Proceedings of IMECHE 2003
ASME International Mechanical Engineering Congress and R & D Expo
November 15-21, 2003 – Washington, D.C.

IMECE2003-42786

INVESTIGATION OF CUSTOMER NEEDS FREQUENCY VS. WEIGHT IN PRODUCT PLATFORM PLANNING

Ravindra M. Kurtadikar
Graduate Research Assistant
Department of Mechanical Engineering
University of Missouri-Rolla
Rolla, MO 65401-0219
rmkt37@umr.edu

Robert B. Stone, Ph.D.
Associate Professor
Basic Engineering Department
University of Missouri-Rolla
Rolla, MO 65401-0210
rstone@umr.edu

ABSTRACT

Customer satisfaction is key for survival and success in today's consumer market. It is crucial that the customer be used to differentiate between different variants of a product, also known as a company's product portfolio. Numerous examples in industry prove the benefit of a platform strategy in product development. The aim is to capture a wider market share by launching a number of products based on a common platform and to reduce design and development cost by reducing design cycle time. In this paper we explore the possibility of using high level customer needs alone to define the product's base platform and differentiating modules. The basic idea is to outline *platform* and *differentiating modules* during conceptual design stage of product development and thus plan a product family before we consider any architecture. Planning platforms in conceptual design stage reduces additional costs associated with designing, manufacturing and managing resources for each variant separately. We use design tools such as the functional basis and functional modeling in our approach. In this work we seek to validate the technique by first applying it to existing products and comparing the results against known product platforms. In this paper we outline platform and differentiating modules for a bike and shop vacuum. Future work will focus on applying this approach for more products and finally to new products during conceptual design stage.

1. INTRODUCTION

A. MOTIVATION

A popular maxim in the business world is "time is money." If a company is unable to offer a product in a particular market segment quickly enough, a competitor is likely to do so and eat into its market share. Getting to market quickly with new products has become an essential feature of competition (Clark and Fujimoto, 1991). No longer is it possible to dominate large markets by developing and mass-producing one product at a time. Increasingly, good product development means developing a family or platform of products (Robertson and Ulrich, 1998). The long-term success of an enterprise depends on a stream of new products. When companies typically design one product at a time, they usually fail to deliver in the long run. The single product must compete for resources against other projects in the corporation's portfolio. Every product team must justify its own existence repeatedly throughout the process of development and commercialization. The end result of single product focus is a failure to embrace commonality, compactability, standardization or modularization among different products (Meyer and Lehnerd, 1997). The solution is to tackle the entire product portfolio at one time, i.e. during the initial design stage. It is estimated that $5 billion to $10 billion are wasted each year because of product strategy deficiencies (McGrath, 1995). Product platforms have become the primary product strategy in high-technology companies. The characteristics of the core platform usually determine the success of the individual products that come from that platform (McGrath, 1995). So it is important that we design platforms properly.

Volkswagen claims to save $1.7 billion annually on development and production costs through effective product architecture (Bremmer, 1999 & 2000). The platform strategy is Volkswagen's strategic approach and a synonym for a group-wide (i.e. covering the four brands of Volkswagen, Audi, Seat, and Skoda) standardization and differentiation strategy for product development, production process and procurement. Thus, platform strategy is a structuring principle comprising the floor group, drive system, running gear and unseen part of cockpit with numerous other elements. Complementary to this is the visible part of the vehicle – the part that is characteristics of the individual brand – and which is referred to as the "hat" (Wilhelm, 1997). The platform approach is currently used extensively in the automobile sector. Nobeoka and Cusumano (1994, 1995) showed that in the auto industry, a platform approach was associated with market share gains of 5.1% per year, while firms pursuing a single model approach lost 2.2 percent per year. Ford is trying to save $3 billion annually by reducing the number of platforms it develops (Moore et al., 1999). General Motors' long term strategy has been to achieve scale economies through standardization of parts and components while offering variety in style and color and customization in the form of optional equipment (Clark and Fujimoto, 1991).

B. EXAMPLES

There are many examples in industry that show the benefit of platform strategy. Fuji introduced the Quick Snap single use camera in the US market in 1987. In the coming years the market in this field was expected to grow by over 50% per year. A year later when Kodak introduced its first model Fuji had already developed a second model. Yet by 1994 Kodak captured 70% of US market back from Fuji (Robertson and Ulrich, 1998). Between 1989 and 1990, Kodak redesigned its base model and introduced 3 more models, all sharing common components and common production process steps. (Clark and Wheelright, 1996). Because Kodak shared components among four products it was able to develop products faster and cheaper. These models appealed to different customers in the market and resulted in increased market share.

Sony has dominated the personal portable stereo market worth $1 billion worldwide with a market share of 40% for over a decade. Based on only four technological platforms, Sony introduced almost 250 models during the 1980's. A product family approach greatly contributed to their success (Sanderson and Uzumeri, 1994). In the field of aviation, Boeing and Airbus Industries use common wings, nose and tail components to leverage many models by using different fuselage modules to create aircrafts of different lengths and capacities (Woolsey, 1994). Black and Decker's power tool business pursued a deliberate strategy to share many elements across its products. In 1970 the company had hundreds of products. The products used more than 30 different motors, 60 different motor housings and dozens of different operating controls. Furthermore, each product had its own unique armature. Management decided to cut costs by using a platform strategy to share parts and subsystems. After investing $20 million in their platform strategy, the company was able to reduce the product costs by 50% and increase its market share by 20% (Meyer and Utterback, 1993).

Hewlett Packard's ink jet printers offer another example of a successful product family. The company's three point strategy consisted of developing derivatives from existing product platforms, enhancing those platforms to address new markets niches or reduce costs and creating entirely new platforms–all at the same time (Meyer and Lehnerd, 1997). Intel's product family of 486 processors, which replaced the 386 line, was based on platform technology (McGrath, 1995). The 486 had twice the performance and was fully compatible with the software developed for 386. Within four years the 486 covered all major market segments.

Looking at the above examples it is evident that platform strategies are important for reduction of development cost, increase of market share and the ability to survive longer in the competitive market

2. RELATED WORK

Here we review existing techniques to define and evaluate product platforms that have been reported in research literature. We classify these techniques into three categories: component, function and managerial based approaches.

A. Component Based Approaches

Martin and Ishii (1997, 2000) developed two indices called Generational Variety Index (GVI) and Coupling Index (CI) to measure a product's architecture. GVI is the amount of redesign effort required for future designs of the product. It is an indication of which components are likely to be changed over time. CI is a measure of the coupling among the product components. The stronger the coupling between components, the more likely a change in one will require a change in the other. These indices are used to develop a product platform architecture that is more robust to changes from external drivers. The method mainly determines those components that are likely to change in the future. However, for measuring coupling indices, we need the components to be already designed. Also, for GVI, we need some sort of architecture already developed. Martin and Ishii (1997) also discuss the importance of cost in providing variety, focusing on methodologies that quantify costs of providing variety to quantitatively guide designers in developing products that incur minimum variety costs.

Kota and Sethuraman (1998) have analyzed the factors that contribute to product complexity in general, and developed an objective measure called Product Line Commonality Index to capture the level of part commonality in a product family. They also suggest robust design and manufacturing strategies, including modularity and postponement of product differentiation to help minimize non-value added variation across models within a product family. The issue of how to increase commonality is not addressed. The methodology shows that a higher level of commonality can be achieved in a particular architecture, but cannot identify a platform before deciding the actual components.

Moore et al. (1999) demonstrate how one can combine different conjoint analyses, each containing a core of common attributes, to help design product platforms. They have shown that platform based designs can be significantly more profitable than isolated line extensions. The importance of fixed and variable costs is stressed when performing such a study. Existing products are analyzed and then the platform is identified and an attempt is made to reduce costs.

The applicability of product variety design concepts to the design of automotive platforms is discussed by Siddique and Rosen (1998). They proposed a platform representation and commonality measures that are supposed to capture important characteristics of platform commonality and car model variety. Two methods for measuring platform commonality were presented. Siddique et al. (2000) developed the product family reasoning system (PFRS) to identify common platforms from a collection of similar, existing products, and to generate product families from these common platforms. The inputs are a set of existing products, assembly facilities and constraints and the output is a candidate set of platforms and products within a family. A collection of similar existing products is needed prior to using this methodology to form platforms.

Farrel and Simpson (2001) have discussed how the strategic incorporation of product platforms into the design process can leverage the design effort of individually customized products. With an example of the design of a yoke cross section (used to mount valve actuators in nuclear power industry) they demonstrated the process of creating a market segmentation grid, selecting a targeted segment, creating a product platform for a yoke cross sections and thus defining the product family.

B. Function Based Approaches

Several approaches have emerged that define product portfolios and architecture based on functional models (Otto and Wood, 2001). Zamirowski and Otto (1999) proposed a method for identifying product architecture alternatives for a family of products based upon customer needs and product function. In this methodology, customer needs and product uses are first interpreted and a function structure for each product use is constructed. All function structures are then clustered and modules are identified using variety heuristics.

Dahamus et al. (2000) presented an approach towards architecting a portfolio of products to take advantage of possible commonality through the reuse of modules across the family of products. Rather than a fixed product platform upon which derivative products are created, the approach here permits the platform itself to be of several possible sizes and types. This is based on the work of Stone et al. (1998) and Zamirowski and Otto (1999) that identifies modules from the family function structure. In this method, a modularity matrix is formed using possible functions from the family function structure versus possible products in the family. Functions are arranged in rows and products in columns. Laying out information in this fashion allows commonalitities to be easily identified. Independently developing functional models and then combining them in a family function structure, however, is tedious job.

Sudijanto et al. (2001) present modularization rules to build a brand platform and a framework for maintaining a distinct brand for each product variant built upon a product platform. They focus on rules for differentiation among brands within a portfolio while simultaneously utilizing a common product platform. It is assumed that starting from a common product platform and expanding by one feature at a time to create brand differentiation will not be successful. Terms like dominant theme, brand signatures and brand differentiation matrix are introduced. The approach in their work uses a modularity matrix augmented with brand aesthetic specifications. Three additional heuristics for identifying modules from a family function structure are formulated. One noted downside with this approach is that combining family function structures (family functional model) can become very tedious when dealing with larger-scale products.

C. Managerial/Business Approaches

Robertson and Ulrich (1998) articulated three tools for supporting platform planning: product plan, differentiation plan and commonality plan. For effective platform planning a company should carefully align these three plans through an iterative process. A platform is defined as a collection of assets that are shared by a set of products. These assets may include components, knowledge and production processes. Platform planning involves two major activities: 1) identify market segments and what customers want in each market segment; and 2) design a product architecture which can be used to simultaneously deliver the different products while sharing many parts and production processes. They use the term differentiating attribute (DA) to denote the characteristics that customers view as important in a product and chunks to represent major physical elements of a product. DA's reflect the level of distinctiveness as seen by the customer while chunks reflect the level of commonality experienced by the firm. The product plan tells what variants will be delivered at what times and to which customers. The differentiation plan, which encompasses DA's, will help differentiate one model from another. The commonality plan describes the extent to which the products in the product plan share physical elements. The methodology presented has been shown to achieve considerable reduction in development costs. Similarly, Ulrich and Eppinger (2001) emphasize proper balance between differentiation and commonality when addressing different market segments with different versions of a product.

The role of commonality in automotive product development has been discussed in detail by Jorgen et al. (1996). The author selected three car makers (Chrysler, Honda and Mazda) to study how each tackled the issue of parts commonality within their product line. It is stated that to gain maximum benefits of commonality while generating highly differentiated models, many firms are moving to a platform approach for product development. A car maker using a platform approach designs the essential features of a family of cars at the same time, instead of one model at a time. The platform is defined as the set of assets shared by different vehicles and these assets also include the experience developed by the engineers who developed the platform. Commonality strategies of these firms are different. Mazda focused on process commonization rather than parts commonization. Chrysler made unique parts for models when customers perceived those parts as adding value. Product variety is very valuable at market level, but generally it is costly to provide full degree of variety. The revenue gain from greater variety must be balanced against the lower unit production costs with fewer variants (Lancaster, 1990).

The reuse of common designs has significantly improved the quality of the final product. It also helps reduce stock levels of common parts reducing inventory costs (McDermott et al, 1994). Earlier, commonality was seen as a means for cost reduction, but now hi-tech firms are using it as a means to reduce new product development time and improve the overall manufacturability of the product line.

A company's know-how in platform technology is very favorable for diversification in the market. A firm with experience in a platform technology is more likely to diversify into the exploration and generation of new markets than a firm that has developed narrowly based skills. (1996, Kim and Kogut). The authors verified their proposition with a sample of 176 semiconductor startup companies.

According to Meyer and Utterback (1993), products that share a common platform but have specific features and functionality required by different sets of customers comprise a product family. They discuss in detail about product family evolution, platform renewal, and new product creation. They define platform as set of subsystems and interfaces that form a common structure from which a stream of derivative products can be efficiently developed and produced. Meyer and Lehnerd (1997) and Meyer et al. (1997) used two new measures named platform efficiency (μ) and platform effectiveness for measuring the performance of product families. Platform efficiency is the degree to which a platform allows economical generation of derivative products. Mathematically, μ = *(R&D cost of derivative product)/(R&D cost of platform version)*. Platform effectiveness is the degree to which the products based on product platform produce revenue for the firm relative to the cost of developing these products. Mathematically, *platform effectiveness = (Net Sales of derivative products)/(Development Costs of a derivative products)*. These measures, when combined with visual interpretation of product family maps, can also help management understand the timing of platform renewal and the frequency of derivative product developments from existing platforms.

McGrath (1995) defines product platform as a collection of the common elements, especially the underlying core technology, implemented across a range of products. A product platform is primarily a definition for planning, development, and strategic decision making. Product platforms are designed to serve specific group whereas the product architecture is not necessarily developed with this group in mind. Also, Baldwin and Clark (1997) have defined three aspects of the product platforms, its modular architecture, the interfaces and the standards (the design rules to which the modules conform).

Sundgren (1999) introduced the concept of interface management (IM) for new product platform development. IM is defined as the process of developing and finalizing the physical interfaces between the platform and end product unique subsystems. It is stated that platform approach associated with IM process will give a high degree of freedom in deciding how to balance time to market for individual products with the effective utilization of design familiarities across all products. Prasad (1998) has discussed about managing complexity while designing products for variety. It is stated that it is the complexity of products and processes, which compels a product manufacturer to look for their breakdown structures. The breakdown is also necessary to exploit any inherent concurrency so that the individual tasks can be overlapped. Pine (1993) has provided empirical evidence that market turbulence and the need for product variety have increased substantially over the past decade and has also stated that product variety will increase in the future. The platform approach is one of the key approaches for successful mass customization, i.e. ability to produce products in high volumes that are custom made to meet the needs of individual customers. (Pine et al, 1993). Kekre and Srinivasan (1990) have stated that when a company has a broader product line, it leads to a high market share resulting in reduced manufacturing costs and increase in profits.

D. SUMMARY

Most of the existing platforming methodologies require existing product architecture. Many researchers have studied commonality in products or families of products. Methodologies have been developed to determine those components that are likely to change in the future. Percentage commonality is used as a tool to measure a degree to which commonality has been achieved. Measuring commonality in existing product families and then deciding on interdependence/part sharing is hypothesized to be a lengthy process. Instead, identifying common parts/ platform/modules in the early design stage can drastically reduce cost and design cycle time. There are methodologies that show that a higher level of commonality can be achieved in a particular existing architecture, but the methods cannot outline a platform before considering the actual architecture. There are several function based approaches for platforming. In most cases, a family function structure is created and then heuristics are applied to identify modules. Independently developing functional models for each product variant and then combining all functional models is a tedious job and will become more complicated as the product scale increases. It is seen that currently there is no methodology that uses high level customer needs alone for planning platforms. We plan to outline a platform directly from customer needs and a functional model before any sort of architecture is developed.

3. RESEARCH APPROACH

From the literature we conclude that commonality and distinctiveness are two important aspects for a successful product family. *Commonality* leads to a platform shared between variants and *differentiating characteristics* distinguish one model from other. In our approach we explore ways to classify customer needs as core and distinctive needs. Our overall hypothesis is that customer needs can be classified based on frequency and weight into core and distinctive needs. Further, core needs will lead to a common platform and distinctive needs will lead to variety. In other words, core needs will form the common platform and distinctive needs will form differentiating modules.

A. Hypotheses

More specifically, we state three hypotheses that are explored in this paper:

H1: Based purely on frequency of customer need statements, we expect low frequency customer needs will lead to a common platform while high frequency customer needs will lead to differentiating modules.

Hypothesis H1 reflects the view that during the interviews, the customer always assumes the basic structure or platform of the product is adequately defined. Consequently, the customer tends to identify more characteristic or specific needs rather than basic needs. Thus the higher frequency needs will lead to differentiating modules and low frequency needs will form the base platform.

H2: Based solely on customer need weight, highly weighted customer needs will lead to a common platform while lightly weighted customer needs will lead to differentiating modules.

Complementary to the interview technique, hypothesis H2 speculates that if the customer is given a list of all needs, then the customer will definitely rate core/basic needs with high weight. Differentiating needs will receive, on average, a lower weight due to the diverseness of the customer pool.

H3: Considering the interaction between customer need frequency and weight, highly weighted, low frequency customer needs will lead to a common platform and lightly weighted, high frequency customer needs will lead to differentiating modules.

The final hypothesis reflects the possibility that neither H1 or H2 alone will adequately describe the situation, but that an interaction of customer need weight and frequency will correlate to a core platform and differentiating modules.

B. Analysis Approach

Robertson and Ulrich (1998) have stated that to keep the problem-solving discussions that occur during platform planning productive, they should be anchored in a common language. To that end, we use the functional basis developed by Stone and Wood (2000) and Hirtz et al. (2002) as our language for representation and modeling of artifacts in our design phase.

Our general research approach is outlined below:

1. Gather customer needs for existing products known to have a platform strategy.
2. Analyze the customer needs to determine how they may be classified into core and distinctive needs.
3. Construct one functional model for the *base platform* using core customer needs.
4. Construct functional model for each *differentiating module* using characteristic customer needs.
5. Formulate a method to identify core and differentiating customer needs as a means to identify the base platform and differentiating modules.

Stone et al. (1998 & 2000) established a set of three heuristics, *dominant flow rule, branching flow rule and conversion-transmission rule* to identify product modules from a functional model. In addition to that, for the entire portfolio, an additional set of rules – *shared functions* and *unique functions* – are developed for identification of modules. (Zamirowski and Otto, 1999). We speculate that the additional set of heuristics for designing a portfolio are not needed once core and differentiating customer needs are identified and that a family of products can be designed based only on the heuristics of Stone et al. (1998 & 2000). Representing a platform in terms of customer needs provides a more direct link between customer needs and platform planning, because ultimately it is the customer who is going to differentiate between different product variants.

In section 4 we present the empirical study (essentially steps 1-4 of the research approach). Following that, section 5 presents our formulation of a customer need motivated platform.

4. EMPIRICAL STUDY

To test hypotheses H1-H3, we first look at frequency and weight correlations independently and then look at their interaction correlations to core and differentiating modules. For our study we selected two products, a bicycle and a shop vacuum, that are known to have many variants but share a common platform. We gathered customer needs for each product interviewing 20 customers for the bike and ten for the shop vacuum. After all interviews, we recorded the frequency of occurrence of customer needs. For the bike, 202 distinct customer needs were identified with a maximum frequency of 16. For the shop vacuum, 66 distinct customer needs were uncovered with a maximum frequency of eight. Additionally, we compiled all customer needs and prepared a questionnaire and asked each customer to rate each need on a scale of 0-5. Ratings were averaged to compute the relative weight of each customer need.

A. Frequency-only Testing (H1)

From the data, we observe that most of the core customer needs have low frequency, although some core customer needs did have higher frequency. We find that the customer needs that are directly related to the basic structure of the product (platform) are not strictly grouped together. Thus, H1 is not directly supported.

B. Weight-only Testing (H2)

To evaluate hypothesis H2, we plot customer need weight vs. customer need, expecting highly weighted customer needs to identify the base platform. Analysis of the data finds no definite correlation between core customer needs and weight. Again, H2 is not supported by this data set.

C. Weight and Frequency Interaction Testing (H3)

To examine any possible interaction of the frequency and weights, we tabulate each customer need with its respective frequency and weight in Tables 1a and 1b. Table 1a and 1b prove very informative as they indicate a possible correlation between customer needs weight and frequency value and modules. Figures 1a and 1b shows this data graphically with plots of customer need frequency on the x-axis and weight on the y-axis. These plots are more meaningful in planning for platform as they identify core customer needs and differentiating customer needs and support H3. A detailed explanation of the support for hypothesis H3 follows.

In Figs. 1a and 1b, each point represents a customer need with frequency and weight value. Our next task is to investigate these plots for possible groupings of core and differentiating customer needs that can aid in defining a platform. We tracked all the points in these plots and recorded the basic (or core) customer needs with their respective weights and frequency values in Tables 2a and 2b.

Table 1a. A sample of customer needs for a bike with weight and frequency (a total of 202 needs were collected).

no.	Customer need	weight	freq
1	Reliable brake at high speed	4.45	1
3	No failure of parts at high speed	4.1	1
4	More value per dollar spent	4.1	2
5	Low frequency of maintenance.	4.1	3
53	Good front shock	3.45	1
54	More power delivered	3.45	1
56	At least 6 months warranty	3.4	1
57	General comfort	3.4	1
58	Riding comfort/easy to use	3.4	6
59	Easy to pedal	3.4	2
197	Space for extra passenger	1.7	1
199	Easy disassembly of mudguard	1.65	1
200	Cycling computer with many displays.	1.6	1
201	Storage space for luggage	1.6	7
202	U shaped handle	1.35	1

Table 1b. A sample of customer needs for a shop vacuum with weight and frequency (a total of 66 needs were collected).

no.	Customer need	weight	freq
1	Reliability/endurance of motor	4.9	1
2	Ease of availability of filters/bag.	4.9	8
3	Long power cord	4.7	8
11	Ability to wind/unwind wire	4.3	5
14	Display dirt level in the collection container	4.3	1
19	Balanced body while using & moving	4.1	1
20	Easy to swap between wet and dry option	4.1	1
21	Two in one filter which can be used for wet & dry dirt.	4.1	1
30	Ergonomic position of switch (easy to operate)	3.8	2
32	Easy to dismantle	3.8	1
33	Low noise	3.7	3
44	Child lock for safety	3.5	1
45	Signs/marks on the body to guide fitting of parts	3.5	1
56	Easy to store	3.1	1
59	Low power consumption	3	2
60	Attachment to use car battery supply	2.9	2
63	Remote for changing wet/dry option	2.7	1
64	Push button type on/off switch preferred	2.7	1
65	Ability to mount on the body while using	2.4	3
66	Attachment to listen music while cleaning	2.4	2

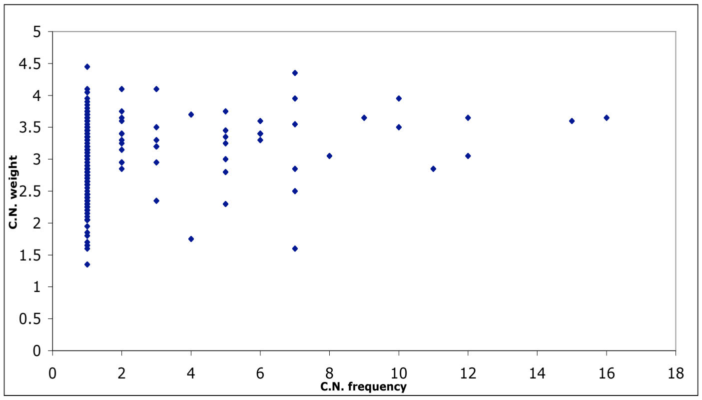

Figure 1a. Frequency vs. weight scatter plot for customer needs of a bike.

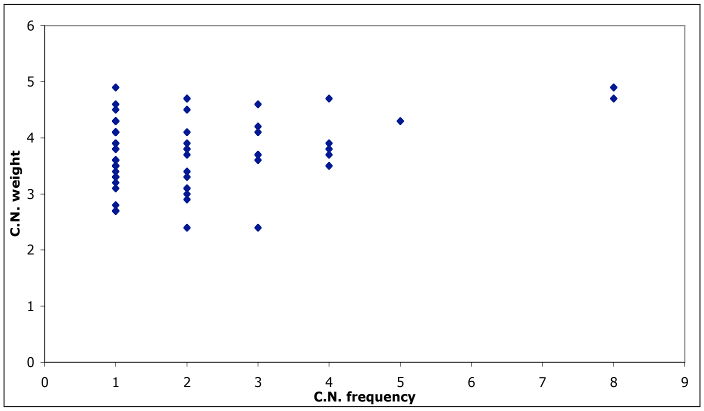

Figure 1b. Frequency vs. weight scatter plot for customer needs of a shop vacuum.

Table 2a. A sample of core customer needs (low frequency and high weight) for a bike.

Core customer needs	weight	freq
Reliable brake at high speed	4.45	1
No failure of parts at high speed	4.1	1
More value per dollar spent	4.1	2
Low frequency of maintenance	4.1	3
Long life of bike	4.05	1
Good performance	3.9	1
No fracture at high speeds	3.8	1
Longevity of frame	3.75	1
Good balance between durability and light weight	3.75	2
No gradual deterioration in performance	3.75	1
Back comfort	3.7	1
Smooth running	3.7	1
Easy to apply brakes	3.65	1
Easy to replace spare parts	3.65	1
Light weight frame	3.65	1
Bearings longevity	3.65	2
Reliable spare parts	3.65	1
Good stability during high speed	3.6	2
Strong spokes	3.5	1
Strong chain	3.5	1
Sturdy frame	3.45	5
Easy to pedal	3.4	2
Noiseless operation	3.4	2
No fading of colors	3.35	5
Optimum sitting space	3.3	2

The customer needs in Table 2a are placed in low frequency and high weight area of the plot. Needs such as reliable brakes, long life, good performance, noiseless operation, sturdy frame, good stability, etc. are all the basic needs, reading to the functionality of a simple bike. So we refer to this set of needs as the core customer needs.

Similarly, we track the points in Fig. 1b for the shop vacuum. The grouping of basic customer needs for the shop vacuum is displayed in Table 2b.

Similar results are obtained for the shop vacuum. The customer needs in Table 2b have a low frequency and high weights. The needs like reliable motor, light weight, low noise, easy to replace filters, easy to store, sturdy material, etc. are all basic needs leading to the core functionality of shop vacuum. These are the needs required for the base platform of this product.

Table 2b. A sample of core customer needs (low frequency and high weight) for a shop vacuum.

Core customer needs	weight	freq
Reliability of motor	4.9	1
Low cost	4.7	2
Light weight	4.7	4
Safety and quality certification	4,7	2
Long hose	4.6	1
Easy to replace filters	4.6	3
Easy to dispose dirt from container	4.5	2
No leakage of dirt from container	4.3	5
Clear safety instructions	4.2	3
Balance body while using	4.1	1
Less body bending while cleaning	4.1	1
Low heat generation	4.1	3
Low frequency of filter change	3.9	1
Leak-proof hose	3.9	2
Proper connection between hose and chamber	3.9	1
Ergonomic position of switch to operate	3.8	2
Easy to dismantle	3.8	1
Low noise	3.7	3
High strength material	3.7	3
No oil leakage	3.5	1
Sign marks for fitting of parts	3.5	1
Easy to store	3.1	1

Table 3a. A sample of differentiating customer needs for a bike.

Differentiating customer needs	weight	freq
U shaped handle	1.35	1
Storage space for luggage	1.6	7
Cycling computer	1.6	1
Provision for bell	1.75	4
Good taillight	2.3	5
Shock in transverse frame	2.05	1
Ability to store pedaling energy	2.05	1
Hydraulic gear shifters	2.25	1
Full suspension with well controlled rebound	2.25	1
Replaceable derailleur hanger to save frame	2.35	1
Space for bottle	2.35	3
Rapid shifters preferred	2.4	1
Provision for headlight	2.5	7
Adjustable handle	2.65	1
Reflectors in front and back	2.8	1
Reflectors in wheels	2.8	1
Reliable shock lock	2.85	1
Adjustable distance between seat and handle	2.9	1
Smart shocks, more stiff in uphill and less stuff in downhill	3.1	1
Adjustable seat height	3.55	7

Observing the results in Table 2a and 2b, we conclude that, low frequency and high weight customer needs lead to base platform. In both cases, the low frequency and high weight customer needs are related to very basic structure of the product.

Our next task is to track differentiating customer needs. Table 3a represents a sample of differentiating customer needs for a bike and Table 3b represents differentiating needs in a shop vacuum. Customer needs in Tables 3a and 3b are very specific. These needs are not a part of basic structure of the product. The core structure/needs of both products is already described in terms of customer needs in Tables 2a and 2b. The characteristic needs stated by the customer in this set tend to assume that the basic product structure is already assured. Individual or small groupings of such needs will form differentiating modules. The combination of the core needs (which form basic structure of platform) with differentiating needs will result in product variants. In the case of the bike, a derailleur hanger, U shaped handle, cycling computer, reflectors, attachment for bottle, hydraulic shifters, full suspension, etc. form different modules/sub-assemblies that can be attached to the core structure of the bike to form product variants for the bike. In the case of a shop vacuum, a blower attachment, push button, battery-powered option, adjustable wheels, etc. will form differentiating modules or sub-assemblies, which can be combined with a base platform to form a product family.

Table 3b. A sample of differentiating customer needs for a shop vacuum.

Differentiating customer needs	weight	freq
Ability to mount on body while using	2.4	2
Push button type on/off switch	2.7	1
Auto power off after some time	2.7	1
Battery powered option	3.1	2
Child lock for safety	3.5	1
Adjustable (push inside) wheels	3.3	1
Spray painting attachment	3.6	3
Blower attachment to clean by force of air	3.8	4
Self adjusting width of front nozzle	2.8	1
Long power cord	4.7	8
Wheels for portability	3.9	4
Attachment to wind/unwind cable	4.3	5

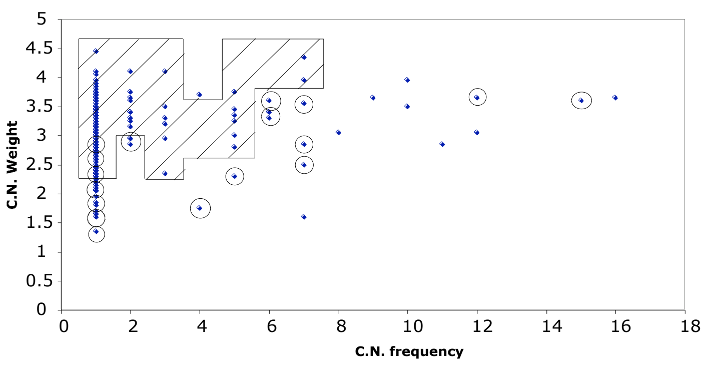

Figure 2a. Base platform and differentiating modules plan for a bike.

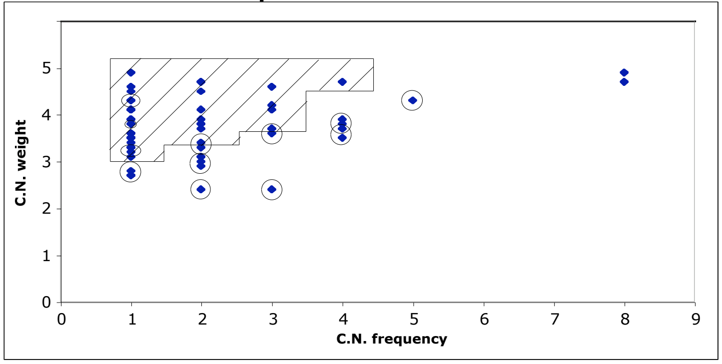

Figure 2b. Base platform and differentiating modules plan for a shop vacuum.

In Figs. 2a and 2b we overlay the customer needs with their respective membership in either a core or differentiating module. The hashed area represent core customer needs that lead to base platform and circles indicate differentiating modules. It can be clearly seen that the platform falls in the upper left quadrant of the plot. This leads us to conclude that planning a core platform means looking for higher weight and lower frequency customer needs.

Next we explore if the identified set of core and differentiating customer needs lead to accurate functional models of the products. Figure 3 represents the functional model of the base platform for a bike based on 92 core customer needs. Figures 4a-d represents functional models of four differentiating modules for bike. Note that this is a subset from the 110 differentiating customer needs.

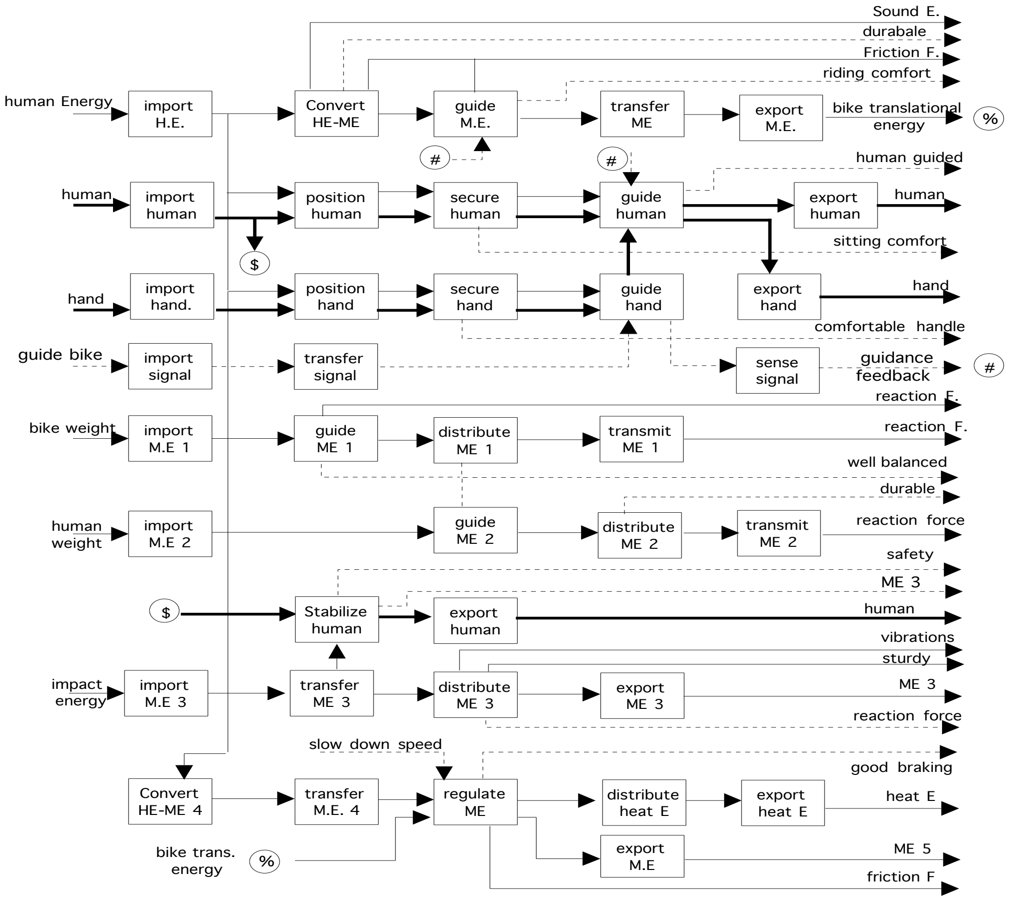

Figure 3. Functional model of base platform for a bike.

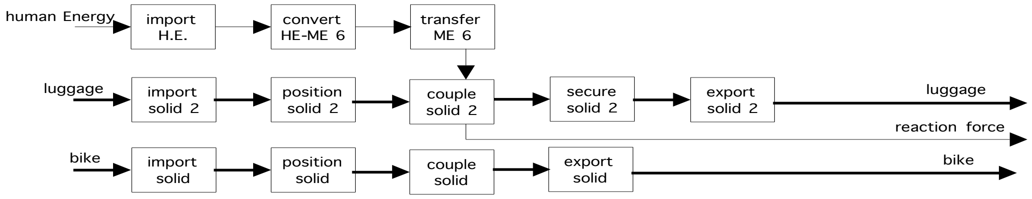

Figure 4a. Attachment for luggage module for a bike.

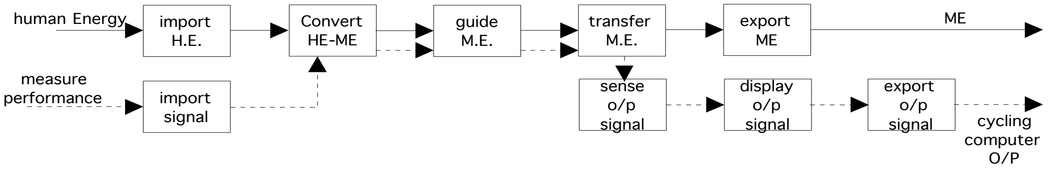

Figure 4b. Cycling computer module for a bike.

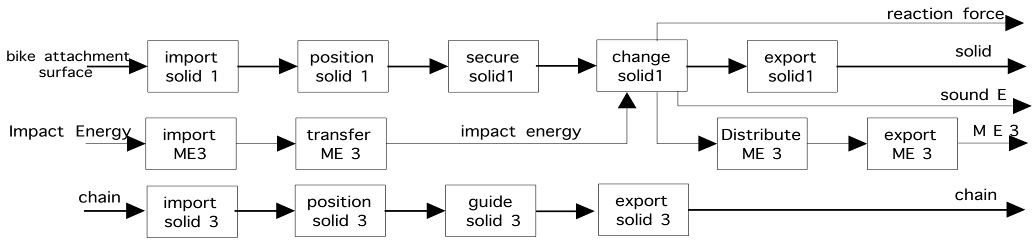

Figure 4c. Replaceable derailleur hanger module for a bike.

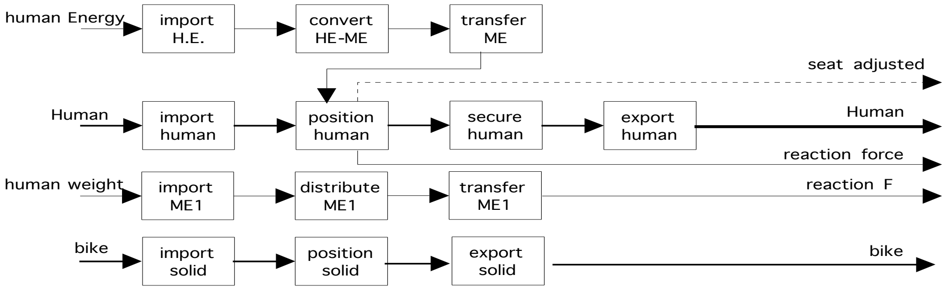

Figure 4d. Adjustable seat module for a bike.

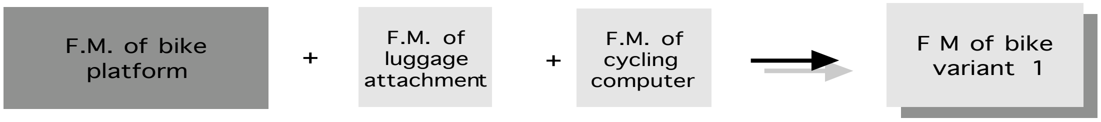

Figure 5. Combining the bike platform with differentiating modules.

At this juncture we have functional model of bike platform and functional models for four differentiating modules. A simple way to form functional model of variants is to combine the functional model of the base platform with that of differentiating modules. Figure 5 schematically represents how we form the functional model of first variant. Figure 6 shows the actual functional model of variant one of the bike, formed by combining functional model of platform for bike (Fig. 3) with functional model of two differentiating modules (Figs. 4a and 4b). The result is a functional model of *bike with a cycling computer and luggage attachment.*

5. PROPOSED METHOD

As a result of the empirical study presented in section 4, we formulate a method for identifying product platforms and differentiating modules directly from customer needs. The method is shown schematically in Fig. 7 and the specific steps are outlined below.

1. Gather customer needs using interview technique. Interview until no new needs are uncovered.
2. Record *frequency* of occurrence for each customer need.
3. Prepare a questionnaire using data from the interviews. Have all customers rate each customer need on a 0-5 scale. Record the *weight* for each customer need.
4. Tabulate each customer need, with corresponding weight and frequency value.
5. Plot *customer need frequency vs. customer need weight* graph.
6. Construct a functional model of the base platform using customer needs in the upper left quadrant (low *frequency* and high *weight),* which represent the pool of core customer needs.
7. Construct functional models of the differentiating modules, using remaining needs individually or in small groups.

6. CONCLUSIONS

In this paper we show that functional models of product variants can successfully be constructed directly from high-level customer needs once they are classified as core or distinctive needs. Our empirical study supports the hypothesis that customer need weight and frequency interaction (in the form of frequency-weight plots) can be used to distinguish core and differentiating needs. Core needs lead to a base platform and differentiating needs lead to variety. Our current database supports the hypothesis that lower frequency and higher weight customer needs lead to a base platform and other customer needs lead to differentiating modules. In the case of bike we found that 76 % of core customer needs have weight ≥ 3 and frequency ≤ 5. In case of shop vacuum 93 % of core customer needs have weight ≥ 3 and frequency ≤ 3.

A product platform and differentiating modules were planned for a bike and shop vacuum. We constructed a functional model for the base platform and combined it with functional models of differentiating modules to form an overall functional model of a variant. Thus, applying design tools such as functional basis and functional modeling to high level customer needs, we successfully planned functional models of product variants. We found a direct link between high-level customer needs and a product portfolio plan. Overall, this initial work supports the conclusion that core and differentiating needs act as important guidelines for planning product variants along with some measure of engineering design judgment on part of the designer.

7. FUTURE WORK

Future work will focus on making this methodology more robust. We will apply this approach to additional existing products. Finally, we will plan a product family for a new product. As an extension to this work, next step will be mapping product architecture from the functional models of variants. As we have the functional model of each variant, we plan to apply single product module heuristics to derive product architecture from functional model.

ACKNOWLEDGEMENTS

This work was supported by the University of Missouri-Rolla Intelligent Systems Center. Any opinions or findings of this work are the responsibility of the authors, and do not necessarily reflect the views of the sponsors.

REFERENCES

B. Wilhelm, 1997, “Platform and Modular Concepts at Volkswagen – Their Effects on the Assembly Process,” In, Takahiro Fujimoto, Ulrich Juergens and Koichi Shimokawa: *Transforming Automobile Assembly: Experience in Automation and Work Organization*, Springer-Verlag, 1997. Chap 3.7, p 146-156.

Baldwin, Carliss Y. and Clark, Kim B., 1997, “Managing in the Age of Modularity,” *Harvard Business Review*, Vol. 75, No 5, 1997, p. 84-93.

Biren Prasad, 1998, “Designing products for variety and how to manage complexity,” *The journal of product & brand management,* Vol 7, No 3, 1998 p 208-222

Bremmer, R., 2000, “Big, Bigger and Biggest,” *Financial Times Automotive World*, June. p. 36-43.

Bremmer, R., 1999, “Cutting edge platforms,” *Financial Times Automotive World,* June, p.30-41.

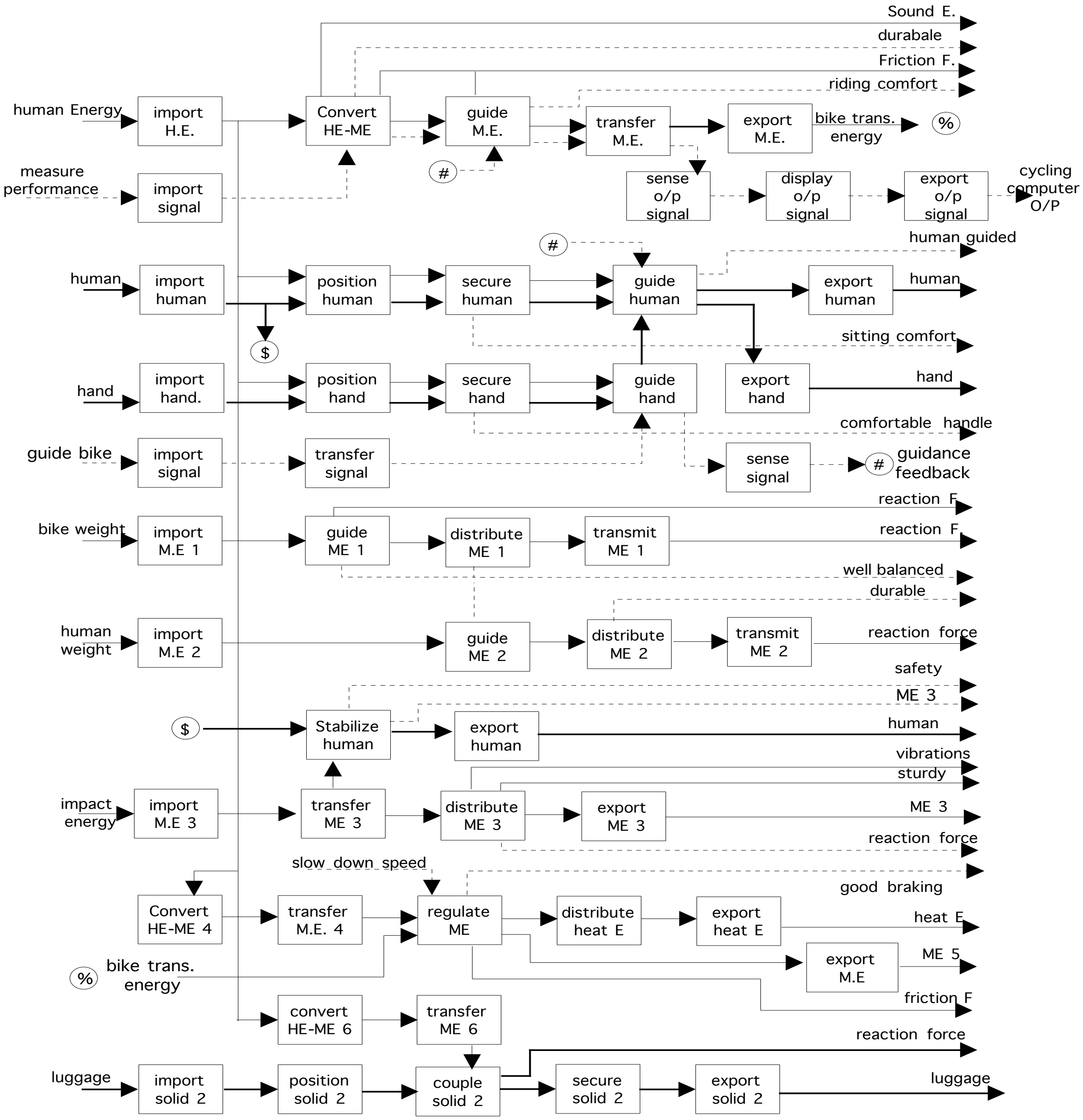

Figure 6. Functional model of variant 1 of a bike (bike with a cycling computer and luggage attachment).

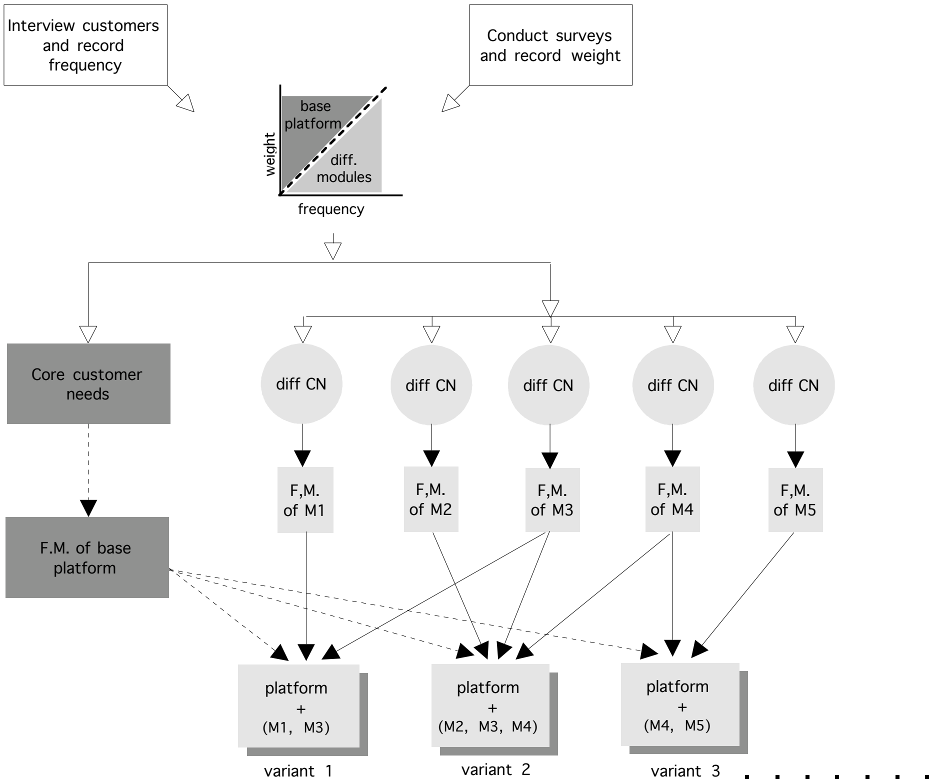

Figure 7. Overview of methodology.

Clark, Kim B. and Fujimoto, Takahiro, 1991, "*Product Development Performance: Strategy, Organization, and Management in the World Auto Industry,*" 1991, Harvard Business School Press, Boston, MA.

Dahmus, J., Gozalez-Zugasti, J.P. and K. Otto, 2000, "Modular Product Architecture," *ASME Design Theory and Methodology Conference*, Baltimore, MD, 2000. DETC2000/DTM-14565.

Dong-Jae Kim and Bruce Kogut, 1996, "Technological Platforms and Diversification," *Organization Science*, May-June1996, Vol7, no3, 283-301

Ericsson, J., Karlsson, P., Mercer, G. and Robertson, D., 1996, "Sharing parts across car models: lessons from the manufacturer," *Europe's Automotive Components Business*. 1st Quarter 1996.

Farrel S.R. and T.W.Simpson, 2001, "Improving commonality in custom products using product platform." DETC2001/DAC-21125, Pittsburgh, Pennsylvania.

Kekre, S. and Srinivasan, K., 1990, "Broader product line: A necessity to achieve success?" *Management Science*, 36: 1216-1231 (1990).

Kota, S. and K. Sethuraman, 1998, "Managing Variety in Product Families through Design for Commonality," *Proceedings of DETC1998*, DETC1998/ DTM-5651, Atlanta, GA.

Lancaster, K. 1990, "The economics of product variety: a survey," *Marketing Science",* Vol9, no3, summer 1990.

Martin, M. and Ishii, K. 2000. "Design for variety: A Methodology for Developing Product Platform Architectures," *Proceedings of* DETC2000, DETC2000/DFM-14021, Baltimore, Maryland,

Martin, M. V. and Ishii, K., 1997, "Design for variety: development of complexity indices and design charts," *Proceedings of DETC 1997*, DFM-4359, Sacramento, CA.

Michael E. McGrath, 1995, "*Product Strategy For High-Tech Companies,*" New York, NY: Irwin Professional Publishing, 1995.

Mc Dermott, M.C and Stock, N. G, 1994, "The Use Of Common Parts In High-Tech Industries: A strategic approach," *Production And Inventory Management Journal,* Third Quarter, 1994, 65-68

Meyer, M. H. and Utterback, J. M., 1993, "The Product Family and the Dynamics of Core Capability," *Sloan Management Review*, Vol. 34, p. 29-47.

Meyer, M.H. and Lehnerd, A. P., 1997, *The power of product Platforms: Building Value and Cost Leadership,* Free Press, NY

Meyer, M.H., Tertzakian, P. and Utterback, J.M., 1997, "Metrics for Managing Research and Development in the Context of the Product Family," *Management Science* 1997; 43(1):88-111.

Moore, W.L., Louviere, J. J. and Verma, R., 1999, "Using conjoint analysis to help design product platforms," *Journal of Product Innovation Management*, v16, n1, Jan 1999. p27-39.

Nobeoka, K. and M. A. Cusumano, 1995, "Multiproject strategy, design transfer, and project performance: A survey of automobile development projects in the US and Japan*," IEEE Transactions on Engineering Managemen*t, Vol. 42, No. 4, p. 397-409, 1995.

Nobeoka, K. and M. A. Cusumano, 1994, " Multiproject strategy and Market Share Growth: The benefits of Rapid Design Transfer in New Product Development," International Center for Research on the Management of Technology Working Paper # 105-94, 1994.

Pine, B. Joseph II, Bart Victor, and Andrew C. Boynton, 1993, "Making Mass Customization Work," *Harvard Business Revie*w, Sept/Oct 1993, Vol. 71, No. 5, p. 108-111.

Pine, J.B., 1993, "*Mass Customization: The New Frontier in Business Competition,"*. Boston: Harvard Business School Press, 1993.

Otto and Wood, 2001, *Product Design: Techniques in Reverse Engineering and New Product Development*, 2001, Prentice Hall

Robertson, D. and Ulrich, K., 1998, "Planning for Product Platforms," *Sloan Management R eview*1998; 39(4):19-31.

Sanderson, S. and Uzumeri, M. 1995, "Managing product families: The case of the Sony Walkman.," *Research Policy* 1995; 24(5):761-782.

Siddique, Z. and David W. Rosen, 2000, "Product Family Configuration Reasoning Using Discrete Design Spaces," *Proceedings of* DETC2000, DETC2000/DTM-14666, Baltimore, Maryland,

Siddique, Z. and Rosen, D. W. 1998 "On the Applicability of Product Variety Design Concepts to Automotive Platform Commonality," *Proceedings of DETC98,* DETC98/DTM-5661 Atlanta, GA.

Stone, R. and Wood, K., 2000 "Development of a Functional Basis for Design," *Journal of Mechanical Design* 122(4): 359-370.

Stone, R., Wood, K., and Crawford, R., 2000, "A Heuristic Method For Identifying Modules for Product Architectures," *Design Studies* 21(1): 5-31.

Sudjianto, A. and K. Otto, 2001. "Modularization To Support Multiple Brand Platforms," *Proceedings of DETC2001,* DETC2001/DTM-21695, Pittsburgh, PA,

Sundgren, Niklas. 1990, "Introducing interface management in new product family development," *Journal of Product Innovation Management.* V 16 n 1 Jan 1999. p 40-51

Ulrich, K . and Eppinger, S., *Product Design and Development*, 2000, Irwin McGraw-Hill.

Woolsey, J. P., 1994, "777," *Air Transport World*, 22-31, 1994.

Zamirowksi, E. J. and Otto, K. N. 1999 "Identifying Product Portfolio Architecture Modularity Using Function and Variety Heuristics," *Proceedings of DETC99*, DETC99/DTM-876 Las Vegas, NV, September 12-1