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LINEAR PROGRAMMING
AND CONSUMERS' IDEAL SENSORY ATTRIBUTES
IN PRODUCT OPTIMIZATION

A Thesis
presented in partial fulfilment of
the requirements for the degree of
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at Massey University

HATHAIRAT UAPHITHAK

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ABSTRACT

Sensory attribute/ingredient relationships and consumers' ideal product profile were used to develop constraints for linear programming in hand cream optimization using rice bran oil to replace mineral oil. At the beginning of the process, consumer testing was conducted in order to elicit the important attributes of the product as perceived by the consumers. Simultaneously, the strengths and weaknesses of hand creams on the market were identified, and an ideal product profile developed for hand creams.

A fractional factorial design, 2^{6-2}, was used to identify the main effects of the ingredients on the product attributes. A quantitative sensory profile technique and a trained sensory panel were employed in the product sensory evaluation of the samples. The mean scores of each sensory attribute were regressed against the levels of the ingredients in the formulations. Only the main effects of the ingredients were identified according to the design of the experiment. Most sensory attributes, consistency, spreadability, oiliness, shine and stickiness, had significant linear relationships with the ingredients. Moistness, softness and absorbability did not.

The linear relationships were then used to develop sensory constraints for the linear programming model. Upper and lower limits of these constraints were set from the consumers' ideal product profile, by adding and subtracting 1 from the ideal attribute levels. Other constraints were on ingredient levels based on formulation needs. LP88 computer program was used to solve this hand cream problem, the objective being minimum cost.

A hand cream was made using the optimum formulation from the linear programming and tested with the trained sensory panel. Ideal ratio scores (i.e. ratio of the sample mean score to the ideal score) of this hand cream's

attributes were not more than 0.3 away from the ideal. The product was then tested with a consumer panel of 20 hand cream users. In consumer testing, the optimum product was tested along with the leading commercial products in order to compare consumer acceptability on these products and to test if the optimum product could compete with the products already in the market. The results showed the consumers preferred the optimum product to the commercial products and the optimum product was closer to the ideal.

From the linear programming model used in this study, the attribute levels of the hand cream can be modified by adjusting the constraints and studies can be made of the effect of changes in ingredients on product attributes.

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CHAPTER 1

INTRODUCTION

Product optimization is one of the important stages in product development. It is defined as a comprehensive and efficient approach which develops a product highly acceptable to the consumer, in a short time, while minimizing the cost.

The goal of optimization is to maximize consumer acceptance of a product, from a fixed number of ingredients, and the outcome of the process should support key decisions evolving from company policy and strategy. Hence, a product optimization method will consider all these constraints and objectives, and will help the product developer to select formulation alternatives. When new products are developed, another goal of the optimization procedure is to provide the product developer with information regarding the effects of input variables on the output variables of the finished products. Thus, it is necessary to develop empirical equations that relate output to input variables for optimization process.

1.1 OPTIMIZATION PROCEDURE

Several optimization methods have been developed by many researchers (Fishken, 1983; Sidel and Stone, 1983; Giovani, 1983; Schutz, 1983; and Moskowitz, 1983 and 1987). Although these methods differ, they include:

* An initial development study in which prototypes are developed; critical input variables are identified during this stage.

* A screening product formulation development step which

includes the determination of the levels (or range) of ingredients and processing variables for the subsequent optimization study. Some authors conduct sensory evaluation tests at this stage.

* A formal optimization study, with or without constraints, that includes consumer testing, data analysis, reformulation, and implementation.

1.2 AN INITIAL DEVELOPMENT STAGE

1.2.1 Find Information about Existing Products

The product developer has to find information about the strengths and weaknesses of competitors, and about changing costs of goods, then makes a decision about what to launch and how to support the product. It is important to understand the situation of the market place before making decisions regarding products. Product developers should always evaluate their own products against the single leading market competitor.

In order to measure consumer reactions to competing products in the market, it is important to obtain a comparative profile of the different products in the marketplace on a series of different product attributes (Moskowitz and Rabino, 1983). By comparing products on this profile it becomes possible to determine quickly which products perform well on which specific attributes.

1.2.2 Product Design Specification

After obtaining enough information about the product to be developed, the product developer has to develop a product design specification to get the clear description about the product. This is to interpret consumer needs or wants into technical terms. A great deal of further information is needed to change the product idea concept into a product design specification including; raw materials, processing, product quality and target market.

1.2.3 Identifying the Variables

The variables are divided into input variables and output variables. For example, in hand cream products input variables are ingredients and output variables are physical and sensory attributes. In studying the variables in a product development process, the product developer has to firstly identify all the variables, then decide which are the most important variables.

It is important to limit the number of variables to be studied but choosing too few variables can limit the usefulness of the experiment. The important variables can often be determined from past experiments, from study of the literature, and from consumer research.

1.3 SCREENING PRODUCT FORMULATION DEVELOPMENT

From the initial development stage, the product developer obtains the direction of the target product. Now the decision has to be made on what prototype(s) should be developed.

Experimenters design experiments in order to answer specific questions and to build a mathematical model. The choice of a specific experimental design will depend upon the project's objectives. An experimental design should be straightforward to plan and execute and simple to analyze.

Traditionally back-and-forth techniques for testing and reformulation of products have been used. Those procedures could require months and were substantially more expensive than an optimization method which reduces the trial and error experiments (Moskowitz, 1983). Giovanni (1983) also stated that these approaches are insufficient for three reasons. Firstly, a large number of experiments is required, which can be expensive and time consuming. Secondly, the optimum product might not be determined by these approaches because the experimenter must use educated guesses to specify the levels of the various ingredients to test. Thirdly, this approach does not establish an equation which describes the relationship between the input decision variables and output responses to these variables.

Most researchers agree that a multi-product procedure is more efficient than the traditional method of back-and-forth testing. The multi-product approach, which is common to most optimization methods, tests many prototypes and develops a model relating decision variables and objective measures. The process requires one to two cycles, and takes about 3 months (Moskowitz, 1983).

Experimental designs have been successfully used in product optimization planning to select a subset of all possible samples which could be tested. While covering the range of factor levels specified in the experiment, the experimental design emphasizes those samples closest to the midpoints of these ranges, thereby decreasing the total number of samples which must be tested (Giovanni, 1983).

Factorial designs, mixture designs and central composite designs are used by many product developers to optimize product formulation.

1.4 OPTIMIZATION

Optimization of a product can be considered in terms of the analogy of 'hill climbing' (Charalambous, 1984). By envisioning the product models as a 'hill', one must find the top of the hill to optimize a product.

To obtain the relationship between input variables and output variables, the data from the previous stage have to be analyzed. Data interpretation is naturally an important step of the optimization process. The experimenter must choose the method of analysis before starting the research because the choice of an experimental design depends upon the type of analysis conducted on the data.

Moskowitz (1987) used multiple regression analysis to develop equations relate sensory characteristics and input variables, as well as an equation relating consumer acceptance to ingredient levels. From these equations the values for the optimum product were substituted and consumer reaction to the product could be estimated. In this method it is possible to minimize cost of the product and maximize overall acceptance at the same time by using the computational algorithm as follows:

* Try a new formula level obtained from the equations.

* Establish whether the new trial formula generates an increased level of acceptance. If it does not, go back to a new trial formula before proceeding. If the new formula does achieve a higher acceptance level, continue.

* Check the costs of the new formula. (If the cost of goods exceeds the maximum, then go back and try a new formula).

This method is not straightforward and the product developer has to try several combinations until the optimal product is obtained.

Linear programming is another important method which has been successfully used in product optimization by several researchers (Kavanagh, 1978; Chan and Kavanagh, 1988; Beausire et al., 1988). Linear programming, a mathematical optimization technique, is used in both the food and non-food industries for resource allocation and product formulation problem solving. Linear programming was used in paint and resin formulation (Kavanagh, 1978) and light duty liquid detergent formulation (Chan and Kavanagh, 1988) in order to obtain a good, low cost formulation, which matched or exceeded the properties of a commercially available product, in a small number of experiments. In this method, a formulation of various components which the formulator, based on experience and knowledge, believed would meet the required specifications was produced and tested. Successive uses of multiple regression analysis and linear programming were applied at each step to obtain a formulation which met the required specifications at the lowest cost. If the tests showed that the formulation did not meet the required specifications, then the formulator adjusted the quantities of the components, added or deleted components to try to obtain a formulation which did meet the specifications.

Whereas the optimal formulation can be obtained in a small number of experiments from this method, formulator experience and knowledge are needed in choosing the input variables for the linear regression. Hence, it is not appropriate if the formulator has no experience about the product.

The sensory properties of a product are very important factors in a formulation problem. In linear programming optimization, sensory properties have been constrained by a combination of ingredient limits (upper and lower bounds), and the development of constraints based on quantitative models of functional properties of the ingredients (Hsu, et al., 1979). The studies by many researchers failed to take into account the relationship between the sensory properties and the consumer acceptance of the product.

Beausire et al. (1988) used linear programming in fresh turkey bratwurst formulation. In their study, an experimental design and in-house sensory panel determined quantitative relationships between the product's textural attributes and the ingredients. Then the product toughness/ingredients relationship was utilized to develop three formulations with different levels of toughness. These formulations were market tested using the acceptor set size as the measure of market acceptability. A relationship between product toughness and acceptor set size was determined, into which was substituted the toughness/ingredient relationship. This model was added to the least cost linear programming model in the form of an acceptability constraint.

Although this method included acceptability constraints into the linear programming, it may not be possible to obtain a product which contains the acceptable levels for the important attributes, since only one sensory attribute is studied. Also in obtaining the model showing the relationship between the sensory attribute and acceptability only three samples were used to get the linear equation; this equation may not have represented the actual relationship.

1.5 USING OPTIMIZATION PROCEDURES IN FORMULATION OF A NEW HAND CREAM PRODUCT.

Consumers have now become aware of safety in product use, and they tend to prefer natural products which are produced from natural raw materials and which do not cause any side-effects.

Mineral oil is used as emolient in most hand creams. Its occlusive action aids in rehydration of the corneum when allowed to remain on the skin for an appreciable length of time. Because the solvent action of mineral oil tends to remove skin surface lipids when the cream is applied for a short period of time, partial replacement with a vegetable oil is needed (Grayson and Eckroth, 1979). It has also been found that mineral oils are a carcinogenic risk to humans (Haas et al., 1987). Hence, vegetable oils have the potential to be used instead of mineral oil in skin care products.

Rice bran oil is obtained from rice bran by conventional expression and solvent extraction techniques using a variety of solvents such as hexane, and ether. The composition of rice bran oil suggests its use as a salad and cooking oil, and for making hydrogenated shortening (Bailey, 1964) . It has also been used as a leather tanning oil (replacing sperm oil), as a textile lubricant by textile mills to keep yarn from fibrillating, and as a rust inhibitor.

Rice bran oil has been used in cosmetic products especially skin care products: soap, bath oils and hand creams.It has been used in a sun screen product (Loo, 1976). It is non-toxic and non-irritating to the skin of all subjects tested, does not discolour, develop odour or otherwise deteriorate upon exposure to sunlight, so it is suitable to use in skin care products. Since rice bran oil contains natural antioxidants (tocopherols), it is not necessary to add any antioxidant in the product.

As rice is one of the major cereal crops in the world, there are several rice bran oil extracting factories; and now there are rice companies in many countries, such as U.S.A., India and Thailand, considering oil extraction so there will be plenty of rice bran oil available to be used. Production of formulated products using rice bran oil in cosmetics is also one way of value adding to this raw material.

In this study, an optimization procedure was used to develop a natural hand cream product. The product concept required the development of a hand cream using rice bran oil as a substitute for mineral oil.

Consumer testing was used to gain consumers' perception of the products already on the market. Important attributes were identified to guide the formulator in developing a product which contained acceptable levels of these attributes. After the experimental study, multiple regression was used to generate linear relationships between input variables and sensory attributes, then consumer acceptance was maximized by inputting the sensory constraints in the linear programming model. The upper and lower bounds of the constraints were obtained from the consumers' ideal attributes.

1.6 AIM OF THE PROJECT

The aim of this project was to use consumers' ideal attributes and multiple regression to develop sensory constraints for a linear programming model in product formulation.

1.6.1 Objectives

* To set up a consumers' ideal product profile for hand cream products.

* To obtain empirical equations showed relationships between input variables (raw materials) and sensory attributes.

* To use the empirical equations in linear programming to formulate a hand cream product.

* To evaluate a prototype hand cream from linear programming with a trained panel and consumer panel.

* To obtain an optimal product which is accepted by the consumers.

1.6.2 Constraints

1.6.2.1 Product constraints

* The product should be formulated by using vegetable oil (rice bran oil) instead of mineral oil.

* The product should have sensory attributes which is accepted by the consumer and can compete with the products in the marketplace.

1.6.2.2 Processing constraints

* Only known technology is to be used and new processing techniques are not to be investigated.

* Commercially available raw materials are to be used as much as possible.