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NEW PRODUCT DEVELOPMENT CONSIDERING PRODUCT CANNIBALIZATION, DEVELOPMENT COST AND PRODUCTION COST

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Abstract This paper explores a situation in which a firm wants to add a new product to its existing product line in order to maximize its profit. A new product contains a group of attributes, and thus its development can be viewed as a configuration of attribute levels. Different attribute levels contribute to product variety and reduce cannibalization by product similarities. On the other hand, large variations in attribute levels often increase development cost and process variation cost. Thus, the impact of product cannibalization, development cost and production cost on new products should be evaluated. We formulate this selection of attribute levels as a nonlinear optimization problem. A heuristic is proposed to solve the problem efficiently, and managerial implications are provided.

Keywords: Decision making, new product selection, product planning, cannibalization, process variation cost

1. Introduction

Customer demands these days are increasingly diverse and ever-changing. Firms must develop a wide variety of new products in a speedy manner to satisfy customer needs. If a new product contains features, functions and attributes similar to existing products, customers will switch from old products to new products and demands for existing products will decrease. Kim and Chhajed [6] defined this phenomenon as product cannibalization due to product similarity as different products satisfy customer needs in a similar way. To reduce cannibalization, firms should develop new products with features different from current products.

The drawback of diverse products is that great efforts may be required in R&D, thus incurring high development cost. New product development is often costly and many resources are required. A new product also increases production cost. Low production cost is often achieved by mass production supported by standardized processes. Firms can save a lot of money by reusing these processes. On the contrary, if changes in product design take place frequently, process variation cost can be very high.

Therefore, firms must develop diverse products to satisfy different customer needs and meanwhile control development and production costs for new products. This paper explores the selection of suitable attributes when developing new products by saving development efforts, reducing production variation and alleviating product cannibalization so that firms can maximize their profits.

The rest of the paper is organized as follows. Section 2 provides the literature review. Section 3 defines product and demand space, and profit and cost functions. Section 4 presents the new product selection problem and provides a solution heuristic. Section 5 tests the methodology in a real-world scenario and provides managerial implications. Finally, we summarize the findings and suggest future research directions in Section 6.

2. Literature Review

First, we review the literature on new product selection. Researchers have investigated new product selection taking cannibalization into account. Academic attention has long been paid to cannibalization. Mason and Milne [8] defined cannibalization from an ecological perspective as a proportion of a product's sales drawn from products carrying the same brand, and offered a framework for identifying cannibalization among product variants. Moorthy and Png [9] considered the profit of a seller who deals with two customer segments with different valuations of product quality, namely high and low. Dobson and Kalish [3] presented heuristics for product-line pricing and positioning, and considered the fixed and variable costs of products and cannibalization effects. Kim and Chhajed [6] investigated cannibalization associated with modular product design differentiated through levels of quality. Morgan, Kouvelis and Daniels [10] explored how product selection through a product family can maximize profits of a firm. Ramadas and Sawhney [15] studied product line extension where components are shared with existing products and revenue interactions because of cannibalization. Fruchter, Fligler and Winer [4] studied product brand selection and pricing to maximize manufacturers' profits with cannibalization between products taken into account, but assumed that manufacturing cost for product brands is a constant for any product configuration. Although the above papers study cannibalization between products, none of them have made an attempt to deal with attribute selection and attribute configuration in a product.

On the other hand, some researchers have studied attribute selection and attribute configuration but ignored cannibalization among products. Green and Krieger [5] gave a literature review on optimal product design and market segmentation models, and focused on marketing segmentation and customer choices without considering product cannibalization, process variation cost and product variation values. Raman and Chhajed [13] presented a model for product line design and process selection with the active level of each product attribute specified and the product price determined in order to maximize incremental profits for manufacturers.

In the following paragraphs, we will review the literature on product variety and process variation cost. The difference between new products and existing products often requires investment in new product development, as well as changes in current production processes, thus entailing process variation cost. The variation in products is called product variety. Ramdas [14] summarized the research on variety management. Carchiolo et al. [2] introduced a model to re-design the process for new products. Sharma and Gao [17] used manufacturing analysis to support the re-design of machining processes whenever a product is changed. Pattanaik et al. [12] developed a similarity measure among machines based on production flow information and auxiliary module requirements.

To reduce product variety cost, different approaches have been proposed. First, reusing current production processes can reduce the required resources, cost and effort, and improve the management and quality of processes. Ryu et al. [16] studied the reuse of past schedules using case-based reasoning (CBR). Second, modularity is also a method to reduce process variation cost. Cameron [1] argued that modularity is a prerequisite for reuse and configurability. Third, a product platform (components and subsystem assets shared across a family of products) can potentially reduce the fixed cost of developing individual product variants by reusing the product architecture, components and subsystems. The platform can also reduce the unit variable cost of products. Simpson [18] gave a comprehensive review of researches to facilitate product family design and platform-based product development. Karishan and Gupta [7] built a mathematical model to illustrate some of the costs and benefits of platform-based product development. The product variety in their research refers to performance levels (quality) of a product. In this paper, we propose using the same attributes of existing products to reduce product variety and production cost. Here, product variety refers to variation in attribute values.

To summarize, there is much in relevant literature about new product selection with attribute selection, process variation cost and product cannibalization. While practitioners recognize the interaction among these factors, none of the research works has dealt with these factors simultaneously when it comes to new product selection. To fill this void in the literature, we select attribute values to configure a new product, taking into account cannibalization, development cost and process variation cost in order to maximize profits. This study also solves a practical problem in new product development, and provides useful and simple guidelines for practitioners.

3. Definition of Variables and Functions

We begin this section by describing the setting of our problem. In the following scenario, a monopolistic firm has a product variant and wants to develop a new product variant to increase its profit. The two product variants provide similar functions for customers. Thus, their product structures, parts/components and operation mechanisms are similar to each other. Nevertheless, they differ in some of their attributes.

In this study, a product is represented by a set of attributes and each attribute has a different number of levels. The new product selection problem can be viewed as a configuration problem of attribute levels. This section is organized as follows. The concept of attribute level is introduced in Section 3.1. To calculate the profit of the firm, Section 3.2 provides the calculation of product demand, and Section 3.3 discusses the cost of the firm. Then, in Section 3.4, the profit function and a summary of the notations are presented.

3.1. Attribute levels

A product is represented by a set of attributes and each attribute has a different number of levels. K is the total number of the attributes and attribute has y_k levels. Let A denote the set of all the attribute levels, $A = \{(k, l) : k = 1, ..., K, \ell = 1, ..., y_k\}$. For example, in the case in Section 5, the product (toilet paper) has five attributes: the size, the number of layers, the number of rolls in a package, the package design pattern and the weight of a roll. In the attribute of the weight of a roll, there are six attribute levels: 110g, 125g, 135g, l40g, 180g and 1350g. If the weight of a roll of a toilet paper is 110g, it means the attribute level of this product variant in the attribute is 110g.

A new product selection can be viewed as a configuration of attribute levels. Suppose Product 1 already exists. The firm wants to select a new product (Product 2) to maximize its profit. To do this, the firm develops the attribute levels of Product 2 different from those of Product 1.

Then each attribute level is produced by certain production processes. The processes producing different attribute levels of the same attribute may be similar but not exactly the same. The difference in the processes is called process variation. Thus, different attribute levels of Product 2 incur two types of costs: development cost and process variation cost.

Let $\alpha_{k,l}$, $(k, l) \in A$, denote the cost for process variation to generate attribute level (k, l), if it is different from the attribute level of attribute k of Product 1. In the example of toilet paper, the process variation cost for different weight of a roll is machine set up cost. Let $\beta_{k,l}, (k, l) \in A$, denote the development cost for attribute level (k, l), if it is different from the attribute level of attribute k of Product 1. In the example of toilet paper, the development cost for different package design pattern is the design fee. Let $\omega_{k,l}, (k, l) \in A$, denote the contribution to product variety by attribute level (k, l), if it is different from the attribute level of attribute k of Product 1. Let $B_{k,l}$, $(k, l) \in A$, be a variable indicating whether attribute level (k, l) is selected, if attribute level (k, l) is selected in Product 2, $B_{k,l} = 1$; otherwise, $B_{k,l} = 0$. Let j be the product variety of Product 2 from Product 1. It is defined as the sum of the varieties contributed by the attribute levels in Product 2.

$$j = \sum_{(k,l)\in A} \omega_{k,l} B_{k,l}. \tag{3.1}$$

3.2. Cannibalization and product demand

The demand of a product is influenced by its price and its variety from other products. This is illustrated by Figure 1. Two products are positioned in a product demand space, where each point denotes a customer type. The customer types are evenly distributed. Each customer type prefers a specific product variant. The reservation price is the amount a customer is willing to pay for a product. Let customer (b, q) denote the customer type who prefers the product variant with product variety b and his reservation price for this product variant is q. The maximum reservation price of any customer is Q^+. A customer will buy a product as long as the customer's surplus towards this product is positive. The surplus of a customer reflects the difference among the customer's reservation price towards a product, the price of the product and the extent to which the customer dislikes the product. The demand curve of a product consists of customer points with zero surplus towards a product. Figure 1 shows the demand curves for Product 1 and Product 2. The customer types above the demand curve will purchase the product since their surpluses are positive, indicated by the shaded area. If the variety between the two products is not large, there will be cannibalization in the demand of the two products. The cannibalization area is an overlap of the two shaded areas.

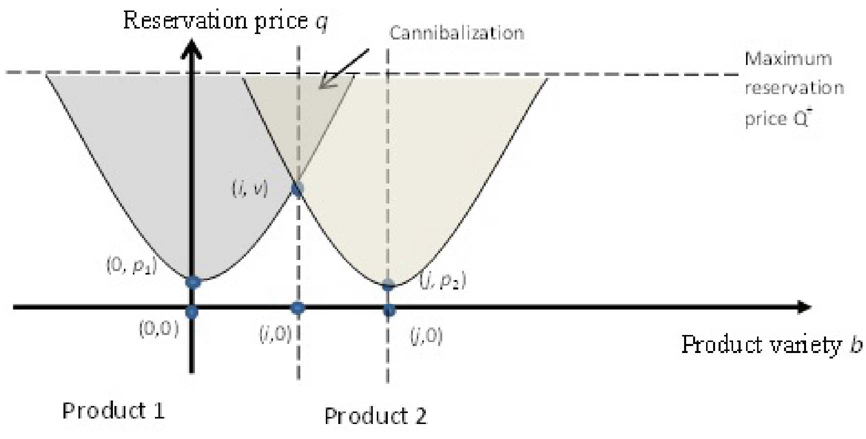

Figure 1: Demand spaces of two products

Product 1 is plotted in the origin of the x axis. Product 2 is plotted with j of the x axis, implying the variety between Product 1 and Product 2 is j. Define $e(b-j)$ as the disutility function for customer (b, q) of Product 2 with product variety j, $0 < q \leq Q^+$. $e(b-j)$ is a finite function with $e(0) = 0$ and $e(x) > 0$ for $x \neq 0$. Define $e^{-1}(y)$ as the inverse function when the disutility is y. The disutility function reflects the extent to which a customer dislikes a product. The customer surplus reflects the difference among the customer's reservation price towards a product, the price of the product and the extent to which the customer dislikes the product. The customer surplus of customer (b, q) towards Product 2 is defined as:

$$S(b, q, j, p_2) = (q - p_2) - e(b - j). \tag{3.2}$$

The first term is the difference between the reservation price of customer (b, q) towards Product 2 and Product 2's price, and the second term is the disutility function of customer (b, q) towards Product 2. When p_2 or the disutility is too high, the surplus will be negative and the customer will not purchase Product 2. Similarly, the customer surplus of customer (b, q) towards Product 1 is defined as:

$$S(b, q, 0, p_1) = (q - p_1) - e(b). \tag{3.3}$$

Point (i, v) is the coordinate of the point of intersection of demand curves of Product 1 and Product 2. At this point, the surpluses of the two products should be equal, and thus we have:

$$S(i, v, j, p_2) = S(i, v, 0, p_1). \tag{3.4}$$

Hence,

$$(v - p_2) - e(i - j) = (v - p_1) - e(i - 0). \tag{3.5}$$

Then we have:

$$(p_1 - p_2) - e(i - j) + e(i) = 0. \tag{3.6}$$

If Product 1 is the only product offered by the firm and its price is p_1, the original annual demand is given by the following customer set:

$$D_1^0(p_1) = \{(b, q) : S(b, q, 0, p_1) > 0\}. \tag{3.7}$$

If Product 2 is the only product offered by the firm and its price is p_2, the original annual demand is given by the following customer set:

$$D_2^0(p_2) = \{(b, q) : S(b, q, 0, p_2) > 0\}. \tag{3.8}$$

If both Product 1 and Product 2 are available in the market and the variety j is not large enough, cannibalization occurs. Due to cannibalization, the demand of both products will be reduced. The cannibalization area is an overlap of the two shaded areas in Figure 1. We define $C^+(p_1, p_2, j)$ as the demand for Product 1 reduced by cannibalization on the right of the overlapped area; define $C^-(p_1, p_2, j)$ as the demand for Product 2 reduced by cannibalization on the left of the overlapped area. They are functions of p_1, p_2 and j. Due to cannibalization demand for both products will be reduced. The annual demand for Product 1 is reduced to this set:

$$\{(b, q) : S(b, q, 0, p_1) > 0 \textit{ and } b < i\} = D_1^0(p_1) - C^+(p_1, p_2, j). \tag{3.9}$$

The annual demand for Product 2 is reduced to this set:

$$\{(b, q) : S(b, q, 0, p_2) > 0 \textit{ and } b \geq i\} = D_2^0(p_2) - C^-(p_1, p_2, j). \tag{3.10}$$

3.3. Development cost and variable production cost

Next, we analyse development cost and production cost. Since Product 1 already exists, its development cost has been invested and is ignored in decision-making. The development cost of Product 2 is denoted as $R_2(j)$, defined as the sum of development cost of different attribute levels in Product 2.

$$R_2(j) = \sum_{(k,l)\in A} \beta_{k,l} B_{k,l}. \tag{3.11}$$

The cost will increase with j. The variable production cost of product 2 is $M_2(j)$, defined as the sum of the process variation cost of different attribute levels and the original process cost of Product 1, M_1.

$$M_2(j) = \sum_{(k,l)\in A} \alpha_{k,l} B_{k,l} + M_1. \tag{3.12}$$

The cost will also increase with j, reflecting the fact that higher product variety will incur larger process variation and hence higher variable production cost.

3.4. Profits

The total profits of Product 1 and Product 2 are given by the following function:

$$\begin{aligned} \pi =& [D_1^0(p_1) - C^+(p_1,p_2,j)](p_1 - M_1)n_1 \\ &+ [D_2^0(p_2) - C^-(p_1,p_2,j)][p_2 - \sum_{(k,l)\in A} \alpha_{k,l} B_{k,l}]n_2 - \sum_{(k,l)\in A} \beta_{k,l} B_{k,l}. \end{aligned} \tag{3.13}$$

The profit is referred to as the total profit when the firm adds Product 2 when Product 1 already exists. In (3.13), the first term is the profit of Product 1, and the second term is the profit of Product 2. Both profits equal the annual demand multiplied by the unit profit and the expected life cycle. The third term is the development cost of Product 2. Function (3.13) can be used to compare the profit of different new product candidates.

The notations used in this paper are summarized below:

Parameters:

$c_{k,l}$: a value associated with each attribute level (k,l), $c_{k,l} = D_2\alpha_{k,l} + \beta_{k,l}$, $(k,l) \in A$
d: the density of each customer type in product demand space
D_2: the total demand for Product 2 if p_2 is known and there is no cannibalization
M_1: the variable production cost of Product 1
n_1: the expected life cycle of Product 1
n_2: the expected life cycle of Product 2
Q^+: the maximum reservation price for customers of any product
$\alpha_{k,l}$: the cost for process variation to generate attribute level (k,l), $(k,l) \in A$
$\beta_{k,l}$: the development cost for attribute level (k,l), $(k,l) \in A$
$\omega_{k,l}$: the contribution to product variety by attribute level (k,l), $(k,l) \in A$
Ω: the value of $\sum_{(k,l)\in A} \omega_{k,l} - [e_1^{-1}(Q^+ - p_1) + e_2^{-1}(Q^+ - p_2)]$

Variables:

$C^+(p_1,p_2,j)$: the cannibalization in demand for Product 1
$C^-(p_1,p_2,j)$: the cannibalization in demand for Product 2

$B_{k,l}$: if attribute level (k, l) is selected in Product 2, $B_{k,l} = 1$, otherwise $B_{k,l} = 0$, $(k, l) \in A$

$\bar{B}_{k,l}$: the dual of variable $B_{k,l}$, $\bar{B}_{k,l} = 1 - B_{k,l}$, $(k, l) \in A$

$D_1^0(p_1)$: the annual demand for Product 1 with price p_1 when Product 1 is the only product offered by the firm

$D_2^0(p_2)$: the annual demand for Product 2 with price p_2 when Product 2 is the only product offered by the firm

j: the product variety of Product 2 from Product 1

p_1: the price of Product 1

p_2: the price of Product 2

$M_2(j)$: the variable production cost of Product 2, a function of product variety j

$S(b, q, 0, p_1)$: the customer surplus of customer (b, q) towards Product 1

$S(b, q, j, p_2)$: the customer surplus of customer (b, q) towards Product 2

(i, v): the coordinate of the point of intersection of the demand curves of Product 1 and Product 2

$R_2(j)$: the development cost of Product 2, a function of product variety j

4. Attribute Level Selection with Rule of Zero Cannibalization

The objective of the firm is to select attribute level $(k, l) \in A$, to configure a new product (Product 2) and determine the prices of both Product 1 and Product 2 in order to maximize its profit. In this section, three problem formulations are presented. Problem 1 is the general problem for the configuration of attribute levels. Due to its complexity, a rule is enforced to simplify the problem to Problem 2. To solve Problem 2, it is further transferred into an equivalent problem, Problem 3, and a heuristic is provided.

The general problem for the configuration of attribute levels is formulated as follows:

Problem 1:

$$\begin{aligned} Max\ \pi =& [D_1^0(p_1) - C^+(p_1, p_2, j)](p_1 - M_1)n_1 \\ &+ [D_2^0(p_2) - C^-(p_1, p_2, j)][p_2 - \sum_{(k,l)\in A)} \alpha_{k,l} B_{k,l} - M_1]n_2 - \sum_{(k,l)\in A} \beta_{k,l} B_{k,l} \end{aligned} \quad (4.1)$$

$S.T.$

$$(p_1 - p_2) - e(i - j) + e(i) = 0 \quad (4.2)$$

$$D_1^0(p_1) - C^+(p_1, p_2, j) = \{(b, q) : S(b, q, 0, p_1)\ and\ b < i\} \quad (4.3)$$

$$D_2^0(p_2) - C^-(p_1, p_2, j) = \{(b, q) : S(b, q, 0, p_2)\ and\ b \geq i\} \quad (4.4)$$

$$j = \sum_{(k,l)\in A} \omega_{k,l} B_{k,l} \quad (4.5)$$

$$\sum_{l=1}^{y_k} B_{k,l} = 1, k = 1, ..., K \quad (4.6)$$

$$i > 0 \quad (4.7)$$

$$p_1, p_2 > 0 \quad (4.8)$$

$$B_{k,l} = 1\ or\ 0, (k, l) \in A. \quad (4.9)$$

The objective function is function (3.13). The first constraint defines the coordinate of the point of intersection (i, v) of the demand curves of Product 1 and Product 2. The second and the third constraints define the demands for Product 1 and Product 2 respectively. The fourth constraint defines the product variety of Product 2. The fifth constraint ensures that each attribute should select one attribute level.

Problem 1 is almost intractable due to the difficulty in calculating cannibalization for the general disutility function and the existence of binary variable $B_{k,l}$. Even without the cannibalization function, product line design is already shown to be NP-complete by Fruchter et al. [4]. Heuristics may be helpful to solve this problem, but complicated heuristics are not useful in practice. If the disutility function is known and a set of product variant candidates are available, simulation can be used to calculate the cannibalization and the profit of each candidate, then the best candidate is obtained. To find the optimal solution, all possible candidates should be enumerated.

On the other hand, since our study aims to provide simple and useful approaches for practitioners, we will simplify the problem so that it is easy to solve in practice.

First, we enforce the rule of zero cannibalization. This rule requires that a firm should develop a new product variant with zero cannibalization to current products. The rule is widely observed in nature. For example, the leaves of a plant always try to avoid overlapping in order to absorb as much sunlight as possible. As an inspiration from nature, we apply the rule to new product design. Figure 2 illustrates the position of two products and their demand curves under the rule. There is no overlapping in the demand of the two products. In addition, product variety is just large enough to make cannibalization zero.

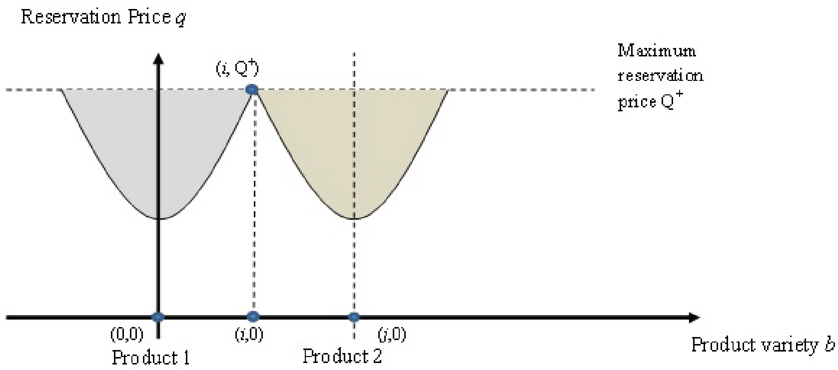

Figure 2: Demand spaces of two products without cannibalization

Define the point of intersection of the two demand curves as (i, Q^+), where customer surpluses of both Product 1 and Product 2 are zero. This leads to:

$$(Q^+ - p_1) - e_1(i - 0) = 0, \tag{4.10}$$

and

$$(Q^+ - p_2) - e_2(j - i) = 0. \tag{4.11}$$

Then according to the rule of zero cannibalization, the product variety of Product 2 should be larger than a threshold:

$$j \geq e_1^{-1}(Q^+ - p_1) + e_2^{-1}(Q^+ - p_2). \tag{4.12}$$

The rule of zero cannibalization leads to modification of the profit function. The cannibalization parts in function (4.1) are not necessary. The demand for Product 2 is independent of variable j and equal to $D_2^0(p_2)$, while the demand for Product 1 is equal to $D_1^0(p_1)$. To further simplify the problem, we assume p_1, p_2 are determined in advance, because Product 1 already exists and p_2 usually refers to prices of similar products in the market. Therefore, the firm's objective is to select attribute levels for Product 2 that maximize its profit. The optimization problem is revised as follows:

Problem 2

$$Max\ \pi = D_1^0(p_1 - M_1)n_1 + D_2^0(p_2)(p_2 - \sum_{(k,l)\in A} \alpha_{k,l}B_{k,l} - M_1)n_2 - \sum_{(k,l)\in A} \beta_{k,l}B_{k,l} \tag{4.13}$$

$S.T.$

$$\sum_{(k,l)\in A} \omega_{k,l}B_{k,l} \geq e_1^{-1}(Q^+ - p_1) + e_2^{-1}(Q^+ - p_2) \tag{4.14}$$

$$\sum_{l=1}^{y_k} B_{k,l} = 1,\ k = 1, ..., K \tag{4.15}$$

$$B_{k,l} = 1\ or\ 0, (k,l) \in A \tag{4.16}$$

In the objective function, the first term is the profit of Product 1, and the second term is the profit of Product 2, which equals the demand multiplied by the unit profit and the expected life cycle, subtracting the development cost of Product 2. The first constraint stipulates that the product variety contributed by the attribute levels should satisfy the rule of zero cannibalization. The second constraint ensures that each attribute selects one attribute level.

It should be noted that several terms in the problem formulation become constant and can be deleted: the profit of Product 1 and the demand for Product 2 in function (4.13); and the right hand side of the first constraint. To further simplify the problem, we use the following notations for these constant values:

D_2: the total demand for Product 2, $D_2 = D_2^0(p_2)n_2$

Ω: the value of $\sum_{(k,l)\in A} \omega_{k,l} - [e_1^{-1}(Q^+ - p_1) + e_2^{-1}(Q^+ - p_2)]$

$c_{k,l}$: a value associated with each attribute level (k,l), $c_{k,l} = D_2\alpha_{k,l} + \beta_{k,l},\ (k,l) \in A$.

In addition, we replace binary variable $B_{k,l}$ with its dual variable $\bar{B}_{k,l}$. $\bar{B}_{k,l} = 1 - B_{k,l}$, $(k,l) \in A$. If attribute level (k,l), is selected, $\bar{B}_{k,l} = 0$, and vice versa.

After deleting all the constant terms and substituting the above variables into the formulas, the objective function (4.13) can be rewritten as:

$$\begin{aligned} -D_2 \sum_{(k,l)\in A} \alpha_{k,l}B_{k,l} - \sum_{(k,l)\in A} \beta_{k,l}B_{k,l} &= -\sum_{(k,l)\in A} (D_2\alpha_{k,l} + \beta_{k,l})B_{k,l} \\ &= -\sum_{(k,l)\in A} (D_2\alpha_{k,l} + \beta_{k,l})B_{k,l} + \sum_{(k,l)\in A} (D_2\alpha_{k,l} + \beta_{k,l})\bar{B}_{k,l} \\ &= -\sum_{(k,l)\in A} c_{k,l} + \sum_{(k,l)\in A} c_{k,l}\bar{B}_{k,l}. \end{aligned} \tag{4.17}$$

And after performing some algebra operations, the first constraint (4.14) becomes:

$$\sum_{(k,l)\in A} \omega_{k,l} - \sum_{(k,l)\in A} \omega_{k,l} B_{k,l} \leq \sum_{(k,l)\in A} \omega_{k,l} - e_1^{-1}(Q^+ - p_1) + e_2^{-1}(Q^+ - p_2). \tag{4.18}$$

It is equivalent to

$$\sum_{(k,l)\in A} \omega_{k,l} \bar{B}_{k,l} \leq \Omega. \tag{4.19}$$

By this way Problem 2 is transferred into an equivalent but much simpler problem: Problem 3. The objective function of Problem 3 is only a linear function of decision variables and there is no complicated inverse disutility functions in the constraints.

Problem 3:

$$Max\ \pi = \sum_{(k,l)\in A} c_{k,l} \bar{B}_{k,l} \tag{4.20}$$

$$S.T.$$

$$\sum_{(k,l)\in A} \omega_{k,l} \bar{B}_{k,l} \leq \Omega \tag{4.21}$$

$$\sum_{l=1}^{y_k} \bar{B}_{k,l} = y_k - 1,\ \ k = 1, ..., K \tag{4.22}$$

$$\bar{B}_{k,l} = 1\ or\ 0, (k,l) \in A. \tag{4.23}$$

It should be noted that if the second constraint does not exist, it is a 0-1 knapsack problem. However, due to this constraint, the problem is NP-complete. Although it can be solved optimally by branch and bound algorithm with linear programming relaxation, the running time is very long. In the worst case, exhaustive search occurs in branch and bound algorithm. Therefore, an efficient heuristic is more desirable in practice. Nemhauser and Wolsey [11] provided several algorithms (dynamic programming) for the 0-1 knapsack problem. We develop a heuristic based on dynamic programming and linear programming relaxation of the 0-1 knapsack problem. If y_k is bounded by Y, the heuristic solves the problem in $O(KYlog(KY))$. The heuristic is shown by Table 1.

In the solution, if $\bar{B}_{k,l} = 1, (k,l) \in A$, attribute level (k,l) will be selected for attribute k; otherwise, it is not selected. The heuristic provides a good solution within a very short time and is easy to implement in practice.

5. Case Study

We investigate new product selection in a real-world scenario. The company we studied is called *Bao*. It is a large company producing consumer paper tissues in southern China. It produces toilet paper, paper handkerchief, facial tissue paper, and other relevant paper products. However, its profit does not increase much even when it offers many product variants to customers. We will investigate the reason for the low profit and analyze which product variants are worth developing and producing.

Table 1: The heuristic for Problem 3

Step 1	Let $\bar{B}_{k,l} = 0$, where $\omega_{k,l} \neq 0, (k,l) \in A$. Denote the set of level (k,l) with $\bar{B}_{k,l} = 0$ as $N_k^0, k = 1, ..., K$.
Step 2	Order and rename level (k,l) in the set $N_k^0, k = 1, ..., K$, so that $c_{k,1}/\omega_{k,1} \geq c_{k,2}/\omega_{k,2} \geq ... \geq c_{k,y_k-1}/\omega_{k,y_k-1}$, $k = 1, ..., K$. And $\omega_{k,y_k} = 0$, $\bar{B}_{k,y_k} = 1$, $k = 1, ..., K$.
Step 3	Set $k = 1$.
Step 4	Select the first attribute level (k,l) from N_k^0. Set $\bar{B}_{k,l} = 1$, delete it from N_k^0. If $\sum_{(k,l)\in A} \omega_{k,l}\bar{B}_{k,l} \geq \Omega$, go to Step 5; Otherwise, if $k = K$, go to Step 3; Otherwise, let $k = k + 1$, go to Step 4.
Step 5	Do: $k = 1, ..., K$ If $N_k^0 \neq \oslash$, Set $\bar{B}_{k,l} = 1$ for other level $(k,l) \in N_k^0$ except the one with the largest $\omega_{k,l}$, Otherwise, set $\bar{B}_{k,y_k} = 0$.

5.1. Product variants and attribute levels

We select one of the product categories of *Bao* to study. Toilet paper is an important product and a revenue generator of *Bao*. As we know, a product is described by a group of attributes. An attribute may select different attribute levels, thus generating many product variants/brands in each product category. The product variants of this product category and their attribute levels are shown in Table 2.

In this product category, we assume there is only one product variant originally, referred to as Product 1, which is the first product variant listed in Table 1. *Bao* wants to select and produce a new product (i.e., Product 2), for this product category. The product variants in Table 1 are candidates for Product 2, suggested by the product development team. Nevertheless, it is not a complete enumeration of all the product variants. The contribution to product variety by the l^{th} level of the k^{th} attribute in a product category is given by the following function:

$$\omega_{k,l} = \frac{w_k(|a_{k,l} - a_{k,1}|)}{\max_l(|a_{k,l} - a_{k,l}|)}, \tag{5.1}$$

where:

w_k: the weight of the k^{th} attribute in a product category, $k \in \{1, ..., K\}$. The weight is the mean of the contribution to product variety by an attribute, with data obtained from a customer survey.

$a_{k,l}$: the value of the l^{th} level of the k^{th} attribute in a product, $(k,l) \in A$

$a_{k,1}$: the value of the first level (in Product 1) of the k^{th} attribute in a product, $k \in \{1, ..., K\}$. The values of attribute levels $a_{k,l}$ are listed in Table 1.

5.2. Demand and disutility function

Next, the demand and disutility function is defined explicitly. For the sake of simplicity, we assume that the prices of Product 1 and Product 2 are equal, $p_1 = p_2 = 2$ RMB. This assumption is reasonable since they are product variants from the same product category

Table 2: Product variants of toilet paper and their attribute levels

Attribute k	1	2	3	4	5
Attribute name	Size	# of PLY(layers)	# of roll/package	Package design pattern	Weight/roll
Weight, w_k	0.123	0.123	0.123	0.012	0.123
GW3125-2	105*114	3	2	GW GREEN	125g
GW3100	100*114	3	10	GW BLUE	125g
JW2150-12	105*114	2	10	JW RED/GREEN	125g
JW2150-11	105*114	2	10	JW GREEN	125g
ZT3160	135*114	3	10	ZT RED	125g
FW3140	105*114	3	10	FW RED	140g
FW3180	105*114	3	10	FW GREEN	180g
YW3150	105*114	3	10	YW BLUE	125g
YW3130-4	105*114	3	10	YW GREEN	135g
YW3130-1	105*114	3	10	YW RED	110g
YW3120	100*114	3	10	YW ORANGE	125g
YW3110	100*114	3	10	YW RED&GREEN	110g
YW3100	100*114	3	6	YW GREEN FLOWER	125g
YW3080	100*114	3	10	YW WHITE	125g
YW3095	95*114	3	10	YW VIOLET	125g
LW3135	100*114	3	10	LW GREEN	135g
LW3125	100*114	3	10	LW RED	125g
LW3110	100*114	3	10	LW BLUE	110g
EW3050	95*114	2	20	EX TRANSPARENT	110g
EX2670	95*115	2	1	EX TRANSPARENT	1350g
EX2775	95*115	2	3	EX TRANSPARENT	110g
EX3375	95*115	2	4	EX TRANSPARENT	110g

and the actual price difference is negligible. d is the density of customers in the demand space. The value of d is equal to 12,000,000 units per year.

We also assume that the shape of the disutility function of customer (b, q) to each product is the same and can be described by a quadratic function:

$$e(b) = c_1 b^2 + c_2 b + c_3, \tag{5.2}$$

where c_1, c_2 and c_3 are the coefficients of variable b. The maximum reservation price is $Q^+ = 10$RMB. If the curve of the disutility function of Product 1 is plotted in the origin of the x axis, and the curve of the disutility function of Product 2 is plotted with j of the x axis in a two dimension space (Figure 2), the disutility function of Product 1 will be:

$$e(b) = 8b^2 + 2. \tag{5.3}$$

j is the threshold variety between each pair of products to satisfy zero cannibalization, and its value is:

$$j = 2e^{-1}(Q^+) = 2. \tag{5.4}$$

5.3. Development cost and production variable cost of attribute levels

Next, we analyze development cost $\beta_{k,l}$ and variable production cost $\alpha_{k,l}$ of each attribute level $(k, l) \in A$. There are twelve steps in the production process: 1. cook wood chips; 2. remove lignin and chemical; 3. remove color/blench; 4. mix with water; 5. spray to mesh screens; 6. press and dry; 7. creep; 8. scrap off from the dryer; 9. wind on jumbo reels; 10. unwind, split, rewind onto cardboard tubing; 11. cut paper log into rolls; 12. wrap and packaging.

In this company, process variations in different attribute levels for an attribute are the same. Thus, the development costs and variable production costs of attribute levels for each attribute are the same. The costs are calculated as follows. New equipment cost per product equals new equipment cost divided by the total production volume of each equipment, which is 12×10^6 units. Variable production cost $\alpha_{k,l}$ is the sum of these costs: machine set-up cost per product, other process variation cost per product, new equipment cost per product and worker training cost per product. The life cycle of a product is set at 8 years. Table 2 provide the costs of each attribute of toilet paper. The unit of costs in this paper is RMB, except those stated otherwise.

Table 3: Costs of attributes of toilet paper

Attribute k	1	2	3	4	5
Set up cost per product ($\times 10^{-3}$ RMB)	6.25	6.25	6.25	2.08	6.25
Workers training cost per product	0	0	0	0	0
New equipment cost per product	0	0	0	0	0
Other process variation cost per product	0	0	0	0.3	0
Variable production cost $\alpha_{k,l}$, $\forall l$ ($\times 10^{-3}$ RMB)	6.25	6.25	6.25	302	6.25
Development cost $\beta_{k,l}$, $\forall l$	5,000	5,000	5,000	30,000	5,000

As seen in Table 3, the attribute levels differ greatly in $\alpha_{k,l}$ and $\beta_{k,l}$ because the generation methods of attributes are different. Some attributes only require the firm to adjust the existing machine setting in the production processes, and thus the variable production cost is only the machine set-up cost. On the contrary, to generate variation "package design pattern", the firm needs to pay significant development cost for package design. To generate different package types, the firm should purchase new packaging machines and provide training for workers to operate them.

5.4. Profits of different product variants

For Problem 1, cannibalization between old and new products is allowable. Due to the complexity of Problem 1, simulation is used to compare the candidates in Table 2 and the best one is selected. The profit of each candidate is calculated by function (3.13). Table 4 shows the cannibalization percentage and profit of the firm if each product variant is selected. For example, if product variant GW3100 is selected, there will be 41.9% cannibalization on the demand of Product 1 and Product 2 and their total profit is 210 million RMB. Table 4 indicates that the profit varies greatly with each product variant. The table provides a guide to select a new product in order to maximize the profit of the firm.

The solution clearly shows that the attribute levels with high contribution to product variety, low process variation cost and development cost should be selected in new product variants. For example, product variant "EW2670" of toilet paper yields the highest profit. It differs significantly from Product 1 ("GW3125-2") in two attributes, namely "size" and

Table 4: The profit of the firm (unit of measurement of profit: RMB)

variants	cannibalization	profit
GW3100	0.419	2.058E+08
JW2150-12	0.013	3.490E+08
JW2150-11	0.013	3.492E+08
ZT3160	0.031	3.429E+08
FW3140	0.232	2.712E+08
FW3180	0.224	2.744E+08
YW3150	0.251	2.653E+08
YW3130-4	0.243	2.677E+08
YW3130-1	0.232	2.715E+08
YW3120	0.186	2.879E+08
YW3110	0.185	2.877E+08
YW3100	0.274	2.567E+08
YW3080	0.169	2.940E+08
YW3095	0.143	3.031E+08
LW3135	0.187	2.871E+08
LW3125	0.183	2.889E+08
LW3110	0.188	2.867E+08
EW3050	0.000	3.524E+08
EX2670	0.000	3.525E+08
EX2775	0.017	3.465E+08
EX3375	0.014	3.476E+08
The product generated by the heuristic	0	3.820E+08

"weight of each roll", which have low $\alpha_{k,l}$, $\beta_{k,l}$ and high $\omega_{k,l}$. On the contrary, product variant "GW3100" only differs from Product 1 in attribute "size", and varies little in attribute "package design", which has high $\alpha_{k,l}$, $\beta_{k,l}$ and low $\omega_{k,l}$, and cannibalization is high. Therefore, this product variant generates the lowest profit.

Next, we apply the heuristic to solve Problem 3, which is to select the attribute levels from the attribute set and configure a new product. The new product should have zero cannibalization towards the existing one according to the rule of zero cannibalization. The solution of the heuristic is in the last row of Table 4. This product variant takes maximum variation from Product 1 in attributes "weight/roll" and "# roll/package", and the other attributes are the same as Product 1. The profit of the heuristic product is 382 million RMB. Since the heuristic product generates higher profit than any product variants in Table 2, the firm should consider developing this new product. On the contrary, the product variants in Table 2 with low profit should be removed from the product lines (e.g., those only differing in package design patterns) as they have high cannibalization towards Product 1 and high development and production costs.

The case study also shows the solution of Problem 3 is much better than that of Problem 1. The solution of Problem 1 is obtained by simulation with a candidate set, while the solution of Problem 3 is obtained by the heuristic with zero cannibalization rule. The case study proves that applying zero cannibalization rule in attribute level selection problem can efficiently generate a good product variant.

The analytical results of the case study provide some useful managerial insights. First, the rule of zero cannibalization should be applied to new product development. However, it should also be realized by developing variation in attributes which require low development cost and process variation cost, and have high contribution to product variety. If cannibalization is almost zero, further variation in product attributes only decreases the profit.

6. Conclusions

In this study, we investigate the issue of new product selection. A new product can be viewed as a configuration of attribute levels. To maximize its profits, a firm should select attribute levels which contribute greatly to product variety, thus reducing cannibalization due to product similarities. We propose the rule of zero cannibalization which enforces zero cannibalization among products. At the same time, the firm should also consider development cost and process variation cost of different attribute levels. We formulate this attribute level selection as a nonlinear optimization problem. A heuristic is also developed to solve the problem efficiently.

The analytical results of the case study provide some useful managerial insights. First, the rule of zero cannibalization should be considered for new product development. Second, it is realized by developing variation in attributes which require low development cost and process variation cost, and have high contribution to product variety.

The paper provides useful managerial implications for a firm in new product development. We prove that a firm should not develop too many product variants. Instead, it should carefully select a new product which requires low development cost and process variation cost, and, at the same time, try to sustain zero cannibalization among products.

Some assumptions and settings of this paper merit further research. First, the paper considers the new product development of a monopolistic firm. We will extend this work to cases in a market with several competitors. Second, our model only considers a new product. The solution and principles obtained may change if multiple new products are developed simultaneously.

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