Designing Effective Portfolio Variety Using
Customer Need Discrimination Thresholds

by

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ABSTRACT

In order to develop a robust product portfolio one must first consider the needs of the market and create the ability to satisfy those needs through a good product architecture. To be successful, the link between a population's distribution of customer needs and the design of the product portfolio architecture created to address those needs must be understood. This thesis describes a method to determine which customer needs on a vehicle should have multiple levels offered to diversify the market coverage and in what order to expand the levels as more products are permitted in the portfolio. The methodology is formulated as a general optimization problem in which the number of levels on an attribute is balanced against the constraints of multiple variants that can be accommodated through manufacturing. This optimization approach is used to design a platform for a sport utility vehicle and its supported product variants.

Thesis Supervisor: Kevin N. Otto

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“Trust in the Lord with all your heart, and lean not on your own understanding.
In all your ways acknowledge Him, and He shall direct your paths.”

Proverbs 3:5-6

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1. Introduction

1.1. Background

A product portfolio is the set of products offered by a company in the entire market over time. The portfolio's function is to satisfy customer needs while mitigating the risk in the market. A robust portfolio would depend on the product mix of the portfolio. From a product design viewpoint, the means to create different product portfolios is established by the product architecture. The product architecture is the manner in which product functions map to the physical form of the product (Ulrich, 1995); integral architectures exhibit a complex mapping whereas modular architectures separate product functions into one-to-one forms.

A portfolio architecture (Yu et al, 1999), on the other hand, is the manner in which variety in functions map to variety in the physical form of a product portfolio. Types of portfolio architecture include an unsharing architecture where the products do not share, a platform family with supported product variants that share a common subset, a platform generations architecture using swappable modules that are fixed once swapped, or a completely adjustable architecture with built-in adjustments that can be changed on-the-fly to provide variety.

One very important type of portfolio architecture is the platformed family of product variants. For example, the sport utility vehicles offered by General Motors Corporation come in a variety of different offerings, but are all built off the same assembly platform. Given a platform with multiple variant vehicles built off the platform, the question arises as to what design targets the portfolio of products should be designed to. Each customer need has a range of desired target values. Each range could be met by offering one or more design target levels. What design targets should a platform team design to, and how many?
1.2. Overview

The goal of this research is to assist in improving the planning methods for product families and portfolios by understanding the customer needs to create a more robust portfolio of products. This project will bring customer information to product planners and develop methods for assessing the robustness of a portfolio plan. The results will enable the rapid determination of product families and platform definition including variety/reuse and vector of differentiation, while providing strong links between the company’s strategic and operational plans.

A method is presented to determine which performance targets on a product line should have multiple levels offered to diversify the market coverage and in what order to expand the levels as more products are permitted in the portfolio. The goal is to explore vehicle line portfolios to understand what options are and are not effective from the viewpoint of the customer. Therefore, customer desired portfolio variety is explored in this work; the impact of added vehicle diversity upon development and production is not considered; such portfolio complexity issues are explored elsewhere.

The approach is, through conjoint studies (Churchill, 1999), to form desired target distributions on each important product attribute. For example, rear knee room has a design target specification that ranges from -10 to 10 inches. This design target is defined relative to a base specification of rear knee room in inches. Over this domain, conjoint studies indicate customer preferences. The same is done on all of the attributes selected in the study. This result is a probability distribution model over the performance attribute space, representing market desire. Then each attribute is examined individually, to determine on that attribute how many target levels should be designed into the portfolio. This is done through a cluster tree analysis. Note that, as will be discussed, each attribute must be considered independently, since each attribute is a separate engineering design decision. Next, these variety trees are combined into an overall market cluster tree through a novel
optimization formulation that indicates which attributes to break out into multiple levels and when. This approach is called the *attribute breakout sequence*. Finally, given this flexible portfolio, actual design targets are selected within this permutative set to determine the actual product line to offer, in association with complexity measures.

In the next chapter, the related work in product development is explored and how it pertains to this study. In Chapter 3, there are definitions for some of the nomenclature used in the research. There are varying definitions for product architecture, product portfolios, and portfolio architecture. The goal is to develop definitions that can be interchangeable. In Chapter 4, the development of the necessary market model to define the scope of the market is illustrated. In Chapter 5 the market segments are identified using a cluster analysis. A graphical analysis is also used to identify clusters in the market. In Chapter 6, an optimization formulation is presented to determine an attribute breakout sequence presented. The application of this methodology is introduced while concentrating particularly on the SUV segment of the automotive market. Finally, an explanation of the design decisions on offering multiple levels is discussed in Section 6.2.
2. Related Work

Over the past few years there has been a desire to gain more understanding on how to create robust product portfolios. Currently, there are several researchers investigating the areas of product portfolio planning, product variety, and product architecture. Product portfolios play an important role in the success of a company. Meyer and Lehnard (1997) discuss the impact of product portfolios on a company’s performance. Furthermore, they discuss the importance of creating a stream of derivative products through a successful product architecture definition. Sanderson and Uzumeri (1996) talk in depth about Sony’s strategy to design product families around platforms and how it effects the product architecture. They illustrate the ability of platform designs to provide mass customization and handle changes in the market. Product families based on well-designed platforms have been used to provide large numbers of product variants to target various market segments, which ultimately lead to a competitive advantage.

Moore, Louviere, and Verma (1998) have work most related to ours. They also use conjoint studies to help design platforms. Their approach is to identify which variables have large variety and which do not, to identify which to fix into a common platform. Krishnan et al (1998) examine rapidly changing technology products. They present a method to identify which content should be platformed and which should be variant from model change to model change over time. That is, their work is focused on the platformed-generations type of portfolio architecture (Yu et al, 1999). Components that rapidly change (and so fall in value) are quantitatively identified for isolation in modules. In our work here, we consider customer demanded variety and identify the most effective combinations of variant design target specifications given a desired product family size.

Many researchers have focused on how product architecture can be structured. Ulrich (1995) established and defined the advantages and
disadvantages of different product architectures and how they relate to product planning. Ulrich and Eppinger (1995), and Cutherall (1997) also discuss benefits and cost of different product architectures. Product architecture (integral versus modular) is a single product concept; it does not describe how a portfolio of products is architected (unsharing, platform, adjustable). Platform architecture types permit or exclude portfolio architecture types, and vice versa.

Yu et al (1999) introduced a methodology to suggest a portfolio architecture that will most effectively provide variety to the market. The work compares the variation on usage distributions of customers to the person-to-person population distributions to determine an effective architecture. The idea is that some architectures are more permissive of on-the-fly changes than others. That analysis, however, provided no statistical means to reduce the number of permitted variants on each need. This paper will expand the methodology into a rank ordering method that sequentially expands the different attributes into different levels using customer discrimination thresholds.


Finally, others are doing work on complexity issues with product platforms. Martin and Ishii (1997) have developed indices for quantifying variety and its cost effects. The basic idea is that the differences that manifest late in an assembly line are easier to accommodate than earlier ones (delayed differentiation). Robertson and Ulrich et al. (1998) present tools and metrics that support analyzing and planning product variants taking cost and differentiation aspects into consideration. Potential revenue is based on analysis of the product coverage and who actually considers the product.
3. Product Portfolio Planning

3.1. Product Architecture

Product architecture is the act of transforming a product function into a product form [5]. It determines the underlying mechanisms for offering variety for products, affects the performance of the product, and can reduce the time it takes to develop new products. Hence, it addresses the overall needs of the customer base while creating a product design. Cutherell defines good product architecture as one that will translate the customer needs effectively. Furthermore, Ulrich defines architecture into two different categories: integral and modular depending primarily on the mapping of the functions to the product components. These architectures can be configured to meet a variety of applications [32]. The architecture decision that is selected would depend primarily on the impacts of cost, performance, and risk [28]. Generally, performance or cost drives integral architectures. Conversely, product change, product variety, engineering standards, and product service requirements drive modular architectures. A more detailed discussion of each of these architectures is discussed in the next section.

3.1.1. Integral Architecture

In an integral architecture the mapping between the functions and the components is complex. This usually means that the individual chunks in the product may have numerous functions [4, 26]. Moreover, the interactions between the chunks are poorly defined. Hence, a change in one area affects other areas of the product. An example of this is a carving knife. This knife only uses one blade, which is designed to slice and to keep a sharp edge for many cuts. The blade and handle are of an integral construction. There are, however, knives specifically designed for the home or commercial markets. Thus, it is more difficult to offer variety with this architecture. It does, at times, reduce the costs and increase the performance of the product. A product
embodying an integral architecture is generally designed with the highest performance in mind. Some implications of this type of architecture are discussed in further detail in Section 3.1.3. Examples of when an integral architecture is useful are videocassette shells, which are mass-produced and share the same architecture across brands and the high-performance wheels for a racing bicycle. These wheels are created with multiple functions so as to reduce the costs to the end user. In short, the function of an integral architecture is significantly more complex than that of a modular architecture.

3.1.2. Modular Architecture

Modular architectures tend to address the issues of product change, product variety, and the speed of market introduction of new products. In a modular architecture, there is a one-to-one mapping between the functions and components. The interactions between the chunks are well defined. One of the advantages of modular product architecture is in the ability to create variety by removing or replacing modules while not disturbing the rest of the design. Modular architectures have advantages in simplicity and reusability for a product family or platform. This creates different products with little investment of resources and time. Figure 3.1 shows the five general types of modular architecture. The five categories of use are component-swapping modularity, component-sharing modularity, fabricate-to-fit modularity, bus modularity, and sectional modularity [34].
Component-swapping modularity is when two or more alternative types of a component can be paired with the same basic product creating different product variants belonging to the same product family. An example of this type of modularity in the automotive industry would be the availability of different audio compact disk decks, windshield glass types, and wheel types for the same automobile.

Component-sharing modularity is quite similar to component-swapping modularity. Note that component-sharing modularity and component swapping are identical except that swapping involves different components using the same basic product and sharing involves different basic products using the same component. Examples of component-sharing in automobile manufacturing are the use of the same spark plugs, alternators, or brake shoes in different product families.

Fabricate to fit modularity is the use of one or more standard components with one or more infinitely variable additional components. Usually the variation is associated with physical dimensions that can be modified (e.g. cut to length). An example of this type of modularity is a group of cylindrical pipes.
that can be produced in arbitrary lengths. Bus modularity is used when a product with two or more interfaces can be matched with any selection of components from a set of component types. Sectional modularity allows a collection of components chosen from a set of component types to be configured in an arbitrary way as long as the components are connected at their interfaces. Some examples of this type of modularity are found in sofa systems (sectionals) and Lego blocks. These modular architectures can accommodate variety and help to build robust product portfolios. Product modularity allows for variants in product families to be created, which will meet different needs. These product families will be compiled to create a complete portfolio of products. This portfolio of derivative products can be produced using product platforms. In the next section, a clear definition of product platforms will be given to get a clear understanding of how product architectures relate to the product portfolio.

3.1.3. Implications of Product Architecture

Many of the decisions about how to separate the product into chunks as well as how to impose modularity on the architecture are linked to several issues to the entire venture: product change, product variety, standardization, and product performance [33]. Hence, the architecture decision is linked to decisions concerning the marketing strategy as well as the manufacturing capabilities. This research does not explore the manufacturing capabilities of a product architecture, however, it is clear that the architectural plan will have to coincide with the manufacturability of the plan.

3.1.3.1. Product Change

The function of a product can be decomposed into a number of functional elements [5, 33]. These physical elements are arranged into major building blocks, called chunks. The architecture of the product is the way that the chunks are assigned to the functional elements and how these chunks interact with the elements. Thus, the architecture defines how the product can be
changed. Depending on the architecture choice, changing a product can be either a smooth transition or a complex process. For example, modular chunks allow changes to be made by isolating the functional elements of the product without affecting the design of the other chunks. Conversely, changing an integral chunk may impose on many functional elements and require necessary changes to other related chunks as well. Some of the motives for product change are upgrades, add-ons, wear, flexibility in use, reuse, and adaptation [33]. Ulrich and Eppinger believe that in each of these cases, a modular architecture permits the company to minimize the physical changes in a design required to achieve a functional change.

3.1.3.2. Product Variety

In examining both integral and modular architectures, it is determined that products built around a modular architecture can achieve variety more easily without adding tremendous complexity to the manufacturing system. Variety is defined as the number of different members of a family existing at the same time in response to market demand [33]. Sony produces hundreds of different Walkman models, but can achieve this variety at relatively low cost by assembling the variants from different combinations of standard chunks [28].

3.1.3.3. Component Standardization

The use of the same component or chunk in multiple products is called component standardization. Many products using the same functions mean the chunks should be standardized. For instance, if a chunk implements only one or a select few useful functional elements then the chunk should be standardized and used in different products. There are many benefits to component standardization. It allows a firm to reduce the number of parts required in their products, which in turn reduces inventory and cost. It also allows the firm to manufacture the chunk in higher volumes as opposed to non-standardization. This can in return lead to an increase in quality and reliability.
3.1.3.4. Product Performance

The performance of a product can be defined as how well a product completes the desired functions. Oftentimes, performance characteristics are measured in speed, life, efficiency, size, and weight. An integral architecture tends to optimize performance characteristics that are driven by the size, shape, or mass of a product. It also allows for redundancy to be eliminated through function sharing with the nesting of components that share functions across the chunks. However, it makes the product more difficult to change during production. Thus, modification to the product may require extensive redesign of the product potentially increasing the cost of manufacturing the product. An example of a product that's performance is optimized by the design is a videocassette tape. The basic functions, to play, record, fast forward, and rewind is optimized in all videocassette tapes without regard to the brand. They are produced in high volume, which cuts down on cost. However, a portable videocassette cannot be interchanged with a regular videocassette tape without an adapter. Presently, an integral architecture is generally not feasible in the automotive market because vehicles are an intricate combination of chunks with numerous functions.

3.2. Product Platforms

There are many varying definitions of a product platform. Depending on whether it is used in industry or academia there can be several interpretations of the concept. For these research purposes, the definition of a product platform is adapted from the one used by Meyer and Lehnard:

A product platform is the set of parts, subsystems, interfaces, and manufacturing processes that are shared among a set of products, and allow the development of derivative products with cost and time savings.

A robust platform design is key to the success and quality of a product family. Meyer defines a product family as the set of products that share common technology and address a related set of market application. Serving as the technological foundation for creating several or more derivative
products, a platform also helps to accommodate variety in the market. Strong platforms provide leverage because each derivative product can be developed at incremental cost relative to the development of the initial product architecture [22]. This is evident by the existence of common components across the current generation of a product family of vehicles. This concept (Wheelwright and Clark, 1992) is generalized in figure 3.2 as an evolutionary model for the product family. It represents a single product family that undergoes successive platform extensions, a new platform development, and follow-on product developments of these platform versions. The figure also suggests that a company must continue to renew the base product architecture while reaping the potential benefits of the existing platform.

Figure 3.2: Evolutionary Platform Renewal Model
Product platforms have received an increased interest in the research arena to determine the effects of cost and time savings for derivative products. Many diverse companies in industry have been involved in intensive research about product platforms that will help in the product development process. By sharing components and production processes across a platform of products, companies can develop differentiated products efficiently, increase the flexibility and responsiveness of their manufacturing processes, and take market share away from competitors that develop only one product at a time [26].

Black & Decker used the strategy to use a common platform as a building block from which a host of derivative products were effectively created. It drove many of their competitors out of the power tools business. The Black & Decker case demonstrates the cost efficiencies, technological leverage, and market power that can be achieved when companies redirect their thinking and resources from single products to families of products built upon robust product platforms.

Creating a successful platform may however be difficult. There is a challenge for the designer to determine what part of the product architecture should be used to create differentiating products while sharing parts and production processes across the products. This is sometimes not intuitive. The successful completion of this task requires input from the company's marketing, design, and manufacturing functions. Furthermore, in platform planning a designer does not want to make the mistake of creating too many products that cannot be differentiated from the end user. Some companies in the past have had a difficult time with products that created too much similarity from the customer's perspective.¹ As a result, several products targeted at different markets did not achieve optimal success due to confusion of whether the products were actually different products.

¹ "Will Success Spoil General Motors?,” Fortune, 22 August 1983
When successfully done, a product platform can give a company many benefits over companies that design products one at a time. The platform approach allows the company to tailor products to the various needs of different customer segments. Moreover, companies can reduce development cost and time. They can reduce manufacturing cost due to the simplifying of parts and processes. However, product platforms must be managed. If a platform is not rejuvenated, its derivative products will become dated and will fail customers in terms of function and value. If a company's platforms are renewed periodically, however, redesigned to incorporate new functions, components, and materials, the product portfolio will remain robust through successive generations.

3.3. Product Portfolio

A product portfolio is a set of products offered by a company in the entire market over time. The portfolio's function is to satisfy customer needs while mitigating various risks. The robustness of a portfolio depends on the product mix. This mix can be created through modular product architectures, which is where sub-systems are designed as modules that complete separable functions [32]. A portion of the General Motors portfolio is shown in figure 3.3. How does one decide how to create the variety in the portfolio?

The strategy to introduce new products into the portfolio is critical to the success of the product. These strategies drive the design decisions on the development of the product portfolio. In choosing a product portfolio some of the strategies considered are product change, product variety, standardization, performance, and manufacturing cost. Product change is the strategy used in the technology for copier toners or camera lenses; product variety is implemented in computers and automobiles; standardization is used in motors, bearings, and fasteners; performance strategy is used in racing bikes and fighter planes. Finally, manufacturing costs driving the design is the strategy used in disk drives and razors. These strategic architecture decisions
determine how variety in the market is addressed through the conception of the platform and its derivative projects [37].

Sony uses an effective strategy to create variety in its portfolio. Sony’s Walkman line offered over 180 models to customers. This variety was created using three platform products. Sony dominated the market segment because of its effective architecture decisions. By creating effective portfolio architecture, much of the variety in the Walkman segment is accommodated and allows the customer to find a product to meet those particular needs. In the next section, we discuss how portfolio architecture can create variety amongst products.

![Figure 3.3: Portion of General Motors’ Product Portfolio](image)

3.4. Portfolio Architecture

Portfolio architecture (Yu et al, 1999) is the manner in which products are designed as a set to provide variety to a market. The portfolio architecture is the way the portfolio is designed to share or not share components among products offered. This could be through a platform and supported variants, or
a platform with *swappable modules* that are fixed once swapped, or through a completely *adjustable architecture*. These architectures: fixed, platform, and adjustable can be used to meet large market variety depending upon which approach minimizes cost and risk while maximizing performance [39]. Figure 3.4 illustrates the various types of portfolio architectures.

### 3.4.1. Types of Portfolio Architecture

We use this framework to analyze the automotive industry in which many of these architecture types can be applied. Fixed portfolio architecture has elements that share no components. Once the architecture is manufactured in the factory it is fixed. In other words, the customer cannot take the vehicle home and alter the design. An example of this is on the physical characteristic, rear knee room. The positioning of the rear seat in the vehicle cannot presently be repositioned. Thus, it is more difficult to cover the diverse customer base for this attribute.

![Portfolio Architecture Diagram](image)

*Figure 3.4: Various Types of Portfolio Architecture.*
Platform portfolio architecture, on the other hand, has elements that share a common subset or subsets. It can be applied to a set of automotive products to create variety. An engine, for example, can be swapped out of an SUV and placed into a similar vehicle like a pickup, or a minivan to meet the demands of the market illustrated in figure 3.5(a). Likewise, this architecture supports both product families and generations, as well as consumable and adjustable for purchase products. Product generations are products of the same architecture that succeed each other in time. Therefore, carryover content is included in the platform. One can improve the 1999 models over the 1998 models by isolating the rapid technologies into modules and improving the modules each generation.

An adjustable for purchase architecture is one that can be custom configured before the consumer accepts the purchase. For example, a customer can select from a variety of hubcaps to be mounted on a vehicle before purchase. Once selected the design is fixed. Consumable platforms are those that design for interchangeability of modules similar to the myriad of films (100, 200, 400 speed) that is used in 35mm cameras. Moreover, in an adjustable feature, the user can change the value of the feature at any time. An example of this is the moveable seats in the rear of a family minivan. Folding down the rear seat, which is illustrated in figure 3.5(b), can accommodate the customer variety for cargo capacity over the market over time. Some benefits that platform architectures generate are the ease of production variety, feasibility of customer modification, and reduction of system-level production costs.

Figure 3.5: Portfolio Architectures in Automotive Segment
These portfolio architectures can allow the product portfolio to be responsive to the evolving needs of the market, with timely anticipation of the rise and decline of the market segments. To be successful, the portfolio plan should simultaneously meet or exceed all performance targets. The architectural choice depends on understanding the key drivers for the customer. Which architecture offers uncompromised delivery of the performance characteristics that make the product? What are the revenue implications of compromising the product? What are the costs of uncompromised delivery of the product? What are the costs of the compromise? Where is the point of balance? In the next section we seek to examine how the portfolio architecture design drives costs and revenue and how one chooses an architecture design.

3.4.2. Portfolio Architecture Design

Oftentimes the question arises as to how one chooses between an integral, platform, and customized portfolio architecture. The customer would definitely be satisfied with a customized product. However, for the manufacturer, this may not always be feasible. Revenue drives the portfolio toward mass customization whereas cost drives the portfolio back towards an integral architecture. An effective architecture decision enables reduced cost. These costs can be reduced through component sharing, tooling and investment, and engineering, while giving manufacturing flexibility. The portfolio architecture decision can allow for an increased throughput and product diversity. This in turn can lead to a faster time to market. In general, an architecture decision is based on a business analysis of the investment of time and money required to create the architecture against the ability of the products manufactured on the architecture to generate revenue. A tradeoff would be made to determine how to create the portfolio architecture design, which is instrumental in creating variety amongst other products.
3.5. Models of Revenue

Portfolio architecture is chosen based on tradeoffs between revenue and cost. In this thesis, the focus is primarily on how the market would point to a particular type of product architecture without regard to cost. Instead of investigating the impact of cost, we use similar framework introduced by [39] et al 1999. First, we assume that integral architectures are more cost-efficient than modular architectures with regard to single offerings. For example, creating a multi-function switch for the windshield wipers and the headlights reduces both assembly and inventory costs. Second, we assume that smaller inventory of parts and ease of design alongside other concerns make modular architecture not as costly to create for multiple offerings of products.

This research explores revenue based on customer preferences. The results indicate what the customer wants in terms of flexibility in use and the variety in the market. These results will need to be incorporated with cost models to make a final design decision.
4. Establishing Market Desired Variety

4.1. Gather customer needs

A market model is a representation of the way customers gravitate naturally towards each other based on their similarities in desired customer preferences. To produce a market model, we first must determine through conjoint studies the important customer needs that are deciding factors in the purchase decision of the product. Conjoint analysis is based on a model of consumer behavior that underlies nearly all of conventional research techniques. The model states that a brand, product, or concept can be considered as a bundle of attributes, or attribute levels, each of which makes some contribution to overall consumer acceptability [6]. In most instances, customers may want a mix of these attribute levels. Furthermore, a customer will be more willing to purchase a product, or even try a new product, if it is closer to his or her desired "mix" than other available alternatives.

Conjoint studies use standard principles of experimental design to approximate the contributions to overall choice behavior of many different attribute-level changes, all in the same study. This is done by asking for respondent preferences between a relatively small number of pairs of hypothetical products (attribute-level bundles) and performing a conjoint to estimate their individual-level propensity to choose any hypothetical product over another such product or group of products encompassed by the conjoint analysis. Hence, by surveying the market on the performance attributes of the vehicles we develop a snapshot of the market. These physical attributes represent the list of customer needs. A customer need is a description, in the customer's own words, of the benefit to be fulfilled by the product or service [9]. In other words, what are the actions that should be carried out through the physical attributes of the vehicle. There are a variety of ways to generate a list of customer needs [4]. Some of these methods are through interviews, questionnaires, focus groups, and other market research techniques.
To begin the analysis, a market research firm gathers a list of customer needs. These needs are each rated by the customer using differential importances on uses in the vehicle. We consider only the key underlying attributes that will display as much variation in the market. Furthermore, the importance of each attribute may be similar, however, the importance of target values for the associated attributes produce the need.

Two types of physical attributes: continuous (e.g. price, fuel economy) and discrete (e.g. make, air bags) are rated on each model of vehicle. Then, we select a set of ten key vehicle attributes relating the important underlying customer needs to help define the scope of the market. These important attributes were analyzed using cluster analysis; attributes included passing acceleration, interior price, base price, cargo capacity, front interior width, rear knee room, turning circle, seating height, fuel economy, and towing capacity.

Passing acceleration is a measure of customer preference for the time required passing a vehicle at highway speed. Interior price is the measure of how much money customers pay for the interior content in the vehicle. Fuel economy is the measure of customer preference on the amount of fuel required to operate a vehicle, which is measured in miles per gallon (mpg). Cargo capacity is a measure of the amount of cargo space available inside the cabin of the vehicle. Front interior width is a measure of the space available between the passenger and the driver. Seating height is the measure of preference for the height of the seat over the dashboard measured in inches. Rear knee room is the customer preference of available knee room for the passenger traveling in the backseat of the vehicle. Towing capacity is a measure of the maximum towing load a vehicle can pull while driving which is measured in pounds. Turning circle is the customer preference for the turning radius of the vehicle. Base price is the customer preference for the purchase-price of a given vehicle. These formed the attributes used to complete the market cluster analysis. Once formed, the market model reveals important information about the view of the customer. In section 4.2 we explore how the market distribution varies
both at any moment in time and over a period of time. The model helps to evaluate the portfolio architecture.

4.2. View of Customer Targets

![Diagram](image)

Figure 4.1: View of Customer Targets

Customers can be viewed in two different ways: by viewing the customer at any one moment in time or by tracing their usage needs over time. At any moment in time, one can assess the market population to determine the desired target values for attributes of the products. These desired target values are then represented graphically as population distributions. The population distribution gives nominal usage target values for the entire target market. When the distribution is normal it is graphed using the mean, \( \mu \), and the standard deviation, \( \sigma \), shown in figure 4.1a. The same can be done for the needs evaluated over time. This usage distribution may vary from the population distribution as shown in figure 4.1b. In this research, there was no comprehensive usage information available; therefore we assume that the variety of the segment would be equivalent to the variety of uses in that segment.
4.3. **Market Distribution**

4.3.1. **Population Distribution**

The population distribution is determined by calculating the mean and standard deviation on target values for each important need. This provides the snapshot of the market at any one moment in time. However, a question that may arise is whether or not these desired target values change over the course of time. In order to capture the needs over time, a usage distribution should be constructed.

4.3.2. **Usage Distribution**

A usage distribution is one that tracks the customer uses of a single product over time. This is accomplished by collecting target values from the customer for each target need considered under different use scenarios. When there is a normal distribution, we can represent this by a mean $\mu_t$, and a standard deviation, $\sigma_t$. These two distributions are needed to apply the MIT architecture selection methodology (Yu et al 1999). One of the concerns in this work is that there is no comprehensive usage information to complete the actual analysis.

To make this analysis more accurate, we need to have some usage data on how customer utilities change over time. During this timespan, the customer may put the vehicle to a variety of uses. What are these different uses and how important are they to the customer? With this information, we can determine how the customer needs change under different use scenarios, how this variety differs from market segmentation variety, and how this impacts the implementation choice of vehicle options. This is indicated through customer preferences. We use these customer preferences to cluster the customers on similar preferences. These clusters will be asked to identify different scenarios of using the products. The needs may vary which means that the desired performance levels to accommodate this variety could vary as well. What performance levels are desired for each use? This can be determined by comparing the distributions over time with the distributions at one moment in
time. For example, if different market segments have diverse target levels but each segment itself has limited variance on the target levels then vehicle options are appropriate on that target. If each segment has variance as high as the population variance on the need then that need is not adequately satisfied by options and the platform itself must supply all requested variance. Low variance needs can be supplied easily with one target level on the platform. However, without usage information, we assume that the variety in the segment is equivalent to the variety of uses that the customer puts the vehicles to. Therefore, the segment average will be an average "customer" in this method and the variance in the cluster will be somewhat equivalent to usage variance of that "customer". Meanwhile, the customer can only put the vehicle to uses that the "cluster vehicle" is capable. Therefore, there cannot be a customer desired target level that cannot be accommodated or a manufacturer does not produce. There is no comprehensive usage information available for the study therefore a portfolio architecture is suggested considering only the customers at any moment in time.

4.4. Architecture Selection Methodology

The MIT architecture model was created to produce a market model in terms of customer needs and then allow that model to determine how to set up the product architecture [39]. Figure 4.2 reviews the steps used in the analysis. First, gather the customer needs using one of the market research techniques e.g. interviews, focus groups, etc. Second, determine the average importances of each need and identify product characteristics that address these important customer needs. Third, survey customers for need target values. For each attribute, the segment and population means and standard deviations were calculated to arrive at a preferred architecture selection. In this analysis, we work to gather a representative sample of the typical customers from the different segments. Fourth, trace usage target values over time by sampling in different use circumstances. The mean and standard deviation for the time-traced usage data is calculated for each mean. Finally, for each need, create a
table of means and standard deviations from time-traced segments and moment in time segments and compare the time-based variance in the segment.

Figure 4.2: MIT architecture selection methodology

4.4.1. Portfolio Architecture Selection Scheme

The MIT architecture selection methodology [Yu et al 1999] for using the variation on time distributions of customer need target values to suggest architecting strategies is the framework we work to herein expand upon. The methodology is herein expanded so that a development team can determine the number of attribute levels necessary given the market information. Figure 4.3
describes the architecture selection process from [39]. The derived segment and population means and deviations are calculated for each need, and are used to select a preferred architecture style given the observed relationship of the distributions. Depending on the relationship observed, one could select either a fixed integral architecture or modular product architecture. This depends on if the architecture can encompass all the variation in the market for a single customer need. If the variation is small then the customers will be satisfied with a fixed offering because the target does not differ greatly from their desired need targets. On the other hand, if the market cannot be satisfied with a single fixed need, there must be additional offerings to capture more of the market. These choices must obviously be made with respect to the cost of manufacturing the offerings, which is beyond the scope of this research.

![Architecture Selection Flowchart](image)

Figure 4.3: Architecture Selection Flowchart
4.4.2. Applicability to General Motors

The product portfolio of the study herein is automotive products produced by our industrial partner, General Motors Corporation. To look at the customer variety aspect of this work, we will take a previously developed customer satisfaction model which expresses customer populations as probabilities over measurable customer need target values and observe the different clusters that naturally form in the market. These clusters are a representation of the different market segments at one instant in time. Once the clusters are formed, there is a need to determine the number of products to offer in a segment. This can be achieved either through a cluster analysis or through other techniques such as factor analysis/principle components, or function structure analysis.
5. Case Study with General Motors

5.1. Analysis Tools

Several tools are necessary to implement the study. The first is a statistical software package, JMP, to perform statistical analysis on data that generates a graphical display of the results. The second is a customer satisfaction model, constructed from conjoint studies, providing utilities (customer preferences) on the attributes. A description of both is presented next.

5.1.1. JMP Statistical Software Tool

JMP (SAS, 1999), the primary tool used in the analysis, helps form the snapshot of the market. It is a statistical software package that provides a graphical interface to display and analyze data. This program is used to perform both a statistical and cluster analysis. In a cluster analysis, JMP creates graphical results, in the form of a dendrogram, which allows us to quickly interpret the results. These results, in the form of graphs and reports, are dynamically linked. That is, for each result, one can click on a point in the dendrogram while the corresponding row highlight in the spreadsheet window and in all other plots where the point is represented. This allows one to alter the clusters in the dendrogram by moving the line to various points with a real time visual assessment of the changes. This is a real benefit since it does not require that one recreate a cluster each time there is a need to change a requirement. Next, we describe the properties of the data used herein in the following section.

5.1.2. Customer Satisfaction Model

The data consists of thousands of vehicles. These vehicles are decomposed into physical attributes rated on the preferences for these performance attributes. A measure of the customer's values for these attributes is provided
in that data. In order to determine the product values based on the attribute values an analyst can recombine the attributes into bundles, which represent the complete product. This can be done using the customer satisfaction model.

The market share for the vehicles is calculated in the model. This represents the customer utilities for each attribute. There are 25 vehicle attributes on which the vehicles are rated. In this study, we select ten physical attributes based on the important underlying needs determined by the customer ratings. The ratings measure each customer's values (utilities) for the levels of the individual attributes. From the data one can work to identify the clusters that form the scope of the market which is detailed below.

5.2. Identify Market Segments

The methodology used is a three-step process. The first step is to examine the performance attributes to define the scope of the market. A conjoint analysis is used to interpret many of the customer's preferences on the attributes. For each attribute, clusters naturally form based on similar preferences on the performance levels. A level is the possible settings for an attribute. For example, the level of "fuel economy" for a vehicle is "26 mpg" and the level of passing acceleration for that vehicle is "5.2 seconds". To ensure that all of the vehicles are a representative of a customer, the vehicles are grouped together solely based on customer preferences. The second step is to graphically analyze the clusters, on each attribute, to determine the number of levels needed to cover the market. The graphs will indicate how small or wide the variance is for each desired target level, which allows one to consider several different architectural options to accommodate this variety. The third step is to suggest a portfolio architecture based on the means and standard deviations for each of the clusters. A more detailed explanation of each step is given in section 5.3 for the cluster analysis, 5.4 for the graphical analysis and 5.5 for the architecture selection.
5.3. *Cluster Analysis*

A cluster is a group of customers that have as much similarity within and difference among groups as possible [4]. In each cluster, the vehicles are driven together based on the utilities of the customer preferences. Hence, for any cluster of vehicles any customer in that cluster could have potentially purchased any one of the vehicles based on similarities in preferences in that cluster. Note it is assumed that the customer is able to think of the various uses before making a purchase and then selecting a vehicle based on that utility. Using these assumptions, we perform a cluster analysis on all of the vehicles in the database, which represents the entire automotive market.

The k-means method was used to do the initial clustering. This clustering method finds disjoint clusters on the basis of Euclidean distances computed from one or more quantitative variables. The clusters do not form a tree structure as with hierarchical clustering. Instead, the number of clusters is specified using this method. Thus, we pre-determine the number of clusters in which to group the vehicles. Thirteen clusters are selected based on the number of vehicle segments currently in the automotive market. There could potentially be more or fewer segments. The correct number is still unclear.

5.3.1. Two Approaches of Clustering

There are two possible approaches to clustering. The first approach is to cluster the vehicles based on the customer utility ratings whereas the second approach is to cluster the vehicles based on the physical attributes.

In the first approach, the vehicles are clustered using the customer utility ratings. In each cluster each vehicle is an equivalently rated alternative. Therefore, any vehicle in these clusters is not grouped by the physical characteristics of the vehicle but by the similarities in the customer utilities on the attributes.

In the second approach, the vehicles are clustered by each individual attribute. In other words, there are ten physical attributes upon which a
cluster analysis is performed. The clusters then consist of vehicles with similar physical characteristics: dimensions, engines, etc.

For this study, we chose to use the first clustering method using the physical domain as a parameter. This method is used to create the clusters and determine the nominal average for all of the clusters. Moreover, any cluster average point is an available "vehicle" to the customers in that cluster. Hence, the average of the cluster is considered a "cluster vehicle" and the statistics show an acceptable deviation. We develop a picture of the market from the cluster analysis and apply the MIT architecture selection methodology previously discussed in chapter 4. This snapshot is used to compare the segment distributions with the population distribution to try to determine the number of levels to offer for each attribute based on the variance in the segment.

5.3.2. Segment Clustering

The MIT methodology is applied using the cluster nominal to form the population distribution. The cluster distributions are equivalent to segment distributions. In other words, the clusters represent a different vehicle segment in the market based on customer preferences. To compare the segment distributions with the population distribution we independently cluster the vehicles on each of the ten attributes. For each attribute, thirteen individual clusters are formed. These clouds represent the groups of like vehicles with similar customer preferences. The 13 vehicle segments identified are passenger vans, passenger/minivans, sport utility vehicles, premium luxury vehicles, large luxury vehicles, minivans, premium midsize vehicles, small sport utility vehicles, sports car coupes, economy small vehicles, premium small vehicles, entry-level luxury vehicles, and trucks.

The first cluster is of passenger vans that primarily consist of the large extended 15 passenger vans. The second cluster is passenger/minivans, which included the larger minivans and some of the extended passenger vans. The
third cluster is the sport utility vehicle, which is comprised of the larger sport utilities like the GMC Suburban and GMC Yukon. The fourth cluster is the premium luxury vehicle comprised of more upscale vehicles. The fifth cluster is the large luxury vehicle, which included vehicles like the Pontiac Bonneville, Buick LeSabare, and the Oldsmobile Aurora. The sixth cluster is minivans comprised of the smaller minivans such as the Silhouette. Premium midsize sedans, the seventh cluster, is comprised of the high-end midsize cars like the Oldsmobile Intrigue, Cutlass, and Buick Regal. The eighth cluster is the small sport utility vehicle. This cluster is composed of the smaller utilities and many of the crossover vehicles like the Chevrolet Tracker, Blazer, and Oldsmobile Bravada. The ninth cluster is the sports car coupe, which is comprised of the two-door sports cars like the Chevrolet Corvette. The tenth cluster is the economy small car segment, which consists of many of the small less expensive vehicles like the Chevrolet Metro. The eleventh vehicle cluster is a group of premium small cars like the Saab 9³. The twelfth vehicle cluster group is the entry-level luxury vehicles like the BMW 3 series or the Acura TL series. Finally, the thirteenth cluster consists of a variety of pickup trucks. This included both two-wheel and four-wheel drive vehicles. The correct number of clusters to have in the market is uncertain. There could potentially be more or even fewer segments than what is actually presented here. This number of segments was based on the assessment of the current picture of the market.

5.4. Graphical Interpretation

Figure 5.1 illustrates the thirteen clusters graphed to 1σ on the attribute, rear knee room, versus its market share. Note the units have been omitted on the graph for proprietary purposes. Notice on the graph that many of the clusters are positioned closely together. Thus, the distances between the cluster nominals are minimal. We now will work to determine the number of levels to offer on each attribute. Permutation of these levels with levels on other attributes determines the number of products to offer in the market. Hence, on each attribute, we now wish to cluster the thirteen segments,
manually using a dendrogram, to determine what is the right number of
desired target levels. The segments can be clustered into a number of fixed
levels on each attribute and also into ranges for adjustable attributes. Using
this framework, we will then determine which levels in each segment could
stand alone in the market due to high variance in an attribute and which
segments should be grouped together due to low variance.

![Cluster breakout on rear knee room attribute](image)

**Figure 5.1: Cluster breakout on rear knee room attribute**

On each attribute, the manual clustering method determines the number of
fixed levels and ranges to offer on each attribute in each segment. To do this,
we cluster the averages of the thirteen market segments, and analyze this tree
to determine how many levels to offer on each attribute. One can select the
higher points on the graph to stand alone as a target level and the lower points
to be grouped together. For example, in figure 5.1 the economy small car
segment may have its own individual design target specification on rear knee
room due to the high utility on this need for this segment. This represents
market satisfaction on this design target. Oppositely, passenger vans and
minivans may share a design target because of a smaller utility on its design target.

Thirteen clusters are manually clustered on rear knee room to indicate the number of possible levels on this attribute. These results were considered along with a graphical interpretation, illustrated in figure 5.2, to suggest three clouds of customers who prefer three possible design targets on rear knee room. The first segment which consist of large luxury vehicles and premium midsize vehicles would desire a low range design target for rear knee room. The second segment consisting of sports coupes, small SUVs, and economy small cars would desire a design target at the medium range of the target specifications. Likewise, the third segment consisting of passenger vans, minivans, SUVs, premium luxury vehicles, entry-level luxury vehicles, and trucks would desire large amounts of rear knee room, therefore, these customers prefer a high design target level.

![Figure 5.2: Manual Clustering of Segments for Rear Knee Room](image-url)
How can we determine if this is the correct number of desired target levels for the attributes? This can be evaluated by first calculating the mean and standard deviation of the clusters in the segment to determine the variance in the levels. For fixed offerings, we can design to the mean of the cluster and for adjustable offerings we can design to the standard deviation of the cluster. For instance, we calculate the mean and standard deviation of the three clouds of customers on rear knee room. These results are placed in a table and another graphical representation is created in the form of a histogram.

A histogram is a form of bar chart in which successive values of the variable are placed along the abscissa, or x-axis, and the absolute frequency or relative frequency of occurrence of the values is indicated along the y-axis, or ordinate [4]. Figure 5.3 shows histogram of the three segment distributions within rear knee room along with the population distribution. Analyzing graphically, the histogram suggests there be three target levels on rear knee room since it is a fixed attribute. The graph shows the probability density function (pdf) for each of the three clusters and the total population. Customers in cluster 1 will be satisfied with a small available amount of rear knee room as an offering; cluster 2 will be satisfied with an average amount of available rear knee room whereas cluster 3 would prefer to have a large amount of available rear knee room. These three levels will be able to accommodate the variety in the segment. This particular approach to create a histogram of the segment and population distributions is performed iterively for each of the ten attributes.


5.5. Suggested Portfolio Architecture

GM has a very large portfolio of products. In general, we must apply clustering work hierarchically. Likewise, a mass customization platform modular vehicle design would permit all permutations of these levels of attributes. For instance, the mass customization solution requires the designer to isolate each one of these levels on the attributes into a module to compose a vehicle architecture that allows the customers to configure and pick the desired requirements on each need. This would require a vehicle architecture design to permit any level on any need to be combined with any level on any other need. However, [Pine, Victor, and Boyington (1993)] report that common problems arise when companies give customers more choices than they want or need. The example cited in which Toyota found that 20 percent of its product varieties accounted for 80 percent of its sales and Nissan
reportedly offered 87 different types of steering wheels. Furthermore, with automotive assembly systems, mass customization is highly unrealistic for the automotive market. It offers too much variety for a single assembly system. The more feasible approach is to create a platform portfolio architecture. This ideal portfolio architecture suggestion is depicted in figure 5.4. In this table each attribute has either two or three performance target levels to satisfy the needs in the market. Every vehicle could be constructed from any permutation of the attribute levels should be made available, and then let the customers pick.

<table>
<thead>
<tr>
<th>Product Characteristics</th>
<th>Performance Target Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Base price, ($)</td>
<td>[11,400 - 17,500]</td>
</tr>
<tr>
<td></td>
<td>[18,000 - 31,500]</td>
</tr>
<tr>
<td></td>
<td>[42,500 - 78,700]</td>
</tr>
<tr>
<td>Rear knee room, (in)</td>
<td>-4.1</td>
</tr>
<tr>
<td></td>
<td>0.1</td>
</tr>
<tr>
<td></td>
<td>2.8</td>
</tr>
<tr>
<td>Turning circle, (ft)</td>
<td>35.5</td>
</tr>
<tr>
<td></td>
<td>40.4</td>
</tr>
<tr>
<td></td>
<td>53.4</td>
</tr>
<tr>
<td>Seating height, (in)</td>
<td>[17 - 20]</td>
</tr>
<tr>
<td></td>
<td>[27 - 33]</td>
</tr>
<tr>
<td></td>
<td>39</td>
</tr>
<tr>
<td>Front interior width, (in)</td>
<td>54</td>
</tr>
<tr>
<td></td>
<td>61</td>
</tr>
<tr>
<td></td>
<td>67</td>
</tr>
<tr>
<td>Fuel economy, (mpg)</td>
<td>15</td>
</tr>
<tr>
<td></td>
<td>21</td>
</tr>
<tr>
<td></td>
<td>28</td>
</tr>
<tr>
<td>Passing acceleration, (s)</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td>7</td>
</tr>
<tr>
<td>Towing capacity, (lbs)</td>
<td>931</td>
</tr>
<tr>
<td></td>
<td>3160</td>
</tr>
<tr>
<td></td>
<td>6840</td>
</tr>
<tr>
<td>Cargo capacity, (ft³)</td>
<td>[8 - 21]</td>
</tr>
<tr>
<td></td>
<td>[17 - 32]</td>
</tr>
<tr>
<td></td>
<td>54</td>
</tr>
<tr>
<td>Interior price, ($)</td>
<td>[-260 - 1290]</td>
</tr>
<tr>
<td></td>
<td>[-70 - 1990]</td>
</tr>
</tbody>
</table>

Figure 5.4: Ideal Portfolio Architecture for Entire Market

For example, the desired performance target levels for fuel economy is 15, 21, and 28 miles per gallon. While on the contrary, the market really only desires two performance target levels for passing acceleration, which are 4 and 7 seconds respectively.
6. Case Study: Sport Utility Vehicles

In this chapter, we focus on sport utility vehicles (SUVs) to determine an effective number of offerings needed to cover the market. The SUV product line for General Motors is shown in Figure 6.1. In this chapter, we discuss the approach that was developed whereby each attribute is considered separately, as a design engineering team must, to form a cluster tree based solely on that one attribute. This is repeated on each attribute, and then analysis is performed comparing the standard deviations of each need to determine which need should have an added target value offering to expand the portfolio, discussed in Section 6.3. From this set of permutations, a traditional targeting cluster analysis is performed based upon all the needs (properly weighted), to determine which permutations are on target with the major clusters, discussed in Section 6.4.

Figure 6.1: General Motors SUV product line.
6.1. Approach

Within the SUV market, one can consider the previously mentioned 10 attributes, and form conjoint studies as above. This essentially provides a distribution function over the attribute space, reflecting density of a market that desires particular combinations of attribute levels. Positions in the attribute space with high density reflect clusters of customers who desire an SUV with such attribute levels. These clusters are where the designer can benefit by placing a design target to attract these customers.

One approach to portfolio design is to design vehicles that meet these cluster requirements. The difficulty with this approach is that each cluster point in the attribute space typically has entirely different target levels on each attribute. For 10 different target clusters, there will be 10 different target levels on each attribute. From a design engineering perspective, this is often unrealistic, introducing excessive complexity into the portfolio architecture, making many of the design elements compromised to accommodate compatibility with the wide diversity of the other attributes.

Note that each attribute must have particular levels chosen to define the fixed design targets for the design engineers. Each of these decisions is, in a design engineering sense, often separate from each other. That is, any target value could be selected on any attribute, and selecting a target value on one attribute does not necessarily constraint the others, other than for technical engineering reasons.

6.2. Positioning of Design Targets

Conversely, from a market cluster analysis, the different attributes may be related, in that the market distribution function is correlated on the attributes. This can happen when a market is stratified on two variables and when one variable is desired high, so is the other, and vice-versa. For example, when a customer prefers a high seating height they also desire a wide front interior. Likewise, when the customer preference for fuel economy is low so is the preference for passing acceleration. From the engineering design point of
view, though in both of these cases, two levels must still be designed for each attribute.

This idea is shown graphically in Figure 6.2, where two attributes are shown with the customer probability density plotted. The market follows a trend in the (fuel economy, towing capacity) space: when customers want fuel economy low, they also want towing capacity high, and vice versa. Clearly, two products should be offered (low fuel economy, high towing capacity) and (high fuel economy, low towing capacity). However, note to do that two levels must also be offered on each attribute to hit these two clusters. Given that, there are four possible products on the platform consisting of the two attributes designed with two levels, but only 2 of those 4 possible products make economic sense to build.

![Figure 6.2: Positioning Design Targets](image)

A design team cannot develop a platform that permits all possible levels on all attributes. This issue is the typical scenario facing a portfolio design
team. A team must find a means to restrict some of the attributes to less numbers of levels. In Figure 6.2, should P₁ or P₂ be restricted to a single level, if offering two levels on each introduces excess complexity?

Another separate issue facing a design team is how to select a design target, even given a well-defined tight normal distribution. Should a team design to the average μ, or to a factor of safety μ + kσ? We consider here design to the average, for attributes that do not involve safety concerns or a high-end market where one might want to offer beyond what is expected. Such cases are easily handled, however, by simply adjusting the target level kσ as above. Besides simply hitting the design targets other factors may play a role in determining how to select a design target. Manufacturability and cost are some of these factors.

In the next section, we develop an approach to determine how to break out the different attributes into multiple levels, and in what sequence.

6.3. Examine Each Attribute Independently

First form the cluster tree, one for each attribute, using the clustering method to create each branch on the tree. Each tree is based solely upon the one attribute. The "trunk" of the tree represents the mean and the standard deviation of the entire segment. This would be the design target if the design team were to only design one sport utility vehicle. This vehicle would be designed at the nominal average of the market. The tree starts with a mean (or nominally equivalent, a design target) μ₁, and exhibits a (comparatively large) standard deviation σ₁. The standard deviation is a measure of how far a typical customer must deviate from their ideal target when only offered the design target μ₁. We, then, expanded the branches on each tree, first finding (μ₂₁,σ₂₁,μ₂₂,σ₂₂) for the two most separable clusters in the market and so on, until an overly large number of targets were determined, such as for 7 permutations. This represents the expansion of additional vehicle offerings in the segment. This is repeated for each attribute. The result is a tree of target values, and at each level, a maximum standard deviation representing how far
customers must compromise their individual desired target value. The tree level breakout for interior price is illustrated in figure 6.3. Notice that the variance in the segment decreases as more levels are added to the branch. That is, the clusters break out into individual clusters. However, it may not be necessary to offer an individual level for each customer.

<table>
<thead>
<tr>
<th>1 level</th>
<th>μ</th>
<th>σ</th>
<th>3 levels</th>
<th>μ</th>
<th>σ</th>
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<th>σ</th>
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<td>μ</td>
<td>σ</td>
<td>6 levels</td>
<td>μ</td>
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<td>3</td>
<td>1498.5</td>
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<td></td>
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<td>1</td>
<td>2439.4</td>
<td>103.7</td>
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</tbody>
</table>

Figure 6.3: Tree Level Breakout and σ/μ for Interior Price ($)

If a company were only capable of developing and manufacturing a single vehicle, the “trunk” level of each attribute would be the most effective design target. For the SUV this is a medium priced vehicle that would offer design target specification at the nominal average on all ten of the design attributes.

If a company wanted to produce two vehicles, they can do that most effectively by offering two levels on the attribute that exhibits maximum market differentiation. That is, one can examine the standard deviation of each attribute (relative to its mean) and compare. The attribute with highest deviation is an attribute that one should most consider offering multiple levels, since it causes customers to most compromise their desired targets. This idea is depicted in Figure 6.4, where the attribute P1 has higher standard deviation, and so should be considered for two levels. For example, on the SUV, the first attribute which a product development team should consider offering multiple levels on is interior price. Offering one level on the interior content would
require the customer to make a large compromise for their desired target. This may deter the customer to the purchase of another vehicle. Next, one should consider multiple levels for rear knee room. The standard deviation for this attribute was large as well. Finally, cargo capacity should offer multiple performance levels. By, extending this iteratively using the rank order method, a designer can develop a procedure to define multiple vehicle permutations.

\[
\begin{align*}
\sigma_{\text{large}} \\
\mu \\
P_1 
\end{align*}
\]

\[
\begin{align*}
\sigma_{\text{small}} \\
\mu \\
P_2 
\end{align*}
\]

Figure 6.4: Attribute level expansion.

After expanding the tree out to the maximum allowable number of full branches, \( \sigma/\mu \) is calculated. This indicates how much the customer would deviate, \( \sigma \), in order to purchase the accepted target value, \( \mu \). The nominal cluster target \( \mu \) normalizes the standard deviation \( \sigma \). After compiling this information for each cluster we determine the maximum differentiation by comparing \( \sigma/\mu \) at each level across the attributes. For example, on the first level, interior price has a \( \sigma/\mu \) value of 1.349. This value is compared with the \( \sigma/\mu \) values across the attributes. Using the rank order method, we sort across the attributes to decide the order upon which the attributes should be expanded in variety.
Next, we illustrate the break out matrix to determine the numbers of levels in which variety will be implemented and in what sequence.

6.4. Form Breakout Matrix

These values are used to form a *breakout matrix* to determine which attributes would require multiple levels in the design attribute space to satisfy the market. The matrix consists of the attributes, \( i \), as rows and the cluster, \( j \), of each branch level as columns, with entries of \((\sigma/\mu)_{ij}\). Figure 6.5 is an excerpt of the matrix that illustrates the number of levels on each attribute to accommodate 16 vehicle variants, showing the top four levels on each need.

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<tr>
<th></th>
<th>( \sigma/\mu_4 )</th>
<th>( \sigma/\mu_5 )</th>
<th>( \sigma/\mu_6 )</th>
<th>( \sigma/\mu_7 )</th>
<th>( N_{total} )</th>
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<tr>
<td>passing acceleration (s)</td>
<td>0.05 0.05 0.02 0.03</td>
<td>0.05 0.08 0.03 0</td>
<td>0.13 0.03 0</td>
<td>0.18 0</td>
<td>1</td>
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<td>interior price ($)</td>
<td>0.01 0.14 1.19 0.04</td>
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<td>1.35 0</td>
<td>4</td>
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<tr>
<td>base price ($)</td>
<td>0 0.07 0.07 0.08</td>
<td>0.07 0.12 0.08 0</td>
<td>0.12 0.11 0</td>
<td>0.28 0</td>
<td>1</td>
</tr>
<tr>
<td>cargo capacity (cu. ft)</td>
<td>0.02 0.20 0.06 0.04</td>
<td>0.20 0.09 0.04 0</td>
<td>0.09 0.32 0</td>
<td>0.34 0</td>
<td>2</td>
</tr>
<tr>
<td>front interior width (in)</td>
<td>0.00 0.00 0.01 0.01</td>
<td>0.00 0.02 0.01 0</td>
<td>0.02 0.01 0</td>
<td>0.04 0</td>
<td>1</td>
</tr>
<tr>
<td>rear knee room (in)</td>
<td>0.15 -1.04 0 0.14</td>
<td>-1.04 0.00 0.26 0</td>
<td>0 0.46 0</td>
<td>0.49 0</td>
<td>2</td>
</tr>
<tr>
<td>turning circle (ft)</td>
<td>0.01 0.02 0 0.01</td>
<td>0.02 0.00 0.02 0</td>
<td>0 0.03 0</td>
<td>0.06 0</td>
<td>1</td>
</tr>
<tr>
<td>seating height (in)</td>
<td>0 0 0.01 0.02</td>
<td>0.00 0.02 0.02 0</td>
<td>0.02 0.06 0</td>
<td>0.06 0</td>
<td>1</td>
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<tr>
<td>fuel economy (mpg)</td>
<td>0 0 0.03 0.04</td>
<td>0.00 0.06 0.04 0</td>
<td>0.09 0.04 0</td>
<td>0.12 0</td>
<td>1</td>
</tr>
<tr>
<td>towing capacity (lbs)</td>
<td>0.09 0 0.07 0.10</td>
<td>0.00 0.07 0.25 0</td>
<td>0.15 0.25 0</td>
<td>0.27 0</td>
<td>1</td>
</tr>
</tbody>
</table>

Figure 6.5: Breakout Matrix

We now proceed to illustrate how the matrix was used in conjunction with an optimization problem to create an attribute breakout sequence.

6.5. Optimize the Problem

A portfolio design team ought to select attribute target levels by minimizing the deviation any customer must make for their desired targets when purchasing an offered vehicle. Therefore, for any number of products we can determine how the variety can be offered by minimizing the maximum \( \sigma/\mu \) of the attributes, while keeping the number of vehicle permutations less than an acceptable number. The concept is to minimize the distance in \( \sigma \) that customers must be from the target offering \( \mu \).
The optimization problem can be stated as follows:

\[
\left( \frac{\sigma}{\mu} \right) = \inf \left( \max_{\text{attributes } i} \frac{\sigma}{\mu_i} \right)
\]  

(1)

such that

\[N = \prod (N_i)\]

\[N_i = \text{minimum level such that } \left( \frac{\sigma}{\mu} \right)_i \geq \left( \frac{\sigma}{\mu} \right)_{\text{max}} \] on attribute \( i \)

\[\frac{\sigma}{\mu_i} = \max_{\text{levels } j} \left( \frac{\sigma}{\mu_j} \right)\]

\( (\sigma/\mu)_i \), what we call the need discrimination level, has an interpretation of how far a customer must deviate \( (\sigma) \) compared to the offerings provided \( (\mu) \). It is used to select the break out order over the attributes for a given number of possible product combinations. The product of \( N_i \) for each attribute gives the number of possible products, \( N \). Increasing \( (\sigma/\mu)_i \) reduces \( N \) until the desired number of products is achieved. This is the complete set of information necessary to determine how to offer an effective portfolio for a fixed number of variants. The result shown in Figure 6.6 would accommodate 16 vehicle variants in the market. These variants are a composition of a permutative set of the four offering levels for interior price, two offering levels for cargo capacity, two offering levels of rear knee room, and the single offering levels at the nominal for passing acceleration, front interior width, turning circle, seating height, fuel economy, and towing capacity.
<table>
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<tr>
<td>base price</td>
<td>1</td>
</tr>
<tr>
<td>cargo capacity</td>
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</tr>
<tr>
<td>front interior width</td>
<td>1</td>
</tr>
<tr>
<td>rear knee room</td>
<td>2</td>
</tr>
<tr>
<td>turning circle</td>
<td>1</td>
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<tr>
<td>seating height</td>
<td>1</td>
</tr>
<tr>
<td>fuel economy</td>
<td>1</td>
</tr>
<tr>
<td>towing capacity</td>
<td>1</td>
</tr>
</tbody>
</table>

\[ \text{Cut-off } \sigma/\mu = 0.3 \quad \text{Total 16} \]

Figure 6.6: Number of Products Given Allowable Levels

6.6. *Select the Portfolio*

To attain a better understanding of the market deviation as a function of number of offerings, one can graph it. Figure 6.7 graphs \( \sigma/\mu \) as a function of number of permutations. Notice from the graph, it appears that 36 vehicle variants is as effective in the market as 126 vehicle variants. The overall decision on the most effective number would have to include cost models in an extended portfolio form of a Pugh concept selection process, which is beyond the scope of this work, but nonetheless straightforward.

Now, we examine the 16 vehicle variants described in figure 4 and present a suggested portfolio architecture. We determine the actual portfolio of products to use, given the platform breakout as above into many permutations. Recall from Figure 6.2 a firm does not have to offer multiple levels on all combinations as actual products. There may be products in the set not worth producing.
Finally, figure 6.8 shows the portfolio architecture suggested by the analysis. Diverse coverage can be achieved even with a single fixed offering on five of the ten attributes used in the analysis. The population distributions on passing acceleration, front interior width, turning circle, fuel economy, and towing capacity can all be satisfied through a fixed integral architecture. An adjustable offering for base price will accommodate the variance in the market. Likewise, an adjustable feature would satisfy the market preference for seating height. That is, it is easy to allow customization despite the low variance, so one should. Rear knee room and cargo capacity break out into two levels, but again since customization is easy to offer, this suggest offering multiple "packages" within which one can adjust the offering for customization. Finally, interior price should have at least four adjustable offerings for this attribute. This could easily be achieved through modules that can be isolated and replaced without altering the rest of the design.
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<td>integral</td>
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<td>fuel economy</td>
<td>integral</td>
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<tr>
<td>towing capacity</td>
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</table>

Figure 6.8: Suggested Portfolio Architecture for 16 Sport Utility Vehicles

6.7. Alternative Methods

Researchers are performing other techniques to similar types of studies. Factor analysis (Green and Rao 1972, Green and Wind 1973, Hauser and Urban 1977, and Pessimier 1977) is an attribute-based technique that examines the correlations between consumers and products through perceptual dimensions. Thus, this technique can be used to identify consumer perceptions as well as innovation opportunities in new markets (Hauser and Urban 1977). “Factor scores” which are based on the attribute ratings measure these perceptions of products. The dimensions are named by examining these “factor loadings” which are estimates of the correlation between attribute ratings and perception measures. This technique may provide a better understanding of many of the customer tradeoffs. However, it is still difficult to determine which attribute dimension is the correct dimension to select. Another technique, functional modeling can be used to create product families and portfolios.

There are several techniques that exist to characterize product functions. Some of these techniques include FMEA, FAST, function structures, and function trees [Little, A.D. 1998, McAdams 1998, Pahl 1988, and Stone 1998]. These methods are effective for a single product. However, in order to create
market variety the designer must create derivative products or product families to satisfy the market. By understanding how the product architecture relates to the physical function of the product the designer can make modularity decisions and incorporate variety. Zamirowski (et al 1999) examines function variety structures and how they can relate to product architecture decisions. The study explores how much influence customer variety has on the functional description of the product family. These market variety requirements are gathered through market research techniques and are used to map customer variety to the function level. The goal is to identify opportunities to segment products into modules that isolate the function and create derivative products by swapping out modules to accommodate customer variety.
7. Results and Conclusions

The goal of this thesis is to understand the competitive positioning strategy of products so appropriate product families can be developed for the variety of market segments into which the market can be decomposed. Moreover, the goal is help improve the planning methods for product families and portfolios by understanding customer needs to create a more robust portfolio of products. This is important because the portfolio can increase product value, profitability, and new breakthroughs in product development.

In this thesis, we sought to determine the number of products to offer in the automotive market that would provide product portfolio variety. Before introducing the method to create this variety, many of the terms frequently used in product development were defined as they relate to this research. Hence, chapter three defined the nomenclature. The various types of product architectures were described using examples of these architectures as they relate to the automotive industry. This chapter also discussed how product architectures are used to create a single product and portfolio architectures are used to create a family of products. Several methods were described about how to achieve variety through modularity. This is based on the type of architecture implemented. The implications of the architecture: product change, product variety, component standardization, and product performance affect the modularity decisions.

Chapter four introduced the framework behind the research. This included how the steps needed to establish desired market variety. The steps began with the gathering of customer needs to view the customer targets. This view of the customer was created through customer distributions. These two types of market distributions: population distribution and usage distribution were discussed including how the distributions differed at any moment in time versus over time. Chapter four also provided an overview of the MIT architecture selection methodology [Yu et al 1999], which was used throughout this research. The portfolio architecture selection was discussed as well as
how this architecture methodology could apply to General Motors. Chapter five
details the framework as it applies to GM. There is a description of how the
scope of the market was created through cluster analysis. The clusters were
created using a graphical interpretation of the population distributions.

Finally, a method was presented in Chapter six for determining portfolio
variety using discrimination thresholds. These thresholds revealed indications
of a preferred architecture for a given segment. This architecture is found by
exploring the maximum number of levels allowable for a given attribute to
accommodate variety in the segment. Chapter six focuses primarily on the
Sport utility vehicles (SUVs) to determine an effective number of offerings
needed to cover the market. An optimization problem is used to determine the
appropriate portfolio architecture for the SUV. The optimization problem gives
results that can help to address the architectural requirements desired to
accommodate variety in the SUV market.

The results of the study show that the customer variance in the SUV
segment can be satisfied using a single fixed level on five of the ten attributes
used in the analysis. The customer desired targets for passing acceleration,
front interior width, turning circle, fuel economy, and towing capacity are
satisfied using a single fixed integral architecture. The data for base price
shows the customers is satisfied with a base price at the average but
oftenentimes the customers would prefer the price to be flexible depending on the
options available on the vehicle. This would suggest a modular architecture
that can adjust for the variation of the customers. Furthermore, due to the
variation in the customer distributions, an adjustable feature would satisfy the
preference for seating height. That is, it is easy to allow customization despite
the low variance, so one should. Rear knee room and cargo capacity break out
into two levels, but again since customization is easy to offer, this suggest
offering multiple "packages" within which one can adjust the offering for
customization. Finally, interior price should have at least four adjustable
offerings for this attribute. This could easily be achieved through modules that
can be isolated and replaced without altering the rest of the design. All of
these design decisions, however, must be compared with cost models to determine which levels should be expanded to offer more variety. Using this information, designers can make a better assessment of what combinations of offerings would make sense to maximize the diversity of coverage in the market.
References


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[40] Zamirowski, E., "Product Portfolio Architecture Definition and Selection" 1999
APPENDIX A

1. Cluster breakout on base price attribute
2. Cluster breakout on fuel economy
3. Cluster breakout on passing acceleration
4. Cluster breakout on cargo capacity
5. Cluster breakout on towing capacity
6. Cluster breakout on interior price
7. Cluster breakout on seating height
8. Cluster breakout on front interior width
9. Cluster breakout on turning circle
Figure A-3: Cluster Breakout on Passing Acceleration
Figure A-4: Cluster Breakout on Cargo Capacity
Figure A-5: Cluster Breakout on Towing Capacity
Figure A-8: Cluster Breakout on Front Interior Width
Figure A-9: Cluster Breakout on Turning Circle
APPENDIX B

1. Manual Clustering of Segments on base price
2. Manual Clustering of Segments on fuel economy
3. Manual Clustering of Segments on passing acceleration
4. Manual Clustering of Segments on cargo capacity
5. Manual Clustering of Segments on towing capacity
6. Manual Clustering of Segments on interior price
7. Manual Clustering of Segments on seating height
8. Manual Clustering of Segments on front interior width
9. Manual Clustering of Segments on turning circle
Figure B-1: Manual Clustering of Segments for Base Price
Figure B-2: Cluster Breakout on Fuel Economy
Figure B-3: Manual Clustering of Segments for Passing Acceleration
Figure B-4: Manual Clustering of Segments for Cargo Capacity
Figure B-6: Manual Clustering of Segments for Interior Price
Figure B.7: Manual Clustering of Segments for Seating Height
Figure B-8. Manual Clustering of Segments for Front Interior Width
Figure B-9: Manual Clustering of Segments for Turning Circle
APPENDIX C

1. Segment and Population Distribution for fuel economy
2. Segment and Population Distribution for base price
3. Segment and Population Distribution for seating height
4. Segment and Population Distribution for towing capacity
5. Segment and Population Distribution for front interior width
6. Segment and Population Distribution for turning circle
7. Segment and Population Distribution for interior price
8. Segment and Population Distribution for cargo capacity
9. Segment and Population Distribution for passing acceleration
Figure C-1: Segment and Population Distribution for Fuel Economy
Figure C-2: Segment and Population Distribution for Base Price
Figure C-3: Segment and Population Distribution for Seating Height

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Figure C-4: Segment and Population Distribution for Towing Capacity
Figure C-5: Segment and Population Distribution for Front Interior Width
Figure C-7: Segment and Population Distribution for Interior Price
Figure C-8: Segment and Population Distribution for Cargo Capacity
Figure C-9: Segment and Population Distribution for Passing Acceleration
Appendix D

1. Tree Level Breakout and σ/μ for passing acceleration
2. Tree Level Breakout and σ/μ for rear knee room
3. Tree Level Breakout and σ/μ for turning circle
4. Tree Level Breakout and σ/μ for front interior width
5. Tree Level Breakout and σ/μ for seating height
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Figure D-1: Tree Level Breakout and σ/μ for Passing Acceleration

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Figure D-2: Tree Level Breakout and σ/μ for Rear Knee Room
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<td>σ</td>
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Figure D-3: Tree Level Breakout and $\sigma/\mu$ for Turning Circle

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Figure D-4: Tree Level Breakout and $\sigma/\mu$ for Front Interior Width

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$\sigma/\mu_{3\max} = 0.019$
$\sigma/\mu_{4\max} = 0.019$
$\sigma/\mu_{5\max} = 0.019$
$\sigma/\mu_{6\max} = 0.015$
$\sigma/\mu_{7\max} = 0.006$

$\sigma/\mu_{1\max} = 0.040$
$\sigma/\mu_{2\max} = 0.019$
$\sigma/\mu_{3\max} = 0.019$
$\sigma/\mu_{4\max} = 0.015$
$\sigma/\mu_{5\max} = 0.005$
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<th>4 levels</th>
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$\sigma/\mu_{3\text{max}} = 0.023$
$\sigma/\mu_{4\text{max}} = 0.020$
$\sigma/\mu_{5\text{max}} = 0.020$
$\sigma/\mu_{6\text{max}} = 0.006$
$\sigma/\mu_{7\text{max}} = 0.003$

Figure D-5: Tree Level Breakout and $\sigma/\mu$ for Seating Height

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$\sigma/\mu_{2\text{max}} = 0.246$
$\sigma/\mu_{3\text{max}} = 0.246$
$\sigma/\mu_{4\text{max}} = 0.095$
$\sigma/\mu_{5\text{max}} = 0.095$
$\sigma/\mu_{6\text{max}} = 0.095$
$\sigma/\mu_{7\text{max}} = 0.036$

Figure D-6: Tree Level Breakout and $\sigma/\mu$ for Towing Capacity

96
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Figure D-7: Tree Level Breakout and $\sigma/\mu$ for Fuel Economy

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Figure D-8: Tree Level Breakout and $\sigma/\mu$ for Cargo Capacity
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Figure D-9: Tree Level Breakout and σ/μ for Base Price
Glossary

**Chunks**: The building blocks of product architecture. They are made up of inseparable physical elements. Other terms for chunks may be modules or major subassemblies.

**Conjoint Analysis**: A quantitative market research technique that determines how consumers make tradeoffs among a small number of features or benefits.

**Customer**: One who purchases or uses your firm’s products or services.

**Focus Groups**: A qualitative market research technique where 8 to 12 market participants are gathered in a room for a discussion under the leadership of a trained moderator. Discussion focuses on a consumer problem, product or potential solution to a problem. The results of these discussions are not projectable to the general market.

**Functional Elements**: The individual operations that a product performs. These elements are often used to describe a product schematically.

**Fuzzy Front End**: The messy “getting started” period of product development processes following the formation of a germ of an idea, but before a firm begins development.

**Integral Architecture**: A product architecture in which most or all of the functional elements map into a single or very small number of chunks. It is difficult to subdivide an integrally designed product into partially functioning components.

**Market Conditions**: The characteristics of the market into which a new product will placed, including the number of competing products, level of competitiveness, and growth rate.

**Market-Driven**: Allowing the marketplace to direct a firm’s product innovation efforts.

**Market Segmentation**: The act of dividing an overall market into groups of consumers with similar needs, where each group differs from others in the market in some way.

**Market Share**: A company’s sales in a product area as a percent of the total market sales in that area.
**Metrics:** A prescribed set of measurements to track product development and allow a firm to measure the impact of process improvements over time. These measures generally vary by firm, but may include measures characterizing both aspects of the process, such as time to market, and duration or particular process stages, as well as outcomes from product development such as the number of products commercialized per year and percentage of sales due to new products.

**Modular Architecture:** A product architecture in which each functional element maps into its own physical chunk. Different chunks perform different functions.

**Needs Statement:** Summary of customer needs and wants, described in customer terms, to be addressed by a new product.

**New Product:** A term of many opinions and practices, but most generally defined as a product (either a good or service) new to the firm marketing it. Excludes products that are only changed in promotion.

**Perceptual Mapping:** A quantitative market research tool used to understand how customers think of current and future products.

**Physical Elements:** The components that make up a product. These can be both components (individual parts) in addition to minor subassemblies of components.

**Platform Products:** The design and components that are shared by a set of products in a product family. From this platform, numerous derivative products can be designed.

**Portfolio:** A set of products offered by a company in the entire market over time.

**Portfolio Criteria:** The set of criteria against which the business judges proposed product development projects to create a balanced and diverse mix of ongoing efforts.

**Product:** Term used to describe all goods and services sold. Products are bundles of attributes (features, functions, benefits, and uses) and can be either tangible, as in the case of physical goods, or intangibles, such as those associated with service benefits, or a combination of the two.
**Product Architecture:** The way in which the functional elements are assigned to the physical chunks of a product and the way in which those physical chunks interact.

**Product Definition:** Defines the product, including the target market, product concept, benefits to be delivered, positioning strategy, price point, and even product requirements and design specifications.

**Product Development:** The overall process of strategy, organization, concept generation, product and marketing, plan creation and evaluation, and commercialization of a new product.

**Product Development Portfolio:** The collection of new product concepts that are within the firm's ability to develop, are most attractive to the firm's customers, and deliver short- and long-term corporate objectives, spreading risk and diversifying investments.

**Product Development Process:** A disciplined and defined set of tasks and steps that describe the normal means by which a company repetitively converts embryonic ideas into salable products or services.

**Product Development Strategy:** The strategy that guides the product innovation program.

**Product Development Team:** A multifunctional group of people chartered to plan and execute a new product development project.

**Product Family:** The set of products that have been derived from a common product platform. Members of a product family normally have common parts and subassemblies.

**Product Interfaces:** Internal and external interfaces affecting the product development effort, including the nature of the interface, action required, and timing.

**Product line:** A group of products marketed by an organization to one general market. The products have some characteristics, customers, and uses in common and may also share technologies, distribution channels, prices, services, and other elements of the marketing mix.
**Product Plan:** Detailed summary of all the key elements involved in a new product development effort, such as product description, schedule, resources, financial estimations, and interface management plan.

**Product Platforms:** The set of parts, subsystems, interfaces, and manufacturing processes that are shared among a set of products, and allow the development of derivative products with cost and time savings.

**Product Rejuvenation:** The process by which a mature or declining product is altered, updated, repackaged, or redesigned to lengthen the product life cycle and in turn extend sales demand.

**Qualitative Market Research:** Consumer research conducted with a very small number of consumers, either in groups or individually. Results are not representative of consumers in general or projectable. Frequently used to gather initial customer needs and obtain initial reactions to ideas and concepts.

**Quality Function Deployment (QFD):** A structured method employing matrix analysis for linking what the market requires how it will be accomplished in the development effort. This method is most valuable during the stage of development when a multifunctional team agrees on how customer needs relate to product specifications and features that deliver those. By explicit linking of these aspects of product design, QFD limits the chance of omitting important design characteristics or interactions across design characteristics. QFD is also an important mechanism in promoting multifunctional teamwork.

**Target Market:** The group of consumers or potential customers selected for marketing. A market segment of consumers.

**Technology-Driven:** A new product or new product strategy based on the strength of a technical capability. Sometimes called solutions in search of problems.

**Threshold Criteria:** The minimum acceptable performance targets for any product development project being proposed or considered.

**Time-to-Market:** The length of time it takes to develop a new product from an early initial idea for a new product to initial market sales. Precise definitions of the start and end points vary from one company to another, and may vary from one project to another within the company.
User: Any person who uses a product or service to solve a problem or obtain a benefit, whether or not they purchase it. Users may consume a product, as in the case of a person using shampoo to clean hair, or eating a potato chip to assuage hunger between meals. Users may not consume a product directly, but may interact with it over a longer period of time, like a family owning a car with multiple family members using it for many purposes over a number of years. Products are also employed in the production of others products or services, where the users may be the manufacturing personnel who operate the equipment.

Utilities: The weights derived from conjoint analysis that measure how much a product feature contributes to purchase interest or preference.

Value-Added: The act or process by which tangible product features or intangible service attributes are bundled, combined, or package with other features and attributes to create a competitive advantage, reposition a product, or increase sales.

Voice of the Customer (VOC): A process for eliciting needs from consumers, which uses structured in-depth interviews to lead interviewees through a series of situations in which they have experienced and found solutions to the set of problems being investigated. Needs are obtained through indirect questioning by coming to understand how the consumers found ways to meet their needs, and more important, why they chose the particular solutions they found.