
Built-In Zoom Lens/No Need For Interchangeable Lens	Two-Option Family
Can Take A Higher Quality Picture	Two-Option Family
Easy To See Viewfinder	Fixed
Easy/Quick Film Loading	Fixed
Fashionable Color/Stylish Design	Generations
Lightweight	Adjustable
Low Price	Adjustable
Manufacturer/Brand Name	Two-Option Generations
Many Accessories Available	Two-Option Generations
Portable Size	Two-Option Family/Adjustable
Rugged Construction	Two-Option Family
Stable To Hold	Two-Option Family
Quick Focusing	Three-Option
Red-Eye Reduction Feature	Two-Option
Weatherproof	Adjustable
Simple Operation/Easy To Use	Fixed
Large Data Display Panel	Adjustable
Large Operating Buttons/Knobs	Two-Option/Adjustable
Picture Quality	Two-Option Family
Instant Developing Of Prints	Two-Option Family
Able To Load Images Into Computer	Two-Option Generations

Since we use standard deviation throughout this method to measure customer and usage variety, it follows that we can evaluate the different benefits of various architectures by measuring the effect on attribute ranking variation. Increasing the number of feature options in a portfolio segments the market into groups determined by which product's perceived location is the minimal Euclidean distance from the customer's ideal point. Thus, implementing a two-option platform family splits the market base into twice as many clusters as existed before and standard deviation can be recalculated for each of these resulting clusters. This new value for deviation represents the variance for each attribute that the feature option is expected to capture. For instance, the total population deviation for the ranking of rugged construction is 5.90. Once the market is segmented into two groups based on rugged construction, one which rates the feature highly and the other poorly, the largest level of standard deviation that the rugged construction feature option is expected to support is reduced to 3.90. We then order the attributes that suggest a multi-option platform family in terms of standard deviation. Since these features are already ranked relative to each other in terms of importance, there is no need to scale or normalize these data. Variance within a single attribute-based cluster indicates the amount customers vary in how highly they rank that particular attribute over all others. We set an upper limit for the size of cluster a feature option is expected to cover by fixing a maximum value for standard deviation. As illustrated by Figure 17, the lower that threshold, the more abundant and smaller the clusters, and thus the larger the portfolio and the lower the overall amount of customer dissatisfaction with their preferred product, the product closest to their ideal point. Reducing this threshold, we form a list of the order in which variety should be implemented to decrease customer dissatisfaction (Table 8).

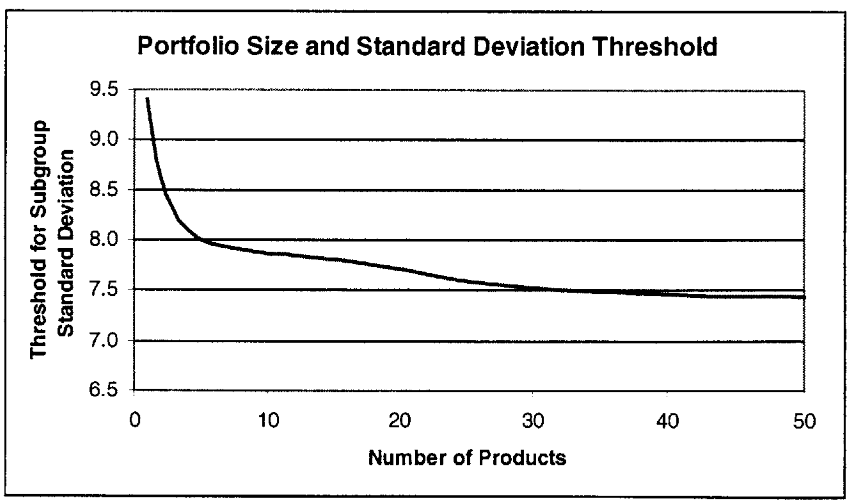

Figure 17: Few products are needed to decrease the maximum subgroup standard deviation dramatically.

Table 8: Portfolio Size Increases as the Cluster Standard Deviation Threshold Decreases

	Attribute	σ	#
1	Built-In Zoom—2	8.6	2
2	Built-In Flash—2	8.1	4
3	Instant Developing Of Prints—2	7.9	8
4	Red-Eye Reduction Feature—2	7.8	16
5	Autofocus Capability—2	7.5	32
6	Many Accessories Available—2 (Gen)	7.4	64
7	Value For Money Spent—2 (Adj)	7.2	128

Another approach to forming a hierarchy of attribute architectures is to sort them by the amount each *decreases* the maximum cluster size, interpreted as standard deviation of attribute rankings within that cluster. By ordering the architectures by the decrease in cluster size, we maximize the effect each additional feature option has on customer satisfaction. Thus, implementing a two-product portfolio consisting of cameras with and without a built-in zoom lens has the largest effect on customer satisfaction. The other most influential architectures are shown in Table 9 . Furthermore, these results coincide fairly well with the hierarchy derived from choosing the architectures that decrease the highest level of standard deviation.

Table 9: Portfolio Size Increases as the Threshold for Change in Cluster Standard Deviation Decreases

	Attribute	Δσ	#
1	Built-In Zoom—2	5.0	2
2	Red-Eye Reduction Feature	3.7	4
3	Many Accessories Available	3.4	8
4	Built-In Flash	3.4	16
5	Weatherproof--Adj	2.9	32
6	Autofocus Capability	2.8	64
7	Lightweight--Adj	2.7	128

Table 10: List of Attributes by Decreasing Effect on Cluster Size

	Attribute	Size	σ	#
1	Lightweight—2 (Adj/2)	996	9.3	2
2	Weatherproof—2 (Adj)	970	9.3	4
3	Red-Eye Reduction Feature—2	940	9.3	8
4	Large Operating Buttons/Knobs—2	899	9.3	16
5	Built-In Zoom—2	874	8.5	32
6	Rugged Construction—2	847	8.5	64
7	Manufacturer/Brand Name--2	793	8.5	128

Chapter 8: Conclusion

We have presented a method for determining appropriate product and portfolio architectures for a set of products based on the needs of the customers and demonstrated its application to a specific product market. Exploring the desired values for product features both for the whole population of customers at a single point in time and for a sample of representative customers over all their uses of the product, and comparing those distributions of needs can yield indications as to the preferred product architecture. Adjustability addresses the needs of the customer when these two distributions match. However, when they differ, fixed architectures or families of platform products best satisfy the desires of the customer. Examples of consumer products were used to illustrate how these market models can be used to shape the structure of the product. This method gives product development teams a tool for making product architecture decisions. With architecture choices based on both production concerns and satisfying customers, teams will be equipped to design flexible, successful products.

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Biographical Note

The author received a Bachelor of Science in Mechanical Engineering from Stanford University in June 1995 and worked for the following two years as a design engineer with the fine folks at Light & Motion Industries, a vertically-integrated manufacturer of underwater photography and lighting equipment based in Monterey, California. Leaving her home state, she started graduate work in September 1997 at the Massachusetts Institute of Technology, where she co-wrote an article also titled "Product Architecture Definition Based Upon Customer Demands" to be published in the American Society of Mechanical Engineers *Journal of Mechanical Design*. She enjoys writing about herself in the third person and owns no toasters or instant-film cameras.

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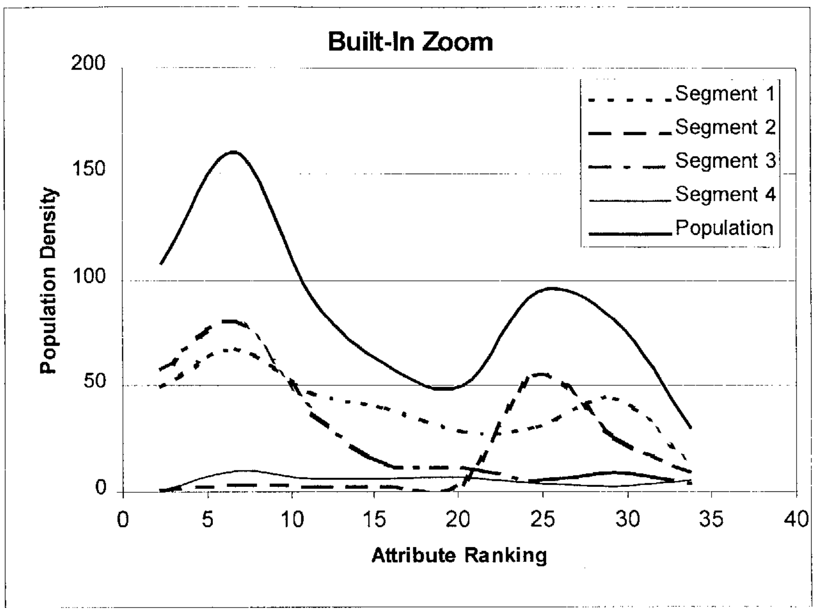
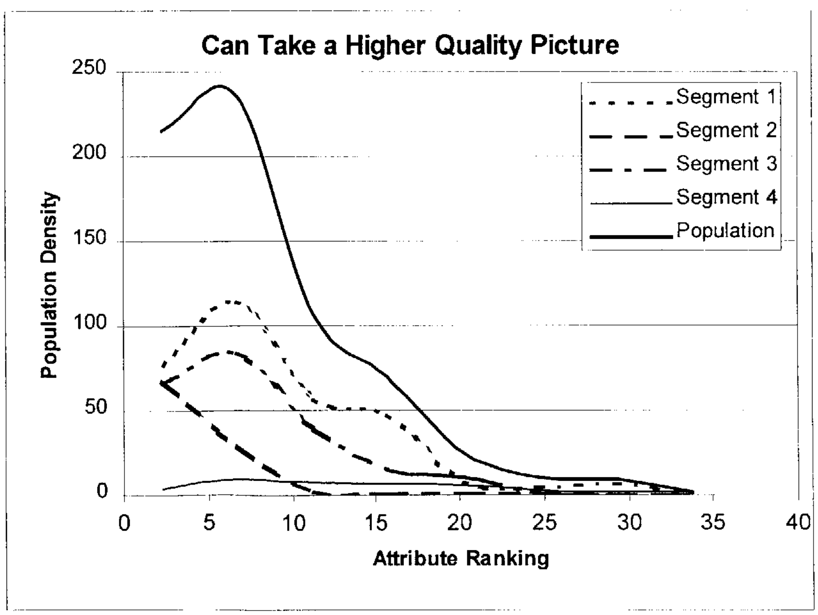
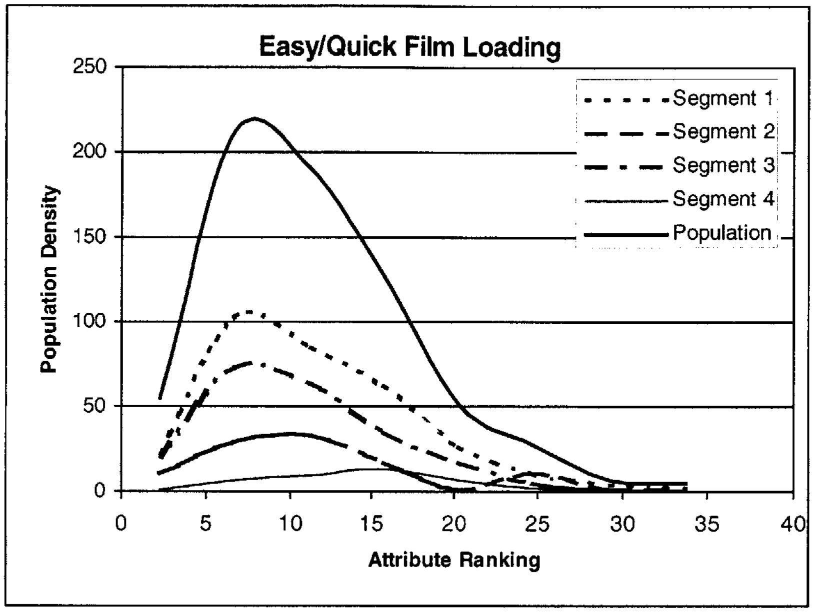
Appendices

Appendix A: PMA Attribute Ranking Distributions



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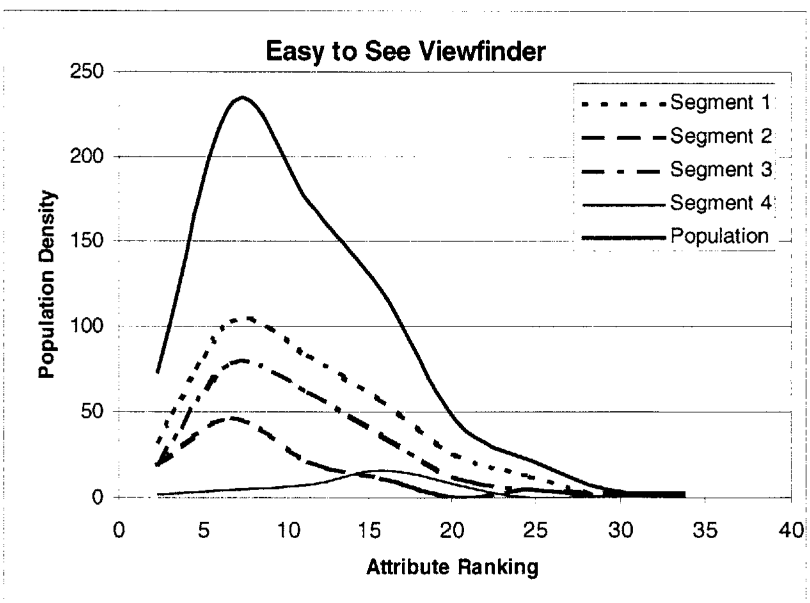
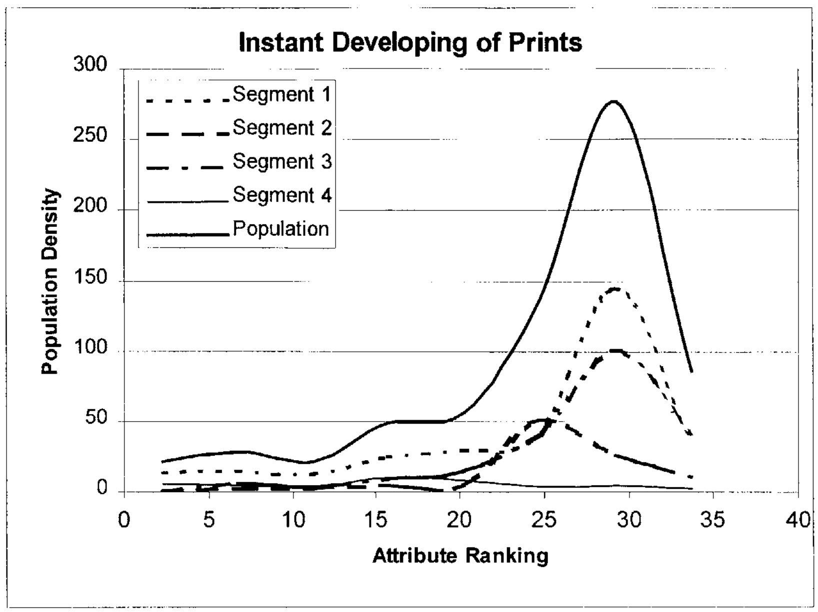
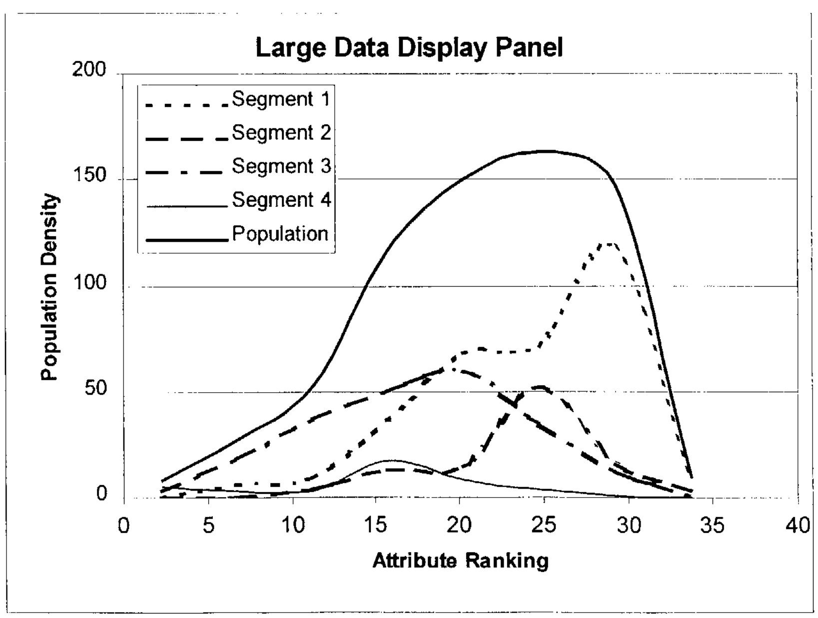
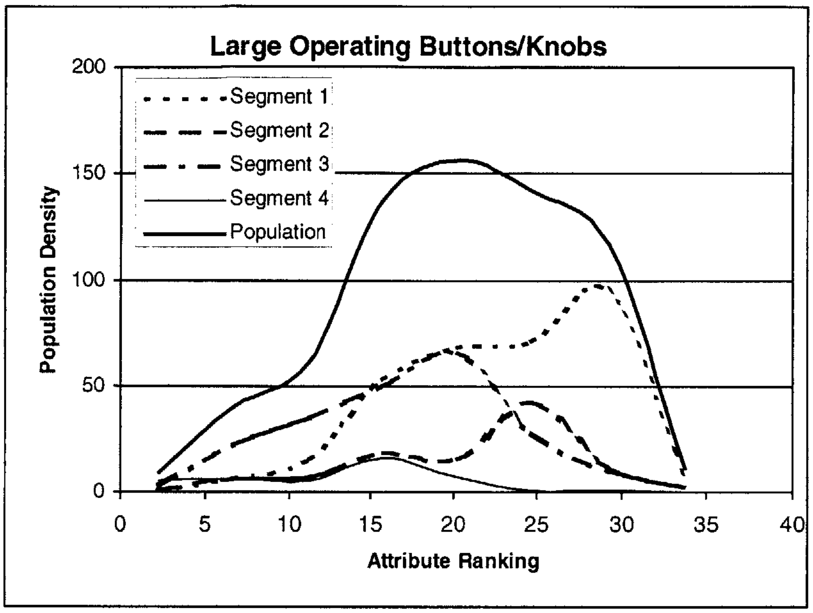
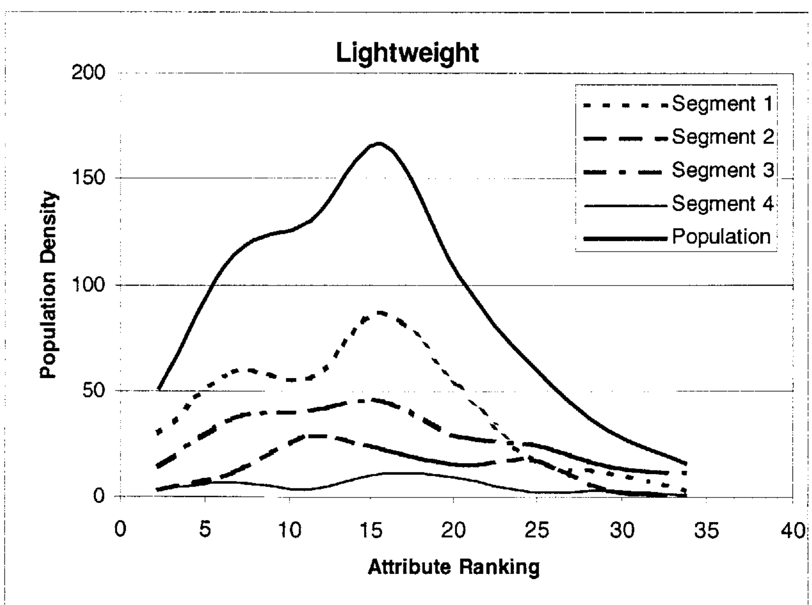
Population Density
Attribute Ranking
Segment 1
Segment 2
Segment 3
Segment 4
Population
250
200
150
100
50
0
0
5
10
15
20
25
30
35
40


Easy to See Viewfinder
Population Density
Attribute Ranking
Segment 1
Segment 2
Segment 3
Segment 4
Population
250
200
150
100
50
0
0
5
10
15
20
25
30
35
40


Instant Developing of Prints
Segment 1
Segment 2
Segment 3
Segment 4
Population
Population Density
Attribute Ranking
300
250
200
150
100
50
0
0
5
10
15
20
25
30
35
40


Large Data Display Panel
Segment 1
Segment 2
Segment 3
Segment 4
Population
Population Density
Attribute Ranking
200
150
100
50
0
0
5
10
15
20
25
30
35
40


Large Operating Buttons/Knobs
200
150
100
50
0
Population Density
Segment 1
Segment 2
Segment 3
Segment 4
Population
0
5
10
15
20
25
30
35
40
Attribute Ranking


Lightweight
200
150
100
50
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Population Density
Segment 1
Segment 2
Segment 3
Segment 4
Population
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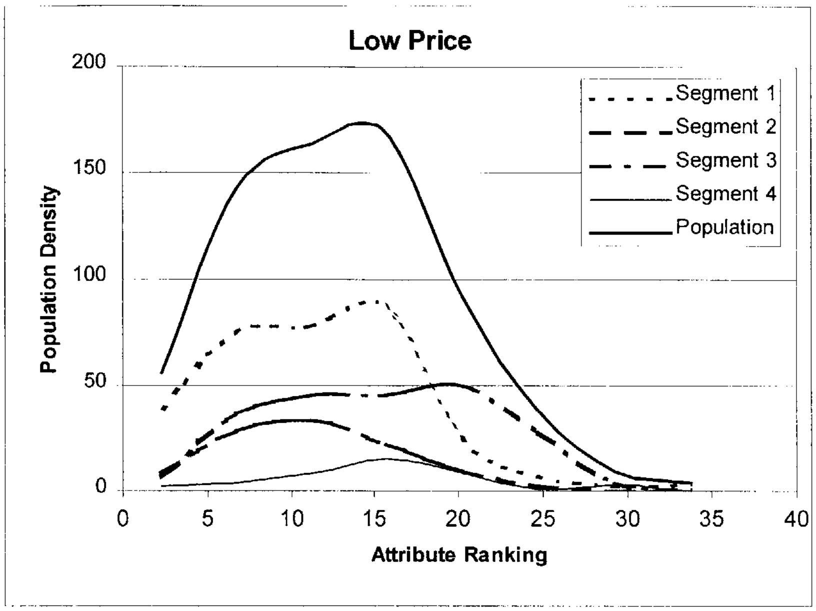
5
10
15
20
25
30
35
40
Attribute Ranking


Low Price
Population Density
Attribute Ranking
Segment 1
Segment 2
Segment 3
Segment 4
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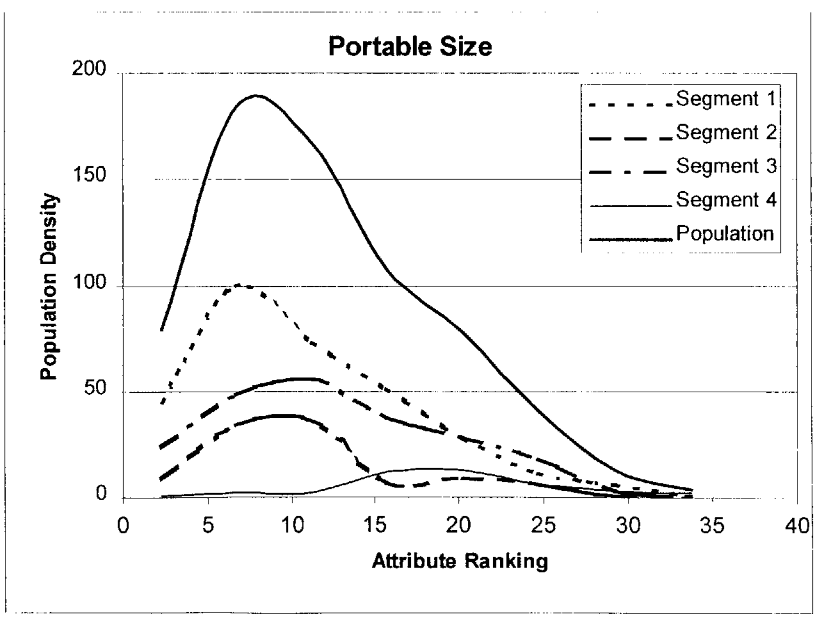
25
30
35
40


Portable Size
Population Density
Attribute Ranking
Segment 1
Segment 2
Segment 3
Segment 4
Population
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100
150
200
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5
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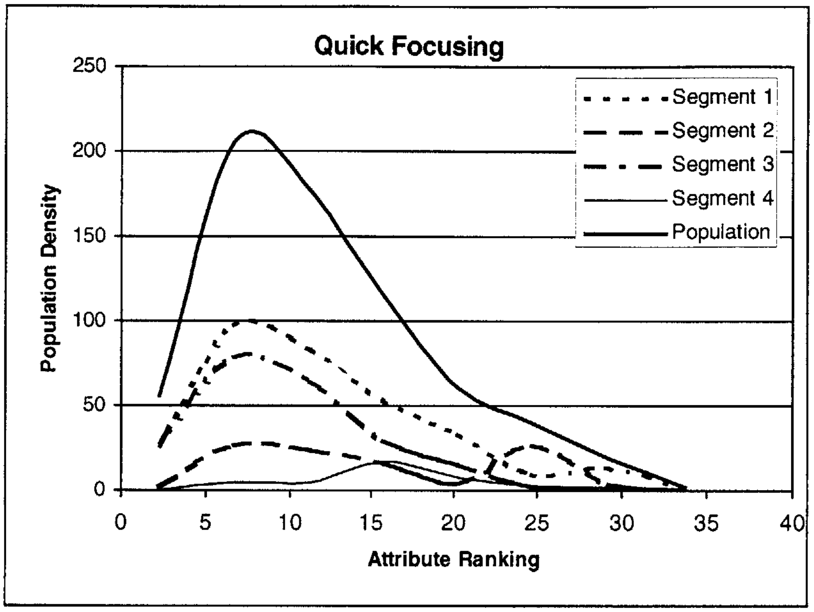
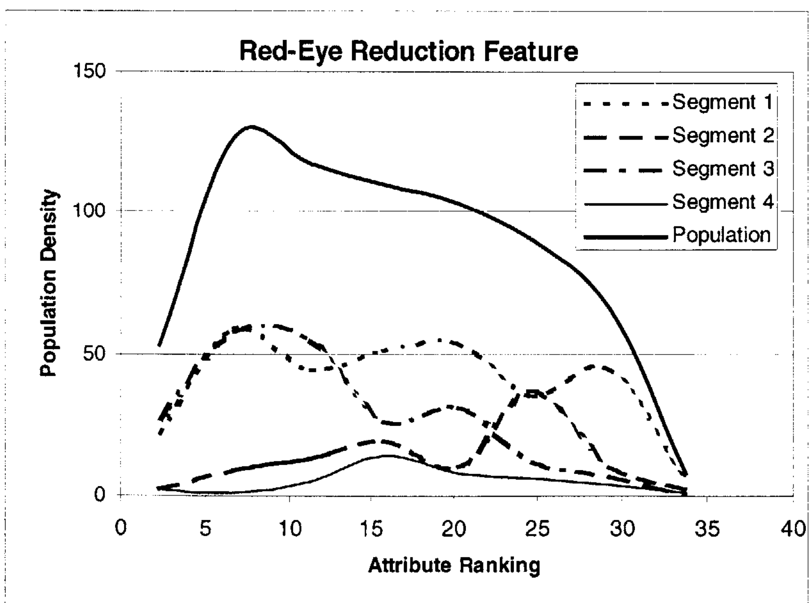
15
20
25
30
35
40


Quick Focusing
Population Density
250
200
150
100
50
0
0
5
10
15
20
25
30
35
40
Attribute Ranking
Segment 1
Segment 2
Segment 3
Segment 4
Population


Red-Eye Reduction Feature
Population Density
150
100
50
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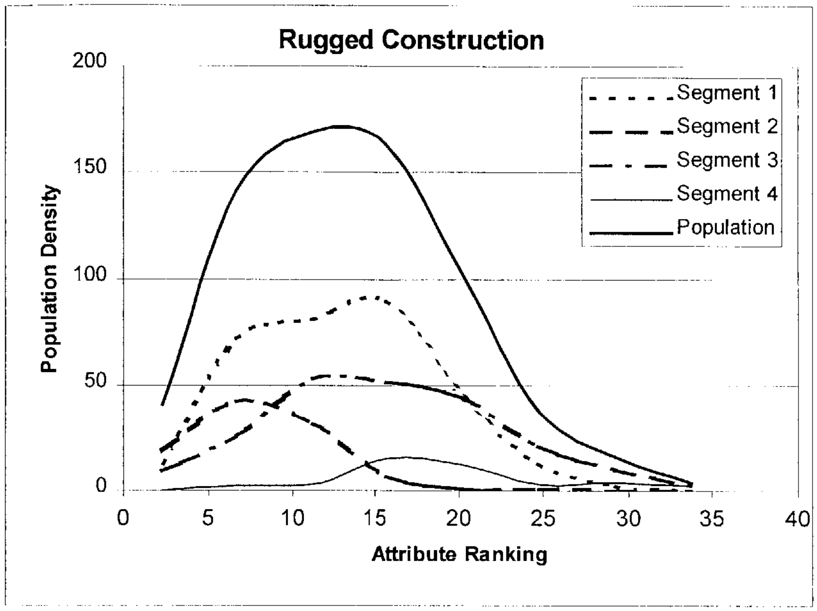
5
10
15
20
25
30
35
40
Attribute Ranking
Segment 1
Segment 2
Segment 3
Segment 4
Population


Rugged Construction
200
150
100
50
0
Population Density
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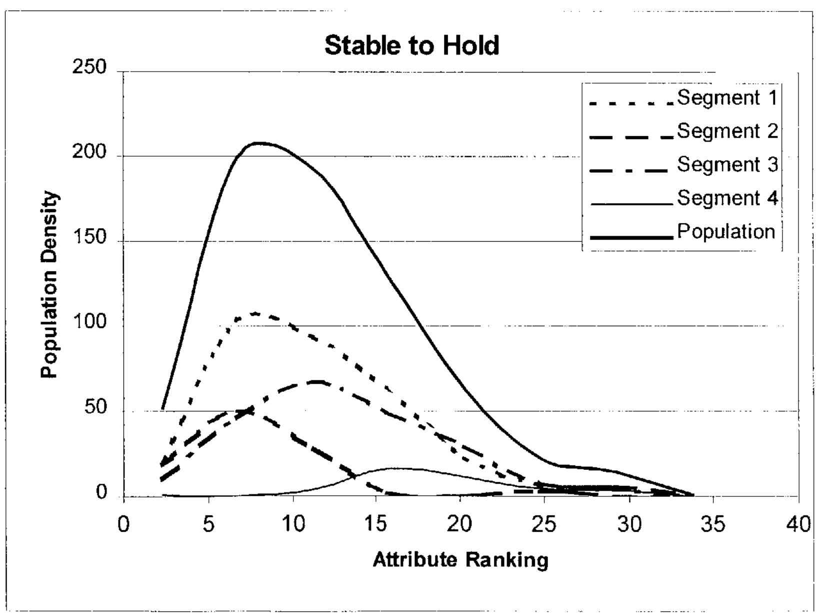
5
10
15
20
25
30
35
40
Attribute Ranking
Segment 1
Segment 2
Segment 3
Segment 4
Population


Stable to Hold
250
200
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Population Density
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20
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30
35
40
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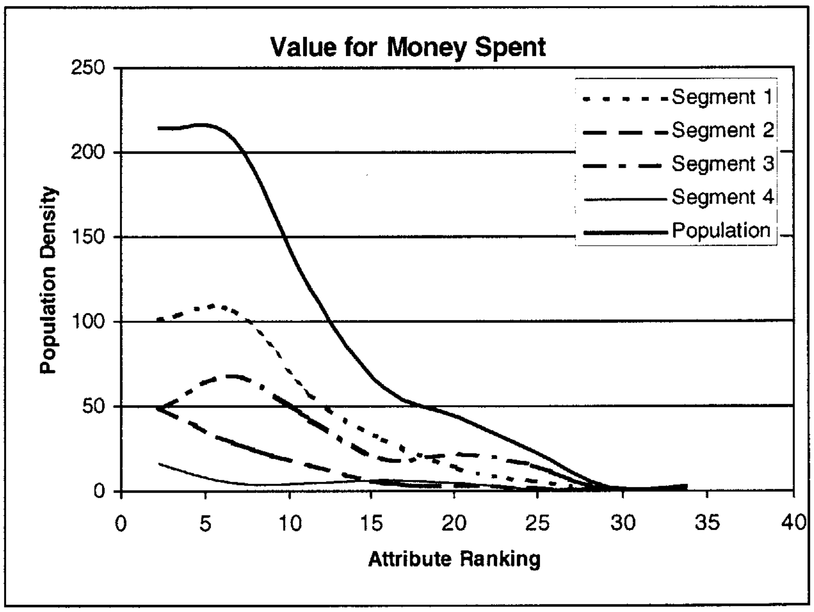
Segment 2
Segment 3
Segment 4
Population



Value for Money Spent
250
200
150
100
50
0
Population Density
0
5
10
15
20
25
30
35
40
Attribute Ranking
Segment 1
Segment 2
Segment 3
Segment 4
Population

Appendix B: Glossary

Cluster analysis: a technique for decreasing the number of factors affecting marketing decisions by grouping the population into similarly behaving clusters

Factor analysis: a method for simplifying marketing decisions by reducing a set of variables to a smaller number of independent variables by searching for correlations in the sample population

Platform: the set of resources designed to be common to a set of products

Population distribution: the distribution of every customer's average target value for a product attribute at a given time

Portfolio architecture: commonality of features between products in a portfolio

Product architecture: the mapping of a product's functions to its components and the level of incidental interaction between components

Product family: a set of products that are designed to share components and/or resources

Product portfolio: the total set of products a company offers a target market

Usage distribution: the distribution of a segment's target values for a product attribute across the entire set of uses and circumstances in which they use the product