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## ASSESSING AND INCREASING PRODUCT AND FAMILY DIFFERENTIATION IN THE MARKET

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### ABSTRACT

To help guarantee profit and stability in today's global market, companies must focus on the differentiation of their products. Successfully differentiated products will attract customers, generate revenue and benefit the brand image, whereas a banal product can lose money and leave a bad impression in the market. Many large companies have recently lost significant market share in part due to poor product differentiation. This paper introduces four indices to assess this differentiation at two levels—family and market—based on product function and function attributes. At the family level, the Product Differentiation Index (PDI) assesses the differentiation between a product and other products in the rest of the family and also the differentiation within the family. At the market level, the Family Differentiation Index (FDI), Family Coverage Index (FCI), and Family Un-coverage Index (FUI) assess the differentiation, the coverage, and the un-coverage of a family with another, and/or with the rest of the market, respectively. These indices help designers and marketers evaluate the positioning of their products and support product family planning. A case study involving two competitive single-use camera families is presented.

**Keywords:** Product differentiation, market coverage, product family planning, product variety, function

### 1. INTRODUCTION

In today's global market, companies must make sure that their products are different from their competitors and from other products produced by the company. In fact, most markets are targeted by numerous products, and competition has become more and more difficult. Successfully differentiated products will attract customers, generate revenue and benefit the brand image, whereas a banal product can lose money and leave a bad impression in the market. In addition, the widespread use of product platform development accentuates this differentiation issue. Platform-based development enables products to share structures, modules, components, and/or

processes to increase market share and reduce the cost of development, but it can lead to similar products in the market.

There are different ways to differentiate a product: functionality, industrial design, cost, quality, etc. This study focuses on the differentiation of products considering functions and associated attributes. Two levels of abstraction are considered: (1) the product itself to make sure, for example, that the product platform does not generate "clones", and (2) to make sure that a given family has a good coverage (and low un-coverage) of the proposed function (same functionality) and a "*competitive advantage*" (different function). Thus, the proposed Product Differentiation Index (PDI) and Family Differentiation Index (FDI) enable designers and marketers to make sure products are correctly differentiated and, if necessary, to increase the differentiation within their own family as well as outside (competitors), compared to the rest of the competitor's products. The Family Coverage Index (FCI) enables designers and marketers to assess how their product family covers the market. The Family Un-coverage Index (FUI) assesses the missing functions of a family compared to another family or to the rest of the market. A case study based on two brands of single-use cameras is performed to demonstrate the model and confirm the interest of these indices. Afterwards, a method is proposed to increase the PDI, the FDI, and the FCI and reduce the FUI score for a product family.

Section 2 reviews related literature. The four indices are introduced in Section 3 and then applied to two single-use cameras (two families at the market level) in Section 4. Section 5 proposes a method to increase the differentiation of a product within its family and the market to improve the family coverage and the differentiation of families. Finally, Section 6 provides closing remarks for this study and future work.

### 2. RELATED RESEARCH

The economic framework proposed by Porter [1] is one of the most widely accepted business planning models. Porter argues that companies should at least pursue one of four strategies types: (1) cost leadership, (2) market differentiation, (3) innovation differentiation, or (4) market focus. A cost-based strategy can increase market share and profitability by lowering

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the cost of each service (development, production, marketing, etc.). Market differentiation can provide advantage to consumers compared to its competitors. An innovation differentiation strategy will build a strong brand image that is more recognizable than its competitors. The fourth strategy, market focus, encourages a company to target one niche in which they can become the technological leader.

In this paper, we focus on market differentiation, considering several factors: cost, aesthetics, features, functions, etc. Other studies have dealt with cost-based differentiation [2,3]. For the aesthetic aspect, Breemen, et al. [4] proposed a model to find a relationship between shape and aesthetic appreciation. Smyth and Wallace [5] worked on the brand DNA (key aesthetic of the brand) to maintain the brand identity during the design process. Sudjianto and Otto [6] proposed a framework to develop a modular product portfolio architecture in the context of a brand portfolio. Considering feature differentiation, Balakrishnan, et al. [7] introduced the role of variety in a “*multidimensional attribute space*”, identifying customer-desired attributes and engineering design attributes. Chakravarty [8] represented the product family as an aggregate benchmark for mapping customer-desired attributes to product features. He also proposed to assess the performance of several product “*features bundles*” and their performance “*frontier*” for each set of features. At the end of this process, only the “good” products were kept. This Darwinian approach is detailed in Chakravarty and Ghose [9] using a technique called Data Envelopment Analysis. They capture patterns of relationships between customer-desired attributes and features of products. The value of a generic product feature is a convex combination of the same features within the studied products.

To design a product platform or family, most of the proposed methods focus on platform leveraging (by segment level, by range level, and by both combined). Meyer and Lehnerd [10] propose using a market segmentation grid to help visualize range (performance-cost) and segments (customers positioning) for the ultimate purpose of designing a product platform or family. Another method proposed by Farrell and Simpson [11] identifies the potential of platform leveraging in a market based on historical sales data.

Another close field of research seeks to design optimal positioning strategies for targeting individual customers and/or market segments (known as the Product Line Selection Problem). This problem is known to be a NP-Hard problem [12]. Some theoretical frameworks have been published [13,14], but most of the literature is based on heuristics to find “good” solutions to introduce new products or to reposition existing product lines (considering cannibalization phenomena). Kohli and Sukumar [12] proposed a state-of-the-art method for three standard problems: (1) the *Share-of-choices* maximize the number of customers; (2) the *Buyer’s welfare* maximizes the total utility; and (3) the *Seller’s return* maximizes the seller’s total marginal profit. These optimal positioning strategies are based on benefit versus cost comparison. In this case, benefit is defined by a product’s

quality, or mostly by Conjoint Analysis (which finds the optimal attributes combination for each market segment) or an extension [15-19]. Finally, Kim and Chhajed [20] examined when modular products should be introduced and how much modularity to offer.

To our knowledge no study has dealt directly with the differentiation of functions and their attributes in engineering design. Therefore, the goal in the current study is to propose indices to assess differentiation within a product family based on functions and function attributes of a given brand. By extension, the coverage and differentiation of this family are assessed relative to the rest of the market.

### 3. DEFINITION OF INDICES

In this section, four new indices are introduced: Product Differentiation Index (PDI), Family Differentiation Index (FDI), Family Coverage Index (FCI), and Family Un-coverage Index (FUI). These indices can be utilized as decision-making tools for improving product family positioning in the market. They can be applied to an existing family of products or in the early product development stage.

#### 3.1. Product Differentiation Index

A product family is composed of several products. Each of these products has different functions that satisfy specific needs (e.g., *store image* for a single-use camera). These needs are detailed by function attributes. We call a *function attribute* a specific characteristic of a function, e.g., a function attribute of “*light scene*” is the “distance covered by the flash”, which can take different values depending on the product (4 meters for example). If a given function is present in a product, we say that this function has an *instance* in this product. A function may have instances in different products. When we compare two products based on function, two types of functions exist:

1. Unique function = a function that is covered by either one or the other product (a family by extension);
2. Shared function = a function that is covered by both products (family by extension).

Based on the *function attributes* the group of shared functions is divided into two sub-groups: the common functions (same function and same function attribute values) and the variant functions (same function but different function attribute values). This new index scores the difference of product *A* and product *B*. When both products share the functions, this index considers only the variant functions and not the common ones. In this case, the score computes the “distance” between the function attributes of the given function for product *A* and the function attribute of the same function for product *B*; this distance is then normalized by the maximum distance within the family for this function attribute. The Product Differentiation Index (PDI) is scored from 0 to 1, where 1 is a perfect differentiation of the two products. When the score is equal to 0, the two products are identical. The mathematical definition for this index is given in Section 3.5.1.

### 3.2. Family Differentiation Index

The Family Differentiation Index (FDI) is an extension of the PDI that scores the differentiation of a family  $F_a$  compared to a family  $F_b$ . Figure 1 shows two families  $F_a$  and  $F_b$  are present in a market  $\mathcal{M}$ . The crosses are the functions, and the associated numbers represent the number of instances in  $F_a$ , number of instances in  $F_b$ , and total number of instances in  $\mathcal{M}$ . All instances of all unique functions in family  $F_a$  are scored as an advantage (+). All instances of all unique functions in family  $F_b$  are scored as a disadvantage (-). The function attributes of the variant functions are also considered. For a given function, the distance between the function attribute values in  $F_a$  and  $F_b$  is computed, multiplied by the number of instances for this function, and normalized by the maximum distance for this function attribute within the market, making each distance relative to the market. The result is scored as an advantage if  $> 0$  (a disadvantage if  $< 0$ ). The overall score assesses the differentiation of a family compared to another family, a group of families, or the entire market.

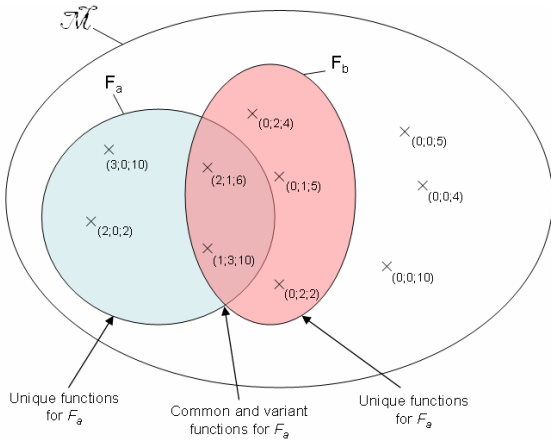


Figure 1. Differentiation of two families:  $F_a$  compared to  $F_b$

### 3.3. Family Coverage Index

Given two families,  $F_a$  and  $F_b$ , the Family Coverage Index (FCI) scores to what extent family  $F_a$  covers the functions offered by family  $F_b$ . Only shared functions (variant and common) are scored (+) for this index. Common functions are considered as perfect coverage. So each function is scored 1 and then normalized by the number of instances in the union of  $F_a$  and  $F_b$  for this function. For variant functions, FCI assesses what values of the function attribute of  $F_b$  are covered by  $F_a$ .

### 3.4. Family Un-coverage Index

The Family Un-coverage Index (FUI) is an extension of the FCI. This index takes into account the function(s) present in  $F_b$  that  $F_a$  does not cover and also scores the variant functions when the values of the function attribute are not covered by  $F_a$ . This index is scored from 0 to 1: 0 means that  $F_a$  covers all of

the functions from  $F_b$ , and 1 indicates that none of the  $F_b$  proposed functions are covered by  $F_a$ .

### 3.5. Mathematical Model

Let  $\mathcal{M}$  be a market composed of  $G$  families of products:  $\mathcal{M} = (F_1, \dots, F_G)$ . A family of products is the set of products offered by a company to customers. Each family  $F_i$  in the market is composed of  $N_i$  products:  $F_i = \{P_{i,1}, P_{i,2}, \dots, P_{i,N}\}$ . Now, every product performs one or more functions. A given function can be offered by several different products in the market; inversely, different products may not offer the same functions. Denote  $\mathcal{F} = \{f_1, f_2, \dots, f_F\}$  as the union of all of the functions achieved by all the products in the market. Figure 2 shows the overall set of functions in the entire market and the composition of two products  $A$  and  $B$  and their functions.

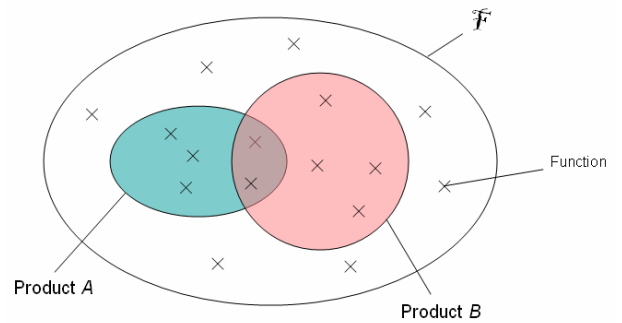


Figure 2. Set of functions (represented by crosses) in the entire market, and two products A and B

For each function  $f_k$  in  $\mathcal{F}$ , we denote  $g^k_{i,j}$  as its instance in the product  $P_{i,j}$ , with the agreement that  $g^k_{i,j} = NULL$  if the function  $f_k$  is not present in the product  $P_{i,j}$ . Now, each function can be qualified by a set of attributes. For example in the case of single-use cameras (see Table 3), the function “Store Image” can be qualified by three attributes: Color, Sensitivity, and Quality. We call these *function attributes*. Each function  $f_k$  in  $\mathcal{F}$  has  $D_k$  function attributes, denoted  $a^k_1, a^k_2, \dots, a^k_{D_k}$ . Furthermore,  $f_k$  having different instances across the products, each of its attributes  $a^k_l$  may take different values, depending on the instance of  $f_k$ . For example, the attribute Sensitivity of the function “Store Image” may take two values: 400ISO (value for one product) and 800ISO (value for another product). Finally, we denote  $v^k_l(i,j)$  as the value of attribute  $a^k_l$  for instance  $g^k_{i,j}$  of function  $f_k$  in product  $P_{i,j}$ .

#### 3.5.1 Product and Family Analysis

Given products belonging to the same family  $F_i$ , we want to be able to assess how “far apart” they are in terms of their functions. Let  $f_k$  be a function in  $\mathcal{F}$ . In the general case, this function has instances in a subset of products in the family  $F_i$ . Denote  $F_i(f_k)$  as this subset of these products. Now, let  $a^k_l$  be a function attribute of  $f_k$ . This attribute may take different values,

depending on the product in  $F_i(f_k)$ . We denote  $\overline{\Delta}_i(a_i^k)$  as the maximum distance between the values taken by the function attribute  $a_i^k$  over the subset  $F_i(f_k)$ :

$$\overline{\Delta}_i(a_i^k) = \max_{P_{i,j} \in F_i(f_k)} \{v_i^k(i, j)\} - \min_{P_{i,j} \in F_i(f_k)} \{v_i^k(i, j)\}$$

Note: non-quantitative function attributes, such as “quality” or “color”, need to be quantified. In this example, designers can specify a scale for the quality, for instance from “very low” to “very high”, corresponding to a scale from 0 to 1. When the function attribute values are purely qualitative (e.g., color: green, yellow, blue) designers may set an arbitrary value to  $\overline{\Delta}_i(a_i^k)$  and then state that all distances  $|v_i^k(i, a) - v_i^k(i, b)|$  are to be equal to  $\overline{\Delta}_i(a_i^k)$ ; in other words, all the “values” are equidistant.

Now, let  $P_{i,a}$  and  $P_{i,b}$  be two products in the same family  $F_i$ , sharing a function  $f_k$ . Let  $g_{i,a}^k$  and  $g_{i,b}^k$  be the respective instances of  $f_k$  on  $P_{i,a}$  and  $P_{i,b}$ . Although these products share the same function  $f_k$ , the function attributes of the latter may take a different value. Let  $a_i^k$  be a function attribute of  $f_k$ . Its respective values in  $g_{i,a}^k$  and  $g_{i,b}^k$  are  $v_i^k(i, a)$  and  $v_i^k(i, b)$ . We define an Attribute Distance Ratio by comparing the distance between  $v_i^k(i, a)$  and  $v_i^k(i, b)$  to the maximum distance over the family,  $\overline{\Delta}_i(a_i^k)$ :

$$\text{Attribute Distance Ratio } (a_i^k, P_{i,a}, P_{i,b}) = \frac{|v_i^k(i, a) - v_i^k(i, b)|}{\overline{\Delta}_i(a_i^k)}$$

Then, by taking the average of the Attribute Distance Ratios over all  $D_k$  function attributes of  $f_k$ , we obtain a Function Distance Ratio (*fdr*):

$$fdr(f_k, P_{i,a}, P_{i,b}) = \frac{1}{D_k} \sum_{l=1}^{D_k} \frac{|v_l^k(i, a) - v_l^k(i, b)|}{\overline{\Delta}_i(a_l^k)}$$

Note that  $0 \leq fdr(f_k, P_{i,a}, P_{i,b}) \leq 1$  and, by construction,  $fdr(f_k, P_{i,a}, P_{i,b}) = 0$  if and only if all the function attributes of  $f_k$  have the same values on  $P_{i,a}$  and  $P_{i,b}$ . Finally, if we sum the *fdr* of all the functions having instances on both  $P_{i,a}$  and  $P_{i,b}$ , we obtain a first partial “Product Differentiation Score”, which only takes into account the functions shared by the two products:

$$PDS_1(P_{i,a}, P_{i,b}) = \sum_{\substack{f_k \text{ having instances} \\ \text{on } P_{i,a} \text{ and } P_{i,b}}} fdr(f_k, P_{i,a}, P_{i,b})$$

Now, we have seen that two products do not necessarily share the same functions (see Figure 2 for illustration). We still have to include unique functions into the Product Differentiation Score. Given  $P_{i,a}$  and  $P_{i,b}$ , we denote  $\mathcal{F}_{i,a+b}$  as the set of functions in  $\mathcal{F}$  having instances in both  $P_{i,a}$  and  $P_{i,b}$ ,  $\mathcal{F}_{i,a|b}$  as the set of functions in  $\mathcal{F}$  having instances in  $P_{i,a}$  or  $P_{i,b}$  (exclusively), and  $|\mathcal{F}_{i,a|b}|$  as the number of elements in  $\mathcal{F}_{i,a|b}$ .

We now are able to define our second partial Product Differentiation Score by:

$$PDS_2(P_{i,a}, P_{i,b}) = \frac{|\mathcal{F}_{i,a|b}|}{|\mathcal{F}_{i,a|b}| + |\mathcal{F}_{i,a+b}|}$$

The global Product Differentiation Index is then defined by:

$$PDI(P_{i,a}, P_{i,b}) = \frac{PDS_1(P_{i,a}, P_{i,b}) + PDS_2(P_{i,a}, P_{i,b})}{|\mathcal{F}_{i,a|b}| + |\mathcal{F}_{i,a+b}|} \quad (1)$$

Note that  $0 \leq PDI(P_{i,a}, P_{i,b}) \leq 1$ , and that we have :

$PDI(P_{i,a}, P_{i,b}) = 0$  if and only if  $P_{i,a}$  and  $P_{i,b}$  share exactly the same functions and all the values of all function attributes are the same,

$PDI(P_{i,a}, P_{i,b}) = 1$  if and only if :

- There is no function shared by  $P_{i,a}$  and  $P_{i,b}$ ;
- Or for every function shared by  $P_{i,a}$  and  $P_{i,b}$ , all the attribute distance ratios of all function attributes are equal to 1.

The  $PDI(P_{i,a}, P_{i,b})$  is the basic index to score the differentiation of a couple of products in the same family. Given a product  $P_{i,a}$ , if we take the average of all the  $PDI(P_{i,a}, P_{i,b})$  for every  $P_{i,b}$  in the family, we obtain a Product Differentiation Score for  $P_{i,a}$  relative to the rest of the products within its family:

$$PDI_{F_i}(P_{i,a}) = \frac{1}{(N_i - 1)} \sum_{P_{i,b} \in F_i, b \neq a} PDI(P_{i,a}, P_{i,b}) \quad (2)$$

Lastly, it is also possible to assess the distribution of the Product Differentiation Scores within the family by taking the average of all the  $PDI(P_{i,a}, P_{i,b})$  in the product family  $F_i$ , which gives the overall Product Differentiation Index:

$$PDI(F_i) = \frac{2}{N_i(N_i - 1)} \sum_{j=1}^{N_i-1} \sum_{k=j+1}^{N_i} PDI(P_{i,j}, P_{i,k}) \quad (3)$$

Note in the previous equations, we assumed that all function weights are identical. This means that all functions and their attributes have the same importance in terms of differentiation. Knowing customers’ preferences, we could give different weights to different functions and to their attributes. The computation principle remains the same.

### 3.5.2 Market Analysis

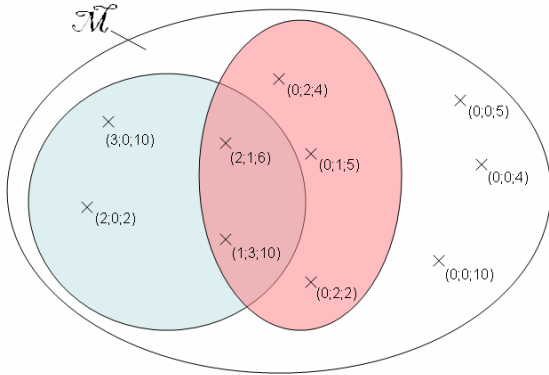
Recall that the market  $\mathcal{M}$  contains a set of  $G$  families of products:  $\mathcal{M} = (F_1, \dots, F_G)$ . The positioning of a family in the market can be characterized by three indices: the Family Differentiation Index (FDI), the Family Coverage Index (FCI) and the Family Un-coverage Index (FUI).

#### A – Family Differentiation Index

The FDI is an extension of the PDI to the entire market. Its aim is the following: given a family of products  $F_a$ , the FDI will score the differentiation between  $F_a$  and another family of products in terms of their functions. By extension, it can also be used to assess the differentiation between  $F_a$  and the rest of the families in the market. Let  $F_a$  and  $F_b$  be two families of products in  $\mathcal{M}$ , see Figure 3. This figure depicts two families  $F_a$  and  $F_b$ . To each function (cross), three values are used to

associate the number of instances in the family  $F_a$ , the number of instances in the family  $F_b$ , and the total number of instance in the market  $\mathcal{M}$ . For example, (2, 3, 10) means that  $F_a$  has this function twice in its product line,  $F_b$  3 times, and this function, occurs a total of 10 times in the market.

We denote  $\mathcal{F}_{F_a-F_b}$  ( $\mathcal{F}_{F_b-F_a}$ , respectively) the subset of functions having instances in  $F_a$  but not in  $F_b$  (in  $F_b$  but not in  $F_a$ , respectively).



**Figure 3. Two families  $F_a$  and  $F_b$  in the market  $\mathcal{M}$**

We denote  $\mathcal{F}_{F_a+F_b}$  as the subset of functions having instances in both  $F_a$  and  $F_b$ . Then, what differentiates  $F_a$  from  $F_b$  are:

- the functions in  $\mathcal{F}_{F_a-F_b}$ , taken as advantages of  $F_a$  on  $F_b$ ;
- the functions in  $\mathcal{F}_{F_b-F_a}$  taken as disadvantages of  $F_a$  on  $F_b$ ;
- the functions in  $\mathcal{F}_{F_a+F_b}$ , for which we have to descend to the function attribute level to assess the advantages / disadvantages.

For each function  $f_k$  in  $\mathcal{F}_{F_a-F_b}$  ( $\mathcal{F}_{F_b-F_a}$ , respectively), we denote  $p_k^{a-b}$  ( $p_k^{b-a}$ , respectively) as the number of instances of the function in the family and  $Q_k$  as the total number of instances of the function in the market. We then define our first differentiation scores as:

$$\text{Family Advantage Score } 1(F_a, F_b) = \sum_{f_k \in \mathcal{F}_{F_a-F_b}} \frac{p_k^{a-b}}{Q_k}, \text{ and}$$

$$\text{Family Disadvantage Score } 1(F_a, F_b) = - \sum_{f_k \in \mathcal{F}_{F_b-F_a}} \frac{p_k^{b-a}}{Q_k}$$

Now, let  $f_k$  be a function in  $\mathcal{F}_{F_a+F_b}$ . Since  $f_k$  is shared by both families, we have to look at its function attributes to determine what differentiates  $F_a$  from  $F_b$  for this function. Denote  $(a_i^k)_{k=1..D_k}$  as the function attributes of  $f_k$ . Let  $a_i^k$  be one of these. We denote  $\mathcal{V}_i^k = \{v_{i,1}^k, v_{i,2}^k, \dots, v_{i,K}^k\}$  as the set of all different possible values taken by  $a_i^k$  over the market ( $K$  normally depends on  $i$  and  $k$ , but for clarity reasons we omit additional indices). For each value  $v_{i,i}^k$ , we denote  $\alpha_{i,i}^k$  ( $\beta_{i,i}^k$ , respectively)

as the number of instances of  $f_k$  in  $F_a$  (in  $F_b$ , respectively) for which the value of  $a_i^k$  is  $v_{i,i}^k$ . The Attribute Scores are then defined as:

$$\text{Attribute Advantage Score } (f_k, a_i^k, F_a, F_b) = \sum_{\substack{i=1 \\ \alpha_{i,i}^k > \beta_{i,i}^k}}^K \frac{(\alpha_{i,i}^k - \beta_{i,i}^k) v_{i,i}^k}{v_{i,K}^k - v_{i,1}^k} \text{ and}$$

$$\text{Attribute Disadvantage Score } (f_k, a_i^k, F_a, F_b) = - \sum_{\substack{i=1 \\ \alpha_{i,i}^k < \beta_{i,i}^k}}^K \frac{(\beta_{i,i}^k - \alpha_{i,i}^k) v_{i,i}^k}{v_{i,K}^k - v_{i,1}^k}$$

With  $v_{i,K}^k - v_{i,1}^k$  being the max delta (in the market) of the possible values for this attribute. By summing over all the function attributes and overall functions in  $\mathcal{F}_{F_a+F_b}$ , we obtain the second differentiation scores:

$$\text{Family Advantage Score } 2(F_a, F_b) =$$

$$\frac{1}{|\mathcal{F}_{F_a+F_b}|} \sum_{f_k \in \mathcal{F}_{F_a+F_b}} \frac{1}{D_k} \sum_{k=1}^{D_k} \text{Attribute Advantage Score } (f_k, a_i^k, F_a, F_b)$$

$$\text{Family Disadvantage Score } (F_a, F_b) =$$

$$\frac{1}{|\mathcal{F}_{F_a+F_b}|} \sum_{f_k \in \mathcal{F}_{F_a+F_b}} \frac{1}{D_k} \sum_{k=1}^{D_k} \text{Attribute Disadvantage Score } (f_k, a_i^k, F_a, F_b)$$

The Family Differentiation Index is then the sum of the four previous scores (unique and shared functions):

$$FDI(F_a, F_b, \mathcal{M}) = \quad (4)$$

$$(\text{Family Advantage Score}_1 + \text{Family Advantage Score}_2) + (\text{Family Disadvantage Score}_1 + \text{Family Disadvantage Score}_2)$$

## B – Family Coverage Index

The Family Coverage Index focuses on how a family  $F_a$  covers the functions and function attributes offered by a group of other families (from a unique family to the rest of the market). For clarity reasons, we denote  $F_b$  as the set of other product families. We only consider the functions that have instances in both  $F_a$  and  $F_b$  (functions having instances in  $F_b$  but not in  $F_a$  will be taken into account by FUI). Let  $f_k$  be one of these functions, and denote  $a_i^k$  as one of its function attributes. Let  $\mathcal{V}_i^k = \{v_{i,1}^k, v_{i,2}^k, \dots, v_{i,K}^k\}$  be the set of all possible values taken by  $a_i^k$  over the union of  $F_a$  and  $F_b$ . Note that unlike what was done for the  $FDI$ ,  $\mathcal{V}_i^k$  does not necessarily represent the values taken over the whole market. For  $i=1..K$ , let  $\alpha_{i,i}^k$  ( $\beta_{i,i}^k$ , respectively) be the number of instances of  $f_k$  in  $F_a$  (in  $F_b$ , respectively) for which the value of  $a_i^k$  is  $v_{i,i}^k$ . The Attribute Coverage Score is defined as:

$$\text{Attribute Coverage Score } (f_k, a_i^k, F_a, F_b) = \frac{1}{K} \sum_{\substack{i=1 \\ \beta_{i,i}^k > 0}}^K \max\left(1, \frac{\alpha_{i,i}^k}{\beta_{i,i}^k}\right)$$

Note that we only consider positive  $\beta_{i,i}^k$ :  $\beta_{i,i}^k = 0$  means that the value  $v_{i,i}^k$  is not present in  $F_b$ , which is out of the scope of the coverage index (but taken into account in the computation of

the *FUI*). Summing over all function attributes and over all functions in  $\mathcal{F}_{F_a+F_b}$  gives the Family Coverage Index:

$$\text{Family Coverage Index} = \frac{1}{|\mathcal{F}_{F_a+F_b}|} \sum_{f_k \in \mathcal{F}_{F_a+F_b}} \frac{1}{D_k} \sum_{k=1}^{D_k} \text{Attribute Coverage Score} \quad (5)$$

### C – Family Un-coverage Index

Symmetrical to the FCI, the Family Un-coverage Index focuses on how a family  $F_a$  does not provide the functions and function attributes offered by the set of other product families (from a unique family to the rest of the market). For clarity reasons, we denote  $F_b$  as the set of other product families. Denote  $\mathcal{F}_{F_b-F_a}$  as the set of functions having instances in  $F_b$  but not in  $F_a$ . For each function  $f_k$  in  $\mathcal{F}_{F_b-F_a}$ , we denote  $p_k^{b-a}$  as the number of instances of the function. We denote  $N_{tot}^{a+b}$  as the total number of instances of all functions in the union of  $F_a$  and  $F_b$ . We then define the first un-coverage score by:

$$\text{Function Un-coverage Score 1} (F_a, F_b) = \frac{1}{N_{tot}^{a+b}} \sum_{f_k \in \mathcal{F}_{F_b-F_a}} p_k^{b-a}$$

Now, let  $f_k$  be a function having instances in both  $F_a$  and  $F_b$ . Let  $a_i^k$  be one its function attributes. Let  $\mathcal{V}_i^k = \{v_{i,1}^k, v_{i,2}^k, \dots, v_{i,K}^k\}$  be the set of all possible values taken by  $a_i^k$  over the union of  $F_a$  and  $F_b$ . For  $i=1..K$ , let  $\alpha_{i,i}^k$  ( $\beta_{i,i}^k$ , respectively) be the number of instances of  $f_k$  in  $F_a$  (in  $F_b$ , respectively) for which the value of  $a_i^k$  is  $v_{i,i}^k$ . The Attribute Un-coverage Score is defined as:

$$\text{Attribute Un-coverage Score} (f_k, a_i^k, F_a, F_b) = \frac{\sum_{i=1, a_i^k=0}^K \beta_{i,i}^k}{\sum_{i=1}^K (\alpha_{i,i}^k + \beta_{i,i}^k)}$$

Summing over all function attributes and over all functions in  $\mathcal{F}_{F_a+F_b}$  gives the second Family Un-coverage Score:

$$\text{Family Un-coverage Score 2} = \frac{1}{|F_a+F_b|} \sum_{f_k \in \mathcal{F}_{F_a+F_b}} \frac{1}{D_k} \sum_{k=1}^{D_k} \text{Attribute Un-coverage Score} (f_k, a_i^k, F_a, F_b)$$

The Family Un-coverage Index is the sum of the two un-coverage scores (unique and shared functions):

$$\text{FUI} = \frac{1}{2} \left( \frac{1}{N_{tot}^{a+b}} \sum_{f_k \in \mathcal{F}_{F_b-F_a}} p_k^{b-a} + \frac{1}{|\mathcal{F}_{F_a+F_b}|} \sum_{f_k \in \mathcal{F}_{F_a+F_b}} \frac{1}{D_k} \sum_{k=1}^{D_k} \text{Attribute Un-coverage Score} \right) \quad (6)$$

### 3.6. Example for the PDI

Table 1 provides an example of three products with a sample of three of their functions: *Store Image*, *Light Scene*, and *Protect against Environment*, and their respective function

attributes: Sensitivity: *ISO number*, *Distance of Flash*, and *Protection Index (PI) value*.

**Table 1. Example of a function in a family of products**

Functions	Function attribute		
	Camera 1	Camera 2	Camera 3
Store Image	400ISO	800ISO	100ISO
Light Scene	4 meters	4 meters	4 meters
Protect Against Environment	50 PI	200 PI	50 PI

These three cameras have the same *Store Image* function, only their function attribute is different; so, the functional differentiation is across this family, but its function attribute is not (different for all cameras: 400, 800, and 100) and is computed regarding the biggest gap within the family (here 800-100 = 700). Thus, the gap between each camera function attribute is normalized against this biggest gap. Thus, the PDI for each pair of products is (Camera 1, Camera 2) = (800ISO-400ISO)/700 = 0.57, (Camera 2, Camera 3) = (800ISO-100ISO)/700 = 1, finally (Camera 3, Camera 1) = (400ISO-100ISO)/700 = 0.43. The function *Light Scene* has the same function attribute for all three products; hence, the resulting PDI is equal to 0. For the function *Protection against Environment*, the function attribute for products 1 and 3 are the same, and the differentiation between these two products and product 2 is 1 (max gap of the function attribute = 150). Afterward, all of the scores of each product are normalized to obtain the final score for each camera for all functions. Table 2 gives the PDI score for this example. In this case it is easy to differentiate the products because this family is very small (three products); the problem is more complex when the family becomes bigger as we show in the example in the next section.

**Table 2. PDI results for the Kodak camera example**

Camera	PDI Score
Camera 1	0.29
Camera 2	0.55
Camera 3	0.40

## 4. CASE STUDY

This case study is based on single-use cameras from two competitive brands: Kodak® and Fuji®. Ten Kodak® cameras (see Figure 4) and 12 Fuji® cameras (see Figure 5) were studied on two levels of abstraction with the PDI, FDI, FCI, and FUI.



Figure 4. Kodak® single-use camera family (official website 12/22/2005), from the left to the right: Zoom, ADVANTIX Switchable, Black & White, Fun Saver 35 Flash, Max High Definition, Max HQ Maximum Versatility, Max Outdoor, Plus Digital, Max Power, Water & sport

The functional decomposition for a single-use camera is given in Figure 6. All the cameras were dissected, and an example of a functional decomposition is presented in Table 3. This table gathers all the functions of all the products and their associated main function attributes. Notice that some functions

have several function attributes (e.g., Store Image: Color, ISO number, quality) while others have only one (e.g., Condition Image: size of the film).



Figure 5. Fuji® single-use camera family–QuickSnap®– (official website 12/22/2005), from the left to the right: True Definition, Smart Flash, Colors, Flash 800 X-TRA, Flash 400, Outdoor, Trial Outdoor, Waterproof 800, Trial Flash, Wedding Pack, Picture America, Camo 800

Some information was not available such as the distance of the flash (not provided by Kodak® and provide only for some cameras for Fuji®); so, this information was not considered for this study.

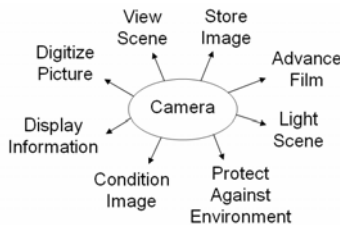


Figure 6. Functional decomposition of a single-use camera

#### 4.1. Kodak® Single-Use Camera Family

The Kodak® family is composed of 10 single-use cameras and 8 different functions: View Scene, Store Image, Advance Film, Light Scene, Protect against Environment, Condition Image, Display Information, and Digitize Picture.

Table 3. Example of functions and function attribute

Function	Display Information	Condition Image	Protect against Environment	View Scene	Light Scene	Store Image	Advance film
Function attributes	Light	35mm	Protection Index	Focal length	meter	Color 800 Quality	Manual

The family is scored using Eq. 2. As an example, Table 5 provides the PDI Score for the Kodak® family for the function “Store Image”. These scores are then normalized to get the PDI score for each camera. The most differentiated cameras are the “Advantix” and “Water & Sport”. Table 4 lists the PDI score for all the cameras normalized by the studied functions. We assume that a family is significantly different when it has at least a score of 1 for one of its functions. In other words, if the product has a perfect differentiation for one of the functions:

- Unique function, and
- Extreme function attribute (min or max).

So, the Kodak Camera are significantly different.

Table 4. PDI score for Kodak® for “Store Image” function

	Zoom	Advantix	B&W	Fun Flash	HD	HQ	Outdoor	+Dig.	Mx. P	W&S
Zoom	0.75	0.75	0.25	0.75	0.5	0.5	0.25	0	0	0
Advantix			0.5	0.5	1	1	0.5	0.75	0.75	0.75
B&W				0.5	1	1	0.5	0.75	0.75	0.75
FunFlash					0.5	0.5	0	0.25	0.25	0.25
HD						1	0.5	0.75	0.75	0.75
HQ							0.75	0.5	0.5	0.5
Outdoor								0.25	0.25	0.25
+Digital									0	0
Max P										0
W & S										
TOTAL	0.28	0.72	0.72	0.28	0.28	0.39	0.28	0.28	0.28	0.28

Table 5. PDI results for each Kodak® camera

Camera	PDI Score
Zoom	0.24
ADVANTIX Switchable	0.40
Black & White	0.20
Fun Saver 35 Flash	0.14
Max High Definition	0.14
Max HQ Maximum Versatility	0.16
Max Outdoor	0.22
Plus Digital	0.25
Max Power	0.14
Water & sport	0.33

#### 4.2. Fuji® Single-Use Camera Family

The Fuji® family is composed of 12 single-use cameras and 7 functions: View Scene, Store Image, Advance Film, Light Scene, Protect against Environment, Condition Image, and Display Information. The family is scored using Eq. 2, and the results are listed in Table 6.

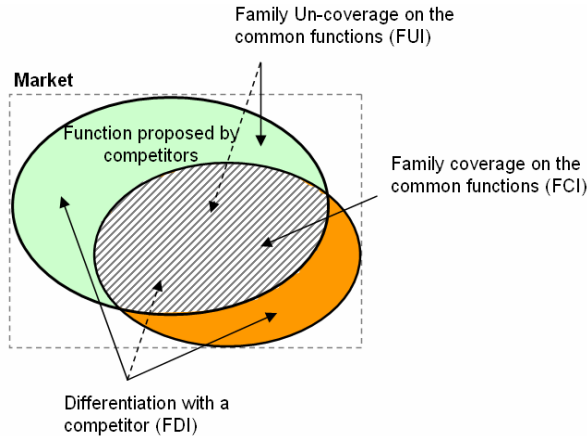
Table 6. PDI results for Fuji cameras

Camera	PDI Score
QuickSnap True Definition	0.05
QuickSnap Smart Flash	0.02
QuickSnap Colors	0.02
QuickSnap Flash 800 X-TRA	0.02
QuickSnap Flash 400	0.05
QuickSnap Outdoor	0.12
QuickSnap Trial Outdoor	0.14
QuickSnap Waterproof 800	0.24
QuickSnap Trial Flash	0.05
QuickSnap Wedding Pack	0.04
QuickSnap Picture America	0.02
QuickSnap Camo 800	0.02

This table highlights an important functional commonality between the Fuji cameras. While some cameras are significantly different such as the QuickSnap Outdoor, QuickSnap Trial Outdoor (mainly because of the lack of flash), and the QuickSnap Waterproof 800 (because of the film and the index of protection), the others are very similar. 4.3. Market Analysis

At the family level, companies want to sell adequately differentiated products to avoid competition within the company’s own offerings (i.e., cannibalization). At the market level, companies are looking for two things: (1) to offer the same functionalities as the competitors and (2) to differentiate

its products from competitors by adding new functionalities. These aspects are illustrated in Figure 7.



**Figure 7. FDI, FCI, and FUI representation at the market level**

All functions were gathered via the World Wide Web. eCameraFilms<sup>®</sup> was added as a competitor since it offers customizable stickers and message cameras (messages appear on pictures themselves). All the market functions and their related function attributes are listed in Table 7. Common functions and function attribute coverage are obtained by normalizing the studied brands and the market information. FDI, FCI, and FUI are obtained using Eqs. 4, 5, and 6, respectively. Fuji<sup>®</sup> and Kodak<sup>®</sup> families are scored compared to the market (see Table 8). Kodak<sup>®</sup> has an exclusive function (+ Digital) from the two other families; and the two other families have two exclusive functions (advantage: 1 function under 24 = 0.042; disadvantage: 2 functions under 24 = -0.083). Three variant functions (condition image, view scene, and store image) have exclusive attribute: respectively, panoramic-zoom / under 3; panoramic-zoom / under 3; Black&White-Highquality / under 4 → advantage:  $(2/3+2/3+2/4)$  / number of functions (10) = 0.183; disadvantage = 0. Thus, the FDI =  $0.042-0.083+0.183+0 = 0.14$ . The Kodak FCI is equal 67%, and the FUI is equal to 0.7%. For Fuji, FDI is equal to -0.51, its FCI is equal to 53%, and its FUI is equal to 36%. The eCameraFilms' FDI is equal to 0.71, its FCI is equal to 0% (no shared function), and its FUI is equal to 100%.

**Table 7. Sample of the single-use camera market**

Cameras	Function	Function attributes
Kodak <sup>®</sup>	Protection Against Environment	50, 200
	Display Information	Light
	Condition Image	35mm, panoramic, zoom
	View Scene	Infinite, zoom, panoramic
	Store Image	Color, black & white, HD quality, HQ quality
	Advance Film	Manual
	Light Scene	Natural, flash
Fuji <sup>®</sup>	Digital Picture (CD)	True
	Protection Against Environment	50, 200
	Display Information	Light

Condition Image	35mm	
View Scene	Infinite	
Store Image	Color, high quality	
Advance Film	Manual	
Light Scene	Natural, flash	
eCameraFilms <sup>®</sup>	Customization	Stickers-message camera
	Messages	Messages on pictures

**Table 8. Market analysis results (FDI, FCI, and FUI) for Fuji and Kodak compared to (eCameraFilms-Fuji-Kodak)**

Family	FDI	FCI	FUI
Kodak <sup>®</sup> compares to Fuji + eCameraFilms			
Fuji <sup>®</sup> compares to Kodak+ eCameraFilms	-0.51	53%	36%
eCameraFilms <sup>®</sup> compares to Kodak+ Fuji	-0.71	0%	100%

Overall, Kodak's market coverage and differentiation is better than Fuji's and eCameraFilms. This can be easily explained: there is an important gap between both brands in terms of product offerings. Fuji (as of 12/22/2005) did not offer significantly different products like Kodak, such as the "Black and White", "Advantix", "Zoom", or "plus Digital" versions.

## 5. INCREASING DIFFERENTIATION, COVERAGE, AND REDUCING UN-COVERAGE

Increasing the Family Differentiation Index means:

- 1) Add new functions or modifying an existing function or its function attributes to make a given product different from the rest of the products in the family and/or market.
- 2) Eliminate products to find an optimal subset of products drawn from the original set of products [21].

In this study the choice is made to add functions or modify current ones to differentiate similar products. Thus, Figure 8 is proposed to help designers find the right market positioning to improve the cameras. The circle represents function and the associated line models the function attribute range. For instance, the function *Light Scene* is represented by the circle "LS" and has two possible values "No flash" and "Flash". In this example, all the functions for this market have been gathered along with the range of their function attributes. Each circle represents a function and its related spectrum of function attributes, e.g., the function *Protection Index* has one function attribute ranging from 50 to 200, and the function *Store Image* has three function attributes (*Color, ISO, Quality*).

To increase the FDI score of a product, the idea is to give this graphic representation to designers as a design tool. This tool can be related to the computational model and directly output the PDI, FDI, and FCI scores when there is a modification in the function or its attribute(s). This tool can help in product positioning and family planning. Designers can position the studied product (or family) in this visual representation, modify its characteristics, and directly get the result of the three proposed indices. The functions and/or their function attributes can also be weighted based on customer preferences. There are several advantages to this approach:

- 1) Assist designers in repositioning products based on the common and unique functions considering the existing family/market;
- 2) Help designers to find extensions and to differentiate a product with a clear picture of all the functions and the range of their attributes; and
- 3) Eliminate the product when there is too much similarity even after increasing the PDI.

As an example, three existing single-use cameras of Fuji were improved: “QuickSnap Smart Flash”, “Color”, and “QuickSnap Flash 800 X-TRA”. These three cameras had a PDI score equal to 0.02. The graphic representation highlights that the function *Digital Support*, *Customize Camera*, and *Messages* were not offered.

**Digital Support:** Considering the function *Digital Support*, designers can choose to:

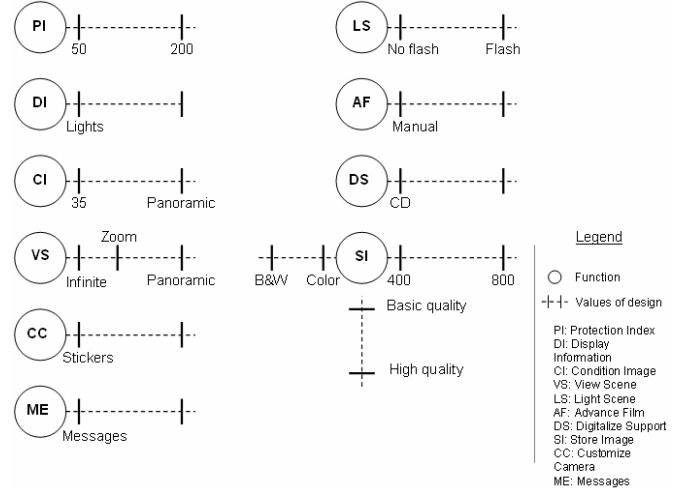
- Propose the same service as Kodak,
- Propose a service using a CD and online (i.e., download your digital picture online).

The second choice increases the market coverage to the same value as Kodak and increases market differentiation with a new service (get pictures online).

**Customize Camera:** Designers can choose to integrate this function into one of the three cameras to differentiate it within the family and increase market coverage compared to Kodak.

**Messages:** Designers can add this function to one of the cameras for the same reasons: to increase market differentiation and the market coverage (offered by eCameraFilms).

The function *Digital Support* can be added to the QuickSnap Flash 800 X-TRA camera, the function *Customize Camera* can be included with Color camera, and the function *Messages* can be integrated into the QuickSnap Smart Flash camera. The new PDI results for each camera are given in Table 9. Note that the PDI increased by 0.16 for the QuickSnap Smart and Color and by 0.28 for the QuickSnap Flash 800 X-TRA. These cameras are now more significantly differentiated. These results illustrate the usefulness of the PDI by highlighting similar functions or function attribute values.



**Figure 8. Graphic showing all of the functions of the market and the range for their related function attributes**

**Table 9. PDI for the studied cameras**

Cameras	PDI		
	Before	After	%
QuickSnap Smart Flash	0.02	0.18	800
Color	0.02	0.18	800
QuickSnap Flash 800 X-TRA	0.02	0.30	1400

The results for the whole family are presented in Table 10. The FDI is increased from -0.51 to -0.05 (still handled by functions: condition image (panoramic, Zoom); view scene (Panoramic, Zoom); and store image (black & white, High Quality). The FCI is improved from 53% to 68%; finally, FUI is decreased from 36% to 35%.

Table 10 highlights another interesting outcome of this method, namely, identifying the unmet functions in the market and clarifying the relationship between competitor’s products.

**Table 10. Results after improvement for the Fuji® family**

Family	FDI	FCI	FUI
Before	- 0.51	53%	36%
After	-0.05	68%	35%

## 6. CLOSING REMARKS

The Product Differentiation Index (PDI) has been introduced to assess the functional differentiation of products within the same family. At the market level, the Family Differentiation Index (FDI), the Family Coverage Index (FCI), and the Family Un-coverage Index (FUI) for the market have been introduced. The process and mathematical model based on this functional differentiation assessment (i.e., functions and function attribute values) have been detailed. The goal of the PDI and FDI is to assess if products are different from others in the same family and within the market. The results from the four indices and the proposed graphic representation help designers identify new functions or new function attributes. In effect, by plotting the different products using the graphic representation, designers can directly manage the enhancement of the market coverage and differentiation of their products.

A case study involving single-use cameras demonstrates these new indices and the graphical method. An improvement of the current family based on the result and a new graphic representation has been performed. In short and mean terms future work will integrate a broader family and market differentiation index by extending the PDI and the FDI, adding aesthetic aspects to assess the differentiation of the family and market. Future work will include the weight of the function (based on customer needs) and their cost, but this aspect is not enough to propose a complete functional decision-making tool, and a long-term goal is to integrate the functional definition of the product family to specify the products in the family to maximize the functional value (contribution) of each product.

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