Engineering Skin Lotion

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Abstract

The objective of this paper is to find the perfect skin lotion for ichthyosis vulgaris patients and to make it profitable to produce. A consumer satisfaction model was created and evaluated using Microsoft Excel to choose the ingredients and concentrations to maximize the consumer satisfaction. The consumer satisfaction is based on the physical properties of the lotion which are directly related to the consumer properties. A demand model was then created in Excel to choose the ingredients and concentrations to maximize the profit.

The maximum consumer satisfaction was found to be 68% with 100% being ideal. The perfect product is not economically feasible while the demand model found a profitable solution with a consumer satisfaction of 62%. The average ROI for the profitable lotion with high advertising is 414%. The NPW for the same profitable lotion is $19 million.

Introduction

There are numerous lotions on the market today that claim to relieve dry skin. Lotions are used to moisturize the skin by restoring the lipid bilayer that holds the water, and adding water to the skin. The main ingredient in lotion is the solvent, primarily chosen to be water or mineral oil. People who have ichthyosis vulgaris (a genetic disorder that causes extreme scaly, dry skin) want a product that can not only replenish the water content in the skin, but also provide relief for an extended period of time. In addition, Icthyosis vulgaris patients need the lotion to aid in the desquamation process. The desquamation process is the shedding of dead skin cells. Certain ingredients will help this process continue, as desquamation is significantly inhibited in icthyosis vulgaris patients.

We have developed a model that will choose the moisturizer's ingredients and concentrations based on the consumer's satisfaction. The consumer's satisfaction is found by weighting

consumer preferences (i.e. effectiveness, smoothness, thickness, etc.). Each consumer preference can be related to a physical property of the lotion (i.e. viscosity, surface tension, etc.). These relationships can be used to find a normalized score for each consumer property.

The perfect product can be produced profitably with some compromise. A closer look at microeconomics allows for the model approach. The concepts that need to be looked at include demand, product price, raw material costs, advertising and capital investment.

A demand model was also created to find the most profitable solution. The demand model finds the ingredients and ingredient concentrations for the most profitable process.

The paper is organized as follows. First a background on skin and Ichthyosis vulgaris is given. Then the consumer satisfaction model is presented followed by the determination of the "perfect" product. We then analyze the manufacturing and costs of such lotions and determine its profitability. We then present a simplified business model that allows assessing better price, demand and composition of the most profitable lotion. Finally, we illustrate the results.

Background on Skin

In order to understand the function of moisturizers, one must first understand the components of skin and the effect of dryness on skin. The skin is the largest organ of the body covering approximately 1.75 m^2 in the average adult.[1] It weighs between 3.5 – 4.5 kg, comprising about 7% of total body weight. Skin is composed of three different layers: the epidermis, dermis, and subcutaneous tissue shown in **Figure 1**. The outermost layer is the epidermis, where most of the moisturizing effects take place. **Figure 2** shows the layers of the epidermis. The dermis connects the epidermis to the rest of the skin. The dermis also contains the nerve endings and blood vessels.

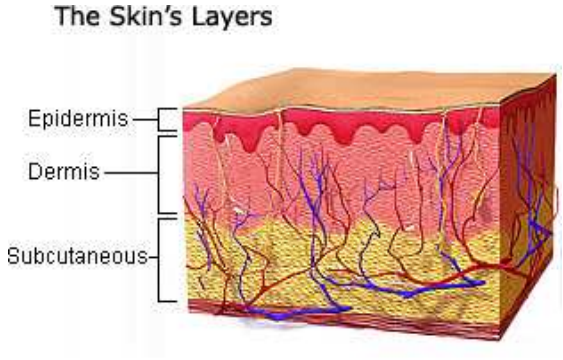

Figure 1: The 3 layers of the skin.[2]

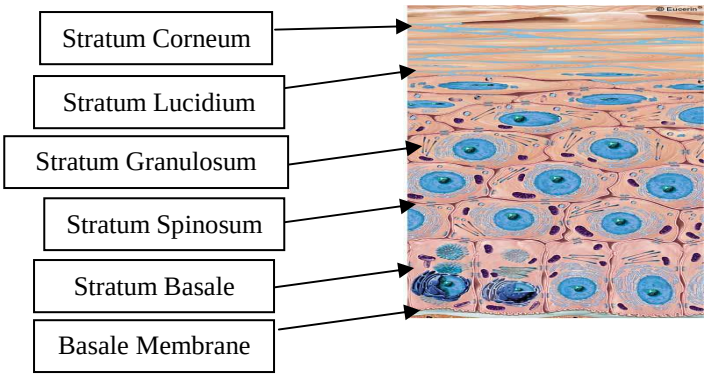

Figure 2: The layers of the epidermis.[3]

The stratum corneum (SC) is the outermost layer (as indicated in **Figure 2**) of the epidermis. It is the layer of the skin that is in direct contact with the environment. The stratum corneum is composed of approximately 20 layers of dead cells.[4] Healthy water content is around 30% in this layer[5], which is important for keeping the desquamation process active and the skin an effective barrier against infection. The skin's natural moisturizing factors (NMF) are located in the stratum corneum. NMF are responsible for the absorption and retention of water.

In order to retain the water, there is a hydrophobic lipid bilayer that surrounds the hydrophilic cells. With the lipid bilayer, the water is retained within the cell.[6] **Figure 3** shows an intact barrier with the lipid bilayer. **Figure 4** shows the added water loss from a compromised barrier.

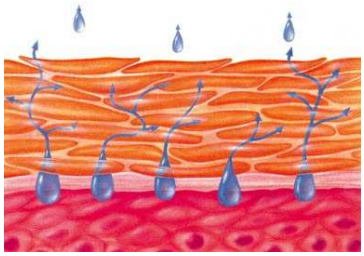

Figure 3: Intact skin barrier.[7]

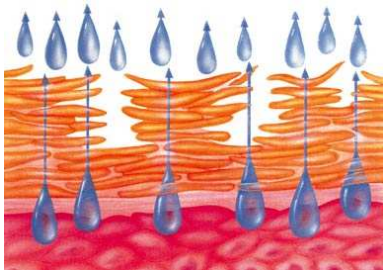

Figure 4: Compromised barrier.[7]

As **Figure 4** shows, there is more water loss with a compromised lipid bilayer. Without the lipid bilayer the cells become more compact and leave spaces for the water to escape.

One important process that occurs in the stratum corneum is desquamation. This process is the shedding of dead skin (on average, one layer of skin is shed per day.) Desquamation allows the damaged cells to be replaced by healthy cells.

Skin becomes rough, dry, and develops a fine scale when the skin hydration falls below the normal 10%.[8] The main cause of dry skin (known as xerosis) is dehydration of the SC. Dehydration can be caused by overexposure to water, harsh soaps or irritants, and the environment. With a lower level of humidity in the air, xerosis can also be caused by colder climates.

Background on Skin Disorders

Ichthyosis is a family of genetically inherited disorders characterized by severely scaly skin. A genetic defect leads to a buildup of the SC which produces the dry scales on the skin as shown in **Figure 5**.

Figure 5: Picture of dry, scaly skin.[9]

Due to a lack of water-binding components in the epidermis, the skin shows low levels of hydration. The desquamation process is also inhibited. Because ichthyosis is a genetic disorder, there is no cure and its treatment centers on managing the symptoms.

The most common form of ichthyosis is ichthyosis vulgaris. It accounts for 95% of all ichthyosis cases. One in every 250 people in the U.S. has ichthyosis vulgaris.[10] A post-transcriptional defect in proflaggrin expression is thought to be the cause of ichthyosis vulgaris.[11] Pro-flaggrin is a histidine-rich basic protein.[12] It is then proteolytically processed into flaggrin which is degraded into NMF during differentiation. A defect in proflaggrin expression causes a reduced level of NMF which causes lower hydration in the SC.

Proteases are inhibited for several enzymatic processes, which is caused by low water content in the SC. One of the processes that are inhibited is the desquamation process. With the inhibition of desquamation, the skin becomes dry and scaly. Reflection of light off of the dried squamous cells on the surface of the skin causes the appearance of scaly skin.[10] With ichthyosis vulgaris, the lower extremities (i.e. lower legs) are the most involved regions of the body. Areas such as the face and folds of the body tend to be more hydrated and do not appear scaly.

The symptomatic treatment of ichthyosis vulgaris involves using moisturizing lotions to restore the lipid bilayer of the SC, deliver moisturizing agents to the skin, and promote desquamation. Moisturizers work in various ways to treat dry skin. One method is trapping the water in the skin. This is done by using a thick moisturizer to hydrate the SC and then seal in the moisture.[10] Occlusives (thick, greasy agents) are chemicals used to prevent water loss from the skin. To promote desquamation and increase water binding, keratolytic agents are used. This includes α-hydroxy acids, such as lactic acid, glycolic acid, salicylic acid, urea, and propylene glycol.[10]

Lotions

There are different types of ingredients used in lotion, each with a specific purpose. The types of ingredients can be separated into two main categories of active and inactive ingredients. Active ingredients are the chemicals that help with the function of the lotion. The inactive ingredients do not affect the function of the lotion, but they make it possible to use the active ingredients on the skin. **Table 1** and **Table 2** list the types of ingredients and their purpose.

Table 1: Active Ingredients and Their Function.

Ingredient	Function
Humectants	Attract and bind to water
Occlusives	Prevent loss of water from skin
Exfoliants	Promote dead skin removal
Emollients	Fill intercellular spaces of skin

Table 2: Inactive Ingredients and Their Purpose.

Ingredient	Function
Solvents	Contain and disperse ingredients
Emulsifying agents	Stabilize the emulsion
Preservatives	Antimicrobial and antioxidant
Thickeners	Increase viscosity
pH adjustors	Adjust pH of moisturizer
Color Additives	Provide desirable color
Fragrant components	Provide desirable scent

The following tables show the ingredients used in the consumer satisfaction model and the concentration bounds for each type of ingredient.

Table 3: Active Ingredients Used in Model and Their Function

Ingredient	Function
Glycerin (Glycerol)	Humectant
Sorbitol	Humectant
PEG	Humectant
Allantoin	Humectant
Petrolatum	Occlusive
Ceramide	Occlusive
Dimethicone	Occlusive
Cholesterol	Occlusive
Mineral Oil	Occlusive
Isopropyl Palmitate	Emollient
Lanolin	Emollient
Stearic Acid	Emollient
Palm Oil	Emollient
Castor Oil	Emollient
C10-30 Alkyl Acrylate	Emollient
Decyl Oleate	Emollient
Cetearyl Alcohol	Emulsifying Agent
Cetyl Alcohol	Emulsifying Agent
Dilaureth-4 Phosphate	Emulsifying Agent
Lactic Acid	Exfoliant
Malic Acid	Exfoliant

Table 4: Inactive Ingredients Used in Model and Their Function

Ingredient	Function
Deionized Water	Solvent
Xanthan Gum	Thickener
Carbomer	Thickener
Oleic Acid	Thickener
Isostearic Acid	Thickener
Phenoxyethanol	Preservative
Methylparaben	Preservative
Propylparaben	Preservative
Citric Acid	pH Adjustor
Triethanolamine	pH Adjustor
Maleic Acid	pH Adjustor
γ-linoleic Acid	Lipid
Peppermint Oil	Fragrance

Table 5: Concentration Bounds for each type of Active Ingredient.

Min Concentration	Max Concentration	Type of Active Ingredient
65.00%	85.00%	solvent
5.00%	35.00%	lipid
1.00%	20.00%	emulsifiers
0.05%	15.00%	humectants & emollients
0.10%	10.00%	preservatives
0.00%	0.25%	fragrance
0.10%	10.00%	occlusive
0.10%	2.00%	thickener
0.001%	0.004%	pH
0.10%	1.00%	exfoliant

Each individual ingredient also had constraints based on the Cosmetic Ingredient Review (CIR) Board. In order to avoid Food & Drug Administration (FDA) approval, the concentrations must stay below the CIR max concentrations[13]. According to the FDA, a cosmetic is defined as the following, "…articles intended to be applied to the human body for cleansing, beautifying, promoting attractiveness."[14] Skin moisturizers are considered cosmetic products as long as the concentration of active ingredients stays below the CIR allowed maximums.

The lotion will undergo review by the CIR Board. This process consists of submitting the lotion to the board where they check the concentration of all the ingredients. There is no cost to this process.

Lotion Structure and Manufacturing

Lotions are oil in water emulsions. The solvent is water while some of the ingredients are insoluble in water. Emulsifying agents are used to stabilize the oil in water solution. The most common type of emulsifier is surfactants. Surfactants decrease the interfacial tension between the two phases.

The actual manufacturing procedure consists of mixing the oil and water phases together. The following steps state how the lotion is made.

1. Heat and mix the aqueous and oil phases separately.
2. Combine both phases into one batch.
3. Perform post treatment modifications (i.e. decrease particle size).

A bath sonicator is used to decrease the particle size. This works by using vibrations to break apart larger particles and mix them throughout the emulsion. A colloid mill and homogenizer are also used to further decrease the particle size.

Consumer Satisfaction Model

In order to be able to quantify consumer satisfaction, a model was developed based on the ingredients in the lotion. We first start with defining the consumer satisfaction score of product *i* (S_i) as a weighted average of normalized scores of different consumer related "properties" ($y_{i,j}$).

$$S_i = \sum y_{i,j} w_i \quad (1)$$

Where w_i are the weights. The scores are typically defined in the range from zero to one. It is important to notice that these are properties defined in plain terms and assessed by consumers using their own procedures. In the particular example of lotions, these properties are shown in **Table 6**. We will then discuss each of these in detail, including ways the consumer assesses them, is described in detail below.

Table 6: Consumer and Physical Properties Used for Consumer Satisfaction Model.

Consumer Properties	Physical Properties
Effectiveness	Diffusion
Spreadability	Surface Tension
Thickness	Viscosity
Smoothness	Coefficient of Friction
Creaminess	Viscosity & Concentration of Insolubles
Absorption Rate	Diffusion Steady State Time
Greasiness	Concentration of Insolubles

For each consumer property, we created a test the consumer could conduct in order to rate the property. The consumer rates the property based on the extremes of the possible test results (i.e. for thickness it ranges from very thin to very thick, for greasiness it ranges from not greasy to very greasy, etc.). This score is graphed verse the consumer satisfaction fraction. This was estimated based on a small scale informal market analysis. The consumer rating was also compared to the physical property in a graph. This is used in the consumer satisfaction model to find the lotions consumer rating. For both of the graphs, a best-fit polynomial is found that is used in the model. The test and graph for each consumer property is explained in more detail in the discussion of each consumer property.

Effectiveness. The effectiveness of the lotion was based on the diffusion of the ingredients into the SC. A geoscience approach, developed by Clifford Ho, was used to model the diffusion through the SC.[15] This approach assumes that Fick's Law dominates the diffusive mass transport through the mobile regions. Equation (2) was used to calculate the diffusion of the lotion ingredients into the skin.[15]

$$\frac{C_w}{C_w^{ideal}} = 1 - \frac{x}{L_{sc}} - \frac{2}{\pi}\sum_{x-1}^{\infty}\frac{1}{n}\sin\frac{n\pi x}{L_{sc}}e^{\frac{-D_{sc}n^2\pi^2 t}{R_{sc}L_{sc}^{\ 2}}} \qquad (2)$$

where, C_w = concentration of ingredient at desired depth

C_w^{ideal} =ideal concentration of ingredient at desired depth

D_{sc}=effective diffusion coefficient of 3-phase stratum-corneum continuum

R_{sc}=retardation factor of the 3-phase stratum-corneum continuum

L_{sc}=distance into the stratum-corneum from the surface

x = desired depth

n = integer from 1-∞

t = time in seconds

The consumer uses the following test to rate the lotion based on its effectiveness.

1. Count the number of scales per square inch of skin.
2. Apply given amount of lotion to one of the designated areas. The control is a designated area with no lotion added.
3. After a specified amount of time, consumer rates the lotion based on the amount of scales remaining in the area compared to the control.

Since consumer satisfaction increases as the effectiveness increases, the following graph was created. From the graph, the y score for the consumer satisfaction equation can be found based on the consumer rating.

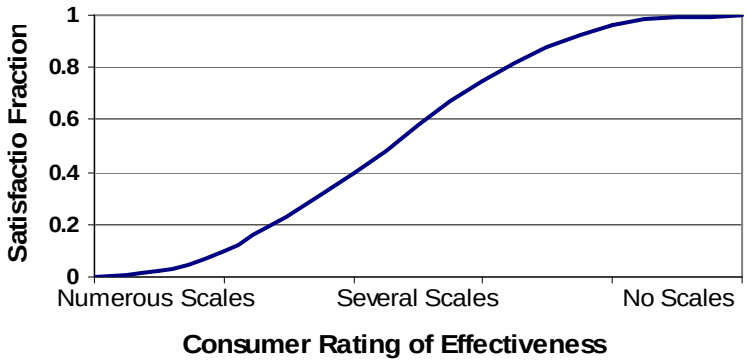

Figure 6. Consumer rating of effectiveness vs. consumer satisfaction fraction

The consumer ratings are then compared against the measured diffusion. The consumer rating scale is numerous scales to no scales. The following graph yields an equation that can be used to find the consumer rating based on the diffusion of the lotion. To create this graph, it was assumed that there is a linear relationship between the effectiveness and the diffusion. If the lotion travels half the ideal distance, than the lotion is half as effective.

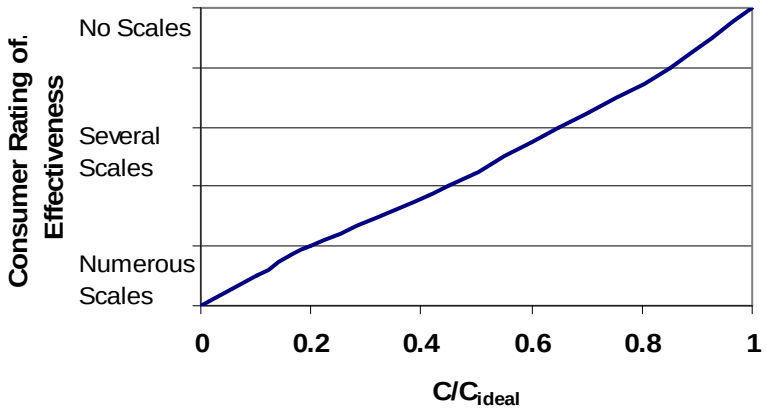

Figure 7. Diffusion vs. consumer rating of effectiveness

Spreadability. Surface tension was used to determine the spreadability of the lotion. Surface tension for each ingredient can be found using the following equation.[16]

$$\gamma = [P(\rho_l - \rho_v)]^4 \quad (3)$$

where, γ=surface tension

P=structural properties of ingredient

ρ_l=density of the liquid

ρ_v=density of the vapor

At low pressures ρ_v can be neglected. Because lotion is an emulsion of water and oil, the surface tension of the emulsion also needs to be calculated. Assuming the oil phase forms perfect spheres in the water phase, the surface tension of the emulsion can be found using Young's equation.[17]

$$\gamma_{ow} = \frac{(\gamma_{oe} - \gamma_{we})}{\cos(\Theta)} \quad (4)$$

where γ_{ow}=surface tension between oil-water

γ_{oe}=surface tension between oil-emulsion

γ_{we}=surface tension between water-emulsion

θ=angle of contact on oil sphere

From here, the surface tension between the emulsion and the skin needs to be found. This was found from a variation of Young's equation.[18]

$$\gamma_{se} = \gamma_s - \gamma_e \cos\theta \quad (5)$$

where γ_s=surface tension of the skin

γ_{se}=surface tension between skin-emulsion

θ=contact angle between emulsion and skin (shown in **Figure 8**)

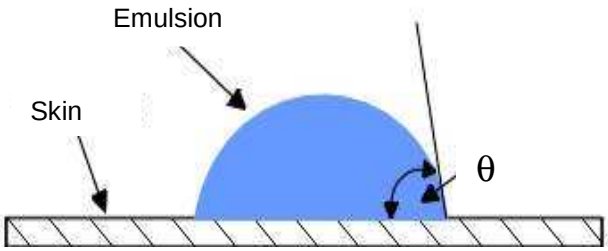

Figure 8: Contact Angle between emulsion and skin[19]

Wettability is a key factor for spreadability. Wetting is when a fluid is spread over a substrate and displaces another fluid, such as air.[20] How well a fluid spreads can be determined from its spreadability coefficient.

$$S_{e/s} = \gamma_s - (\gamma_{se} + \gamma_e) \quad (6)$$

where $S_{e/s}$=spreadability coefficient

If $S_{e/s}$ is positive, the fluid will spontaneously spread. If it is negative, the fluid will not spontaneously spread.

Although this is a key factor for spreadability, a range of values for $S_{e/s}$ for lotions could not be found due to trade secrets. Due to this, spreadability was approximated using the surface tension between skin and the emulsion for the consumer satisfaction model.

The following test is used by consumers to rate the lotion based on spreadability.

1. Pour designated amount of lotion on the hand.
2. Measure the distance the lotion travels in a given amount of time.
3. Consumer rates the spreadability of the lotion.

With spreadability the consumer satisfaction function has a maximum with a medium surface tension. If the surface tension is too low, the lotion will run off the hand too easily. If the surface tension is too high, the lotion becomes too difficult to spread out. The following graph was created to compare the consumer score with the fraction.

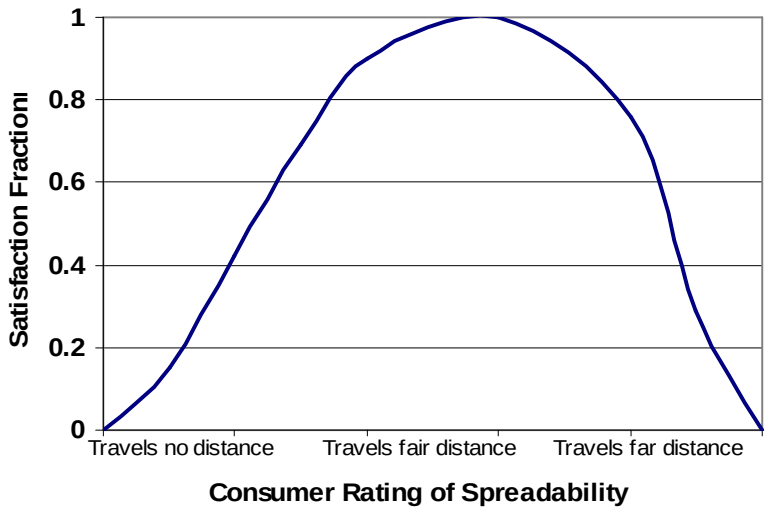

Figure 9. Consumer rating of spreadablity vs. consumer satisfaction fraction.

The consumer rating scale is traveling very far to traveling no distance. The following graph was created comparing the consumer scores with the surface tension of the lotion. This graph was created by assuming that spreadability is inversely proportional to the surface tension between the skin and the emulsion.

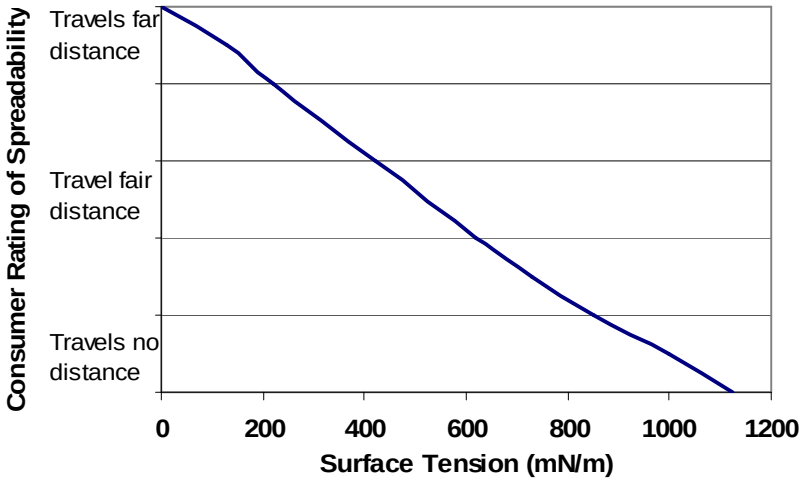

Figure 10. Surface tension vs. consumer rating of spreadability.

Thickness. The thickness of the lotion is based on its viscosity (η). It is found from the following equation.[21]

$$thickness = \eta^{0.5} \qquad (7)$$

In order to find the viscosity of the lotion, the following model was used.[22]

$$\eta = 1 + I(\lambda)\phi \tag{8}$$

where ϕ=volume fraction of dispersed phase

and

$$I(\lambda) = \frac{5.5\left[4\lambda^7 + 10 - \left(\frac{84}{11}\right)\lambda^2 + \left(\frac{4}{\kappa}\right)\left(1-\lambda^7\right)\right]}{10\left(1-\lambda^{10}\right) - 25\lambda^3\left(1-\lambda^4\right) + \left(\frac{10}{\kappa}\right)\left(1-\lambda^3\right)\left(1-\lambda^7\right)} \tag{9}$$

where λ=(ϕ)^1/3

$$\kappa = \frac{\text{viscosity of dispersed phase}}{\text{viscosity of continuous phase}}$$

The following consumer test is used to gather consumer scores.

1. Consumer places a designated thickness of lotion on pad of thumb.
2. Consumer rubs lotion between thumb and index finger in a lateral motion.
3. Consumer rates thickness of lotion.

As with spreadability, there is a max consumer satisfaction with a medium thickness. When the thickness is too high, the lotion becomes hard to work with. When the thickness is too low, the lotion does not create a good layer over the skin to keep the water in the skin. The following graph can be used to compare the consumer score to the consumer satisfaction fraction.

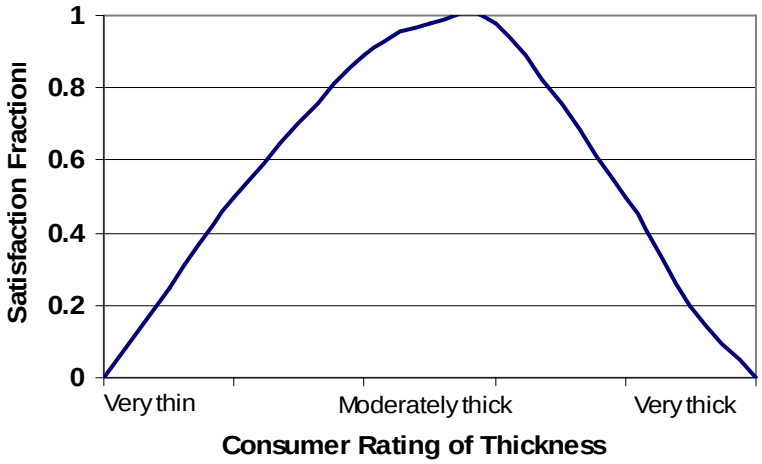

Figure 11. Consumer rating of thickness vs. consumer satisfaction fraction.

The scale for the consumer rating of thickness is very thin to very thick. A graph was created comparing the consumer scores to the thickness of the lotion.

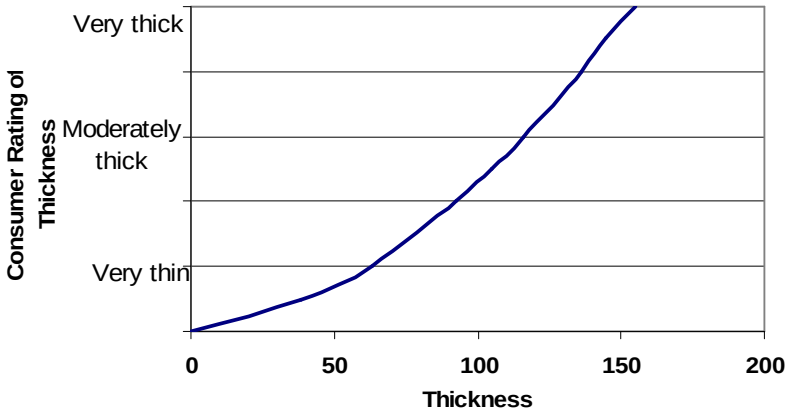

Figure 12. Thickness vs. consumer rating of thickness.

Greasiness. The sum of every water insoluble ingredient multiplied by its concentration is used to find the greasiness of the lotion. The following consumer test is used to find the consumer score.

1. Apply given amount of lotion to designated area on skin.
2. Place a piece of paper on the lotion.
3. Slowly rotate arm 90 degrees.
4. Consumer rates lotion based on how easily the paper slides off the skin.

As the greasiness increases, the consumer satisfaction decreases. Based on this, the following graph was created to compare the consumer satisfaction fraction to the consumer score.

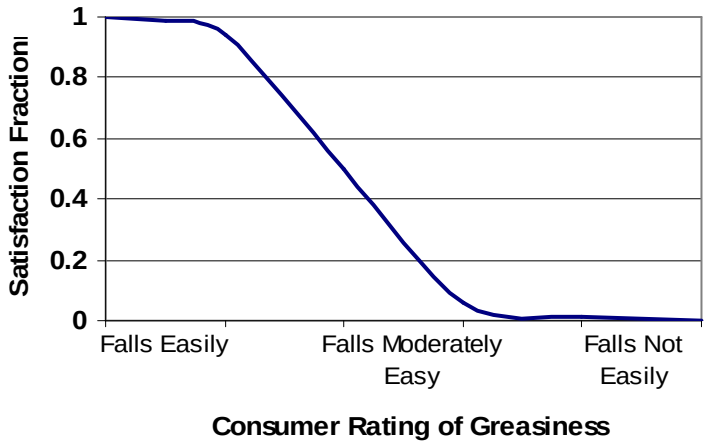

Figure 13. Consumer rating of greasiness vs. consumer satisfaction fraction.

The consumer rating scale is not greasy to very greasy. The following graph was created to compare the consumer score to the concentration of insolubles. This graph was created by assuming that the ease at which the paper falls at is proportional to the concentration of insolubles. As the concentration nears one, the emulsion starts to shift to a water-in-oil emulsion. As this happens, the greasiness of the emulsion increases significantly.

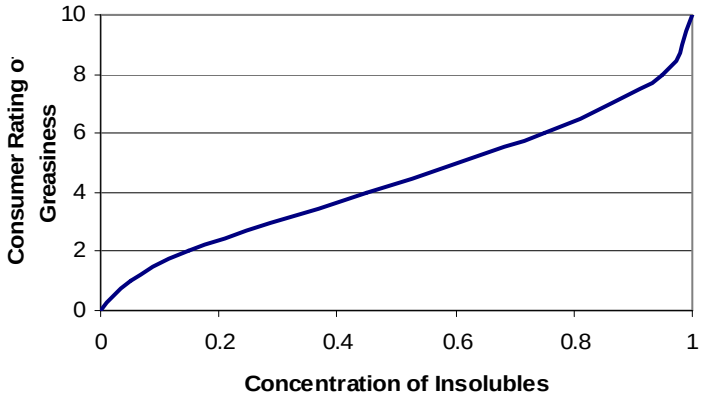

Figure 14. Concentration of insolubles vs. the consumer rating of greasiness.

Smoothness. The smoothness is based on the coefficient of friction and the greasiness. Smoothness is inversely proportional to the coefficient of friction. Greasiness is also inversely proportional to the coefficient of friction. The following relationship between smoothness and greasiness was found by experimentation.

$$smoothness = 0.236\left(-0.0174 * C_I + 2.098\right) \tag{10}$$

Where C_I=the concentration of the insolubles

The following test is used to determine the consumer score of the lotion based on smoothness.

1. Apply a given amount of lotion to skin in a lateral motion.
2. Consumer rates smoothness of lotion.

As the smoothness of the lotion increases, the consumer satisfaction for the consumer increases. The following graph was created to find this relationship.

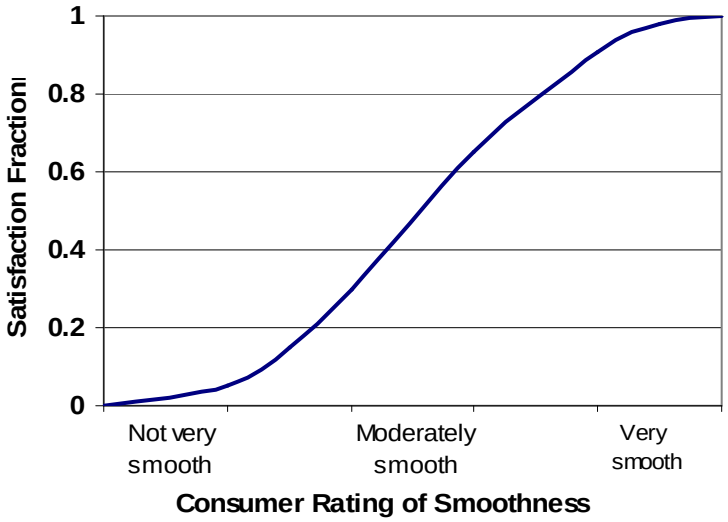

Figure 15. Consumer rating of smoothness vs. consumer satisfaction fraction.

The consumer rating scale is not very smooth to very smooth. The following graph compares the coefficient of friction and concentration of insolubles to the consumers score. An inversely proportional relationship was used between the consumer rating and concentration of insolubles due to smoothness being inversely proportional to the coefficient of friction and proportional to greasiness.

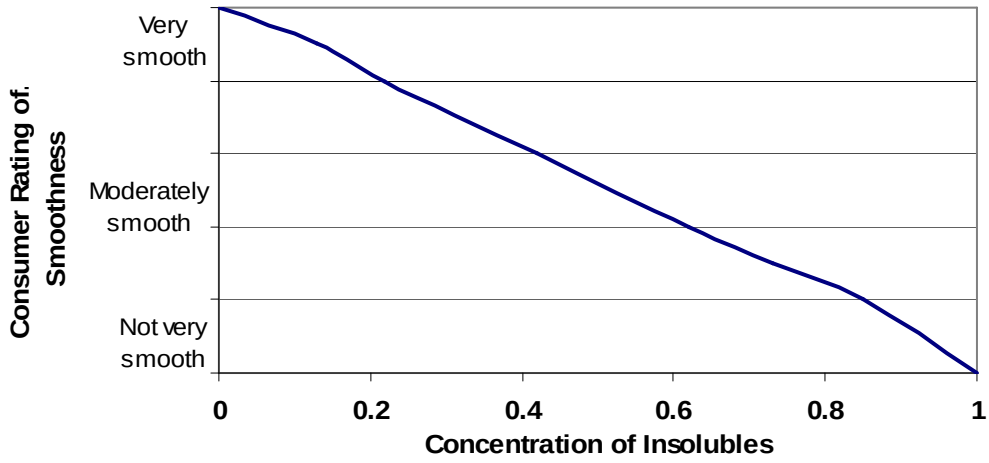

Figure 16. Coefficient of friction and concentration of insolubles vs. the consumer rating of smoothness.

Creaminess. Creaminess is based on thickness and smoothness in the following relationship.[21]

$$\text{creaminess} = [\text{thickness}*\text{smoothness}]^{0.5} \quad (11)$$

The following test is used to find the consumer score of the lotion based on the creaminess of the lotion.

1. Swirl finger in a container of lotion.
2. Consumer rates creaminess of lotion.

Creaminess is similar to smoothness and thickness in that there is a max consumer satisfaction with a medium value of creaminess. The following graph shows this relationship.

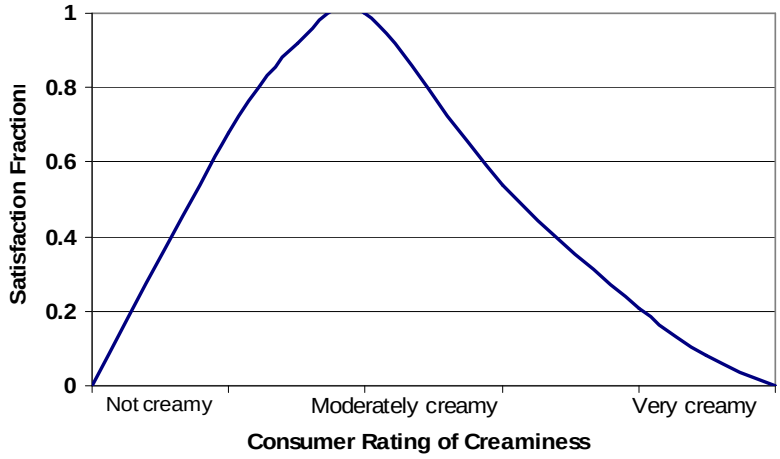

Figure 17. Consumer score vs. consumer satisfaction fraction

The consumer rating scale is not creamy to very creamy. The following graph shows the relationship between smoothness and the consumer score.

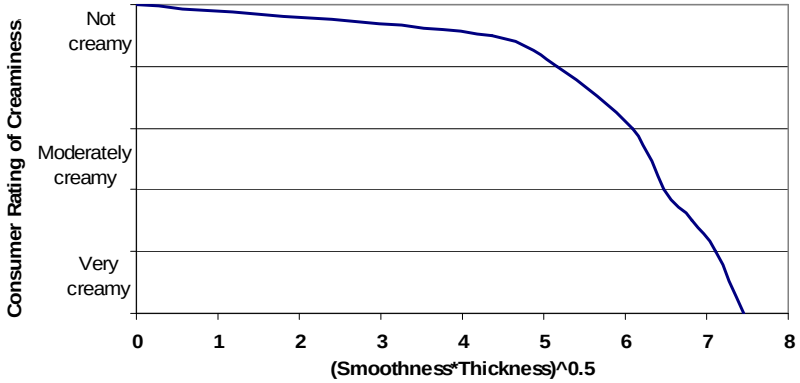

Figure 18. Creaminess vs. consumer rating of creaminess

Absorption Rate. The absorption rate is based on the time it takes for the diffusion to reach steady state in the SC. The following equation from the geometric approach to diffusion through the skin gives the time to steady state.[15]

$$t_{ss} = \frac{0.45 x R_{sc}}{D_{sc}} \tag{12}$$

The consumer score is found from the following test.

1. Apply a known amount of lotion to a designated area of skin. The control is a designated area of the same size located next to the lotion area with no lotion added.
2. Measure the time for the lotion to completely absorb into the skin.
3. Consumer rates the absorption rate of lotion.

The shorter the absorption rate, the higher the consumer satisfaction. Based on this the following graph was created.

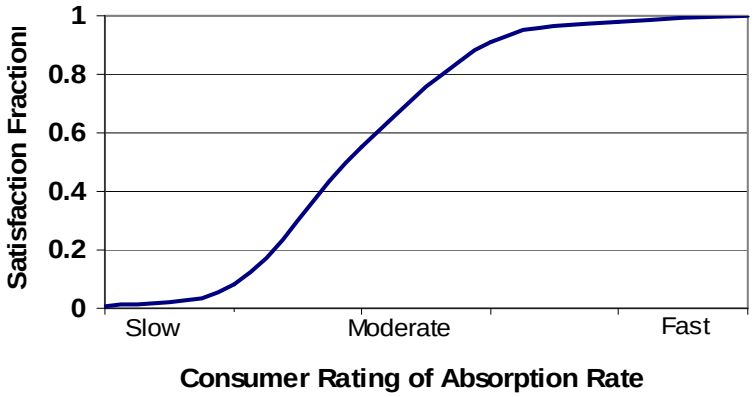

Figure 19. Consumer absorption rate score vs. consumer satisfaction fraction.

The consumer rating scale is slow to fast. Based on the consumer scores, the following graph was created. This curve was made based off of the informal surveys.

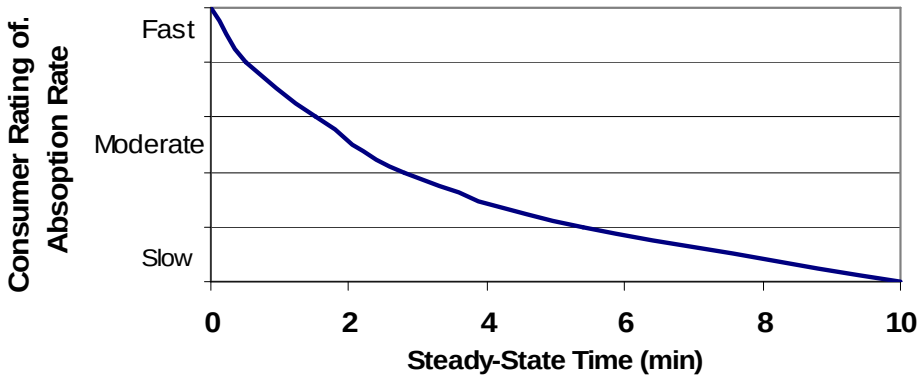

Figure 20. Steady state time vs. consumer rating of absorption rate.

Market. Because ichthyosis vulgaris is a non-life threatening and incurable genetic disease, the market should only increase and never decrease. Approximately 15,000 are born with ichthyosis vulgaris every year.[10] In addition, The symptoms worsen in colder and drier climates.

In order to find our optimum target market, the consumer satisfaction model is used to find the market with the highest consumer satisfaction.

Maximizing Consumer Satisfaction

Microsoft Excel was used to calculate the y value (normalized score) for each property. The weights were determined for the Northwest, Northeast, Southwest, and Southeast regions for old men, old women, young men and young women. The weights were determined based on the climate of the region and a small scale preliminary market analysis.

Solver was set up to change the weights as well as the concentrations of the ingredients to maximize the consumer satisfaction. This allowed the model to choose the best marketing region for the lotion. The following table shows the ranges for the weights that were used in the Microsoft Excel Solver to determine the max consumer satisfaction.

Table 7: Range of Weights for Each Property

Property	Min Weight	Max Weight
Effectiveness	0.45	0.6
Spreadability	0.03	0.1
Thickness	0.02	0.1
Greasiness	0.1	0.2
Smoothness	0.02	0.1
Creaminess	0.05	0.1
Absorption Rate	0.1	0.25

From the consumer satisfaction model, Solver found that the Southwest region is the best region to market the lotion. The weights used for the southwest region is found in **Table 8**.

Table 8: Weights for the Southwest Region

	Southwest			
	Old Men	**Young Men**	**Old Women**	**Young Women**
Effectiveness	0.55	0.45	0.5	0.45
Spreadability	0.05	0.03	0.03	0.05
Thickness	0.03	0.02	0.02	0.05
Smoothness	0.02	0.05	0.02	0.05
Creaminess	0.05	0.05	0.03	0.05
Absorption Rate	0.2	0.25	0.25	0.2
Greasiness	0.1	0.15	0.15	0.15

In addition to choosing the concentrations of the ingredients, Solver also chose the ingredients. For each type of active ingredient, multiple choices were added to the model. A constraint was added that the sum of the concentration for each type of ingredient needed to be within the bounds stated in **Table 5**.

Using all of these constraints, Solver found the max consumer satisfaction to be 68%. **Table 9** shows the ingredients and their concentrations in the maximum consumer satisfaction lotion.

Table 9: Maximum Consumer Satisfaction Ingredients and Concentrations

Ingredient	**Composition**
Deionized Water	70.000%
Sorbitol	0.050%
Ceramide	3.002%
Dimethicone	0.014%
Cholesterol	1.001%
Castor Oil	0.050%
Carbomer	5.000%
Phenoxyethanol	5.000%
EDTA	5.000%
γ-linoleic acid	1.000%
Maleic Acid	0.004%
Cetyl Alcohol	8.832%
Lactic Acid	1.000%
Titanium Dioxide	0.050%

While this composition gives the highest consumer satisfaction, it is not economically feasible. The net present worth (NPW) was calculated for various prices and α values. The α value is a measure of how well the population knows about the product. **Figure 21** shows that for product price of $1 to $100 is not profitable.

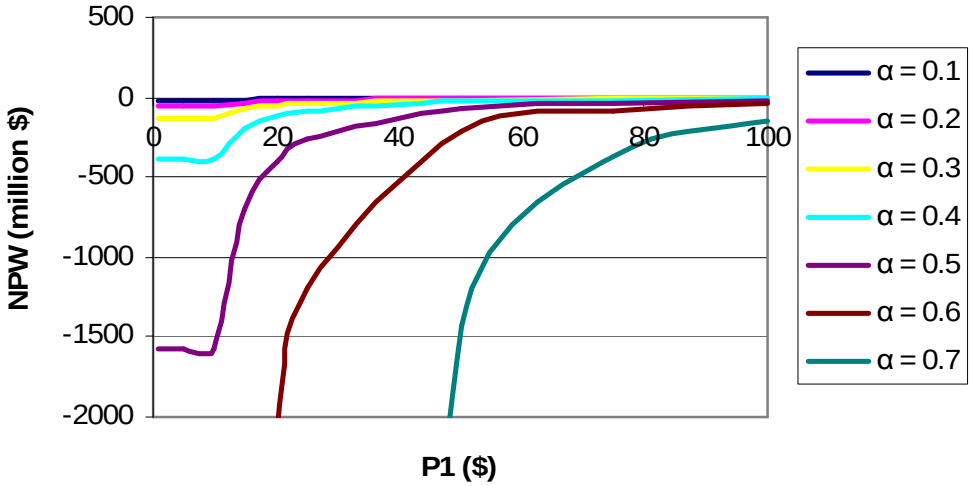

Figure 21. NPW vs. product price (p_1) at various α

As it is seen in **Figure 21**, the NPW never attains a positive value no matter how high the product price is. It is clear from this analysis that the product must be adjusted in order to make the product profitable. An analysis was done to see what the affect of the competitor's price (p_2) has on the profitability of the maximum consumer satisfaction lotion. The following figures show NPW vs. p_1 for p_2 values of $5 and $15.

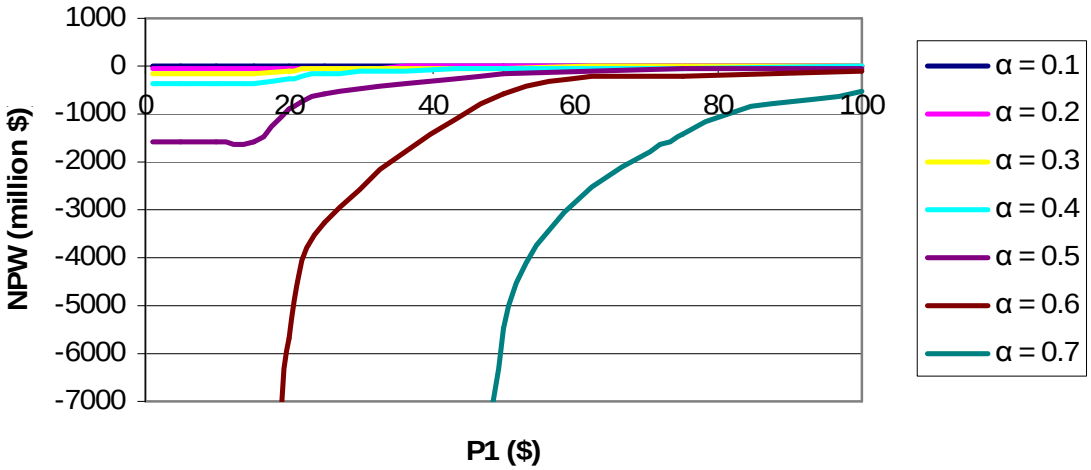

Figure 22. NPW vs. product price (p_1) at various α for p_2 = $5

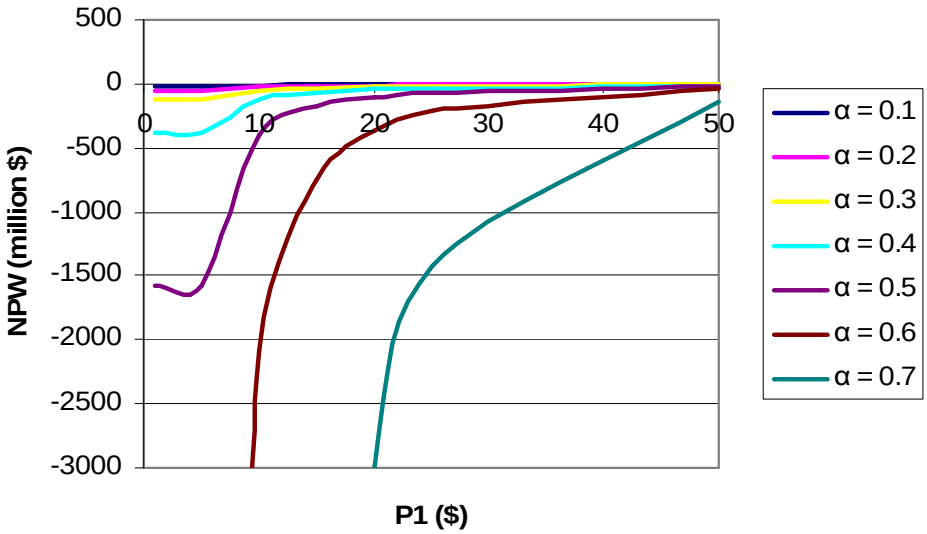

Figure 23. NPW vs. product price (p_1) at various α for p_2 = \$15

Both figures show that the maximum consumer satisfaction lotion is not profitable for various competitor prices. The lotion must be adjusted in order to make it profitable.

Business Model

In order to make the process economically feasible, a demand model was created. The demand model changes the ingredients used and their concentrations to find the most economical solution. It can also change the price of the product and the demand.

Price-Demand-Quality Models

The demand model was based on the following equation.

$$\beta p_1 d_1 = \alpha p_2 d_2 \left(\frac{d_1^{\alpha}}{d_2^{\beta}} \right) \tag{13}$$

where, $\beta = \frac{S_2}{S_1} = \frac{Competitors\ Happiness}{Our\ Products\ Happiness}$

α=awareness of existence of new product

p_1=our price

p_2=competitors price

d_1=our demand

d_2=competitors demand

There are actually two models within our demand model. Depending on the size of our demand, the NPW and ROI is calculated with a budget model or a fixed demand model. The Budget model is used when d_1+d_2 is less than the total demand (D). When this happens, the price of the product becomes the main constraint. When the individual demands (d_1+d_2) exceed the total demand, the fixed demand model is used. With this model, the demand constraint is reached before the price. When our price is equal to or greater than the competitors, the budget model worked. When our price is below that of the competitors, the budget model failed and the fixed demand model worked.

For each of the models, a circular reference was used to calculate d_1. A $\Phi(d_1)$ formula was found for each model based on equation (22). An initial d_1 was estimated and Excel iterates until $d_1= \Phi(d_1)$. The following is the formula for the budget model.

$$\Phi\left(d_1\right)=\left(\frac{\alpha}{\beta}\right)\cdot\left(\frac{p_2}{p_1}\right)\cdot\left\{\left(\frac{Y}{p_2}\right)-\left(\frac{p_1}{p_2}\right)\cdot d_1\right\}^{1-\beta}\cdot d_1^{\alpha} \qquad (14)$$

Where $Y=p_2D=p_1d_1+p_2d_2$

$$d_2=\frac{Y}{p_2}-\frac{p_1}{p_2}$$

This model works as long as d_1+d_2 is less than D. If this is not true, then the fixed demand model is used. The following formula is used for the fixed demand model.

$$\Phi\left(d_1\right)=\left(\frac{\alpha}{\beta}\right)^{1/1-\alpha}\left(D-d_1\right)^{1-\beta/1-\alpha} \qquad (15)$$

Where $D = d_1+d_2$

$$d_2=D-d_1$$

The overall price-demand-quality model uses an if/then statement that allows both the budget and the fixed demand model to be calculated simultaneously. If the budget model is not valid than the overall model uses the numbers calculated from the fixed demand model.

The demand model uses the overall demand for lotion by patients with ichthyosis vulgaris. The overall demand was found by multiplying the population of the market region by 15.4%. This percentage came from 0.4% of the population having ichthyosis vulgaris and assuming that 15% of the population has xerosis at any given time.

To find the most profitable lotion, the return on investment (ROI) was maximized. The ROI was calculated using the following equation.[23]

$$ROI = \frac{Net\ Profit}{TCI} \tag{16}$$

There are several things that go into the calculation of the profit, including administrative, advertising, raw material costs and equipment cost. Since the equipment costs depend on the amount of product, an equation was formulated that relates the cost to the size. For the max consumer satisfaction, the equipment cost varied with the demand. For the max profit product, it was assumed that the plant would be built for the largest capacity, so the equipment cost was fixed. The equipment costs are summarized in the following table.

Table 10: Equipment Cost[24, 25, 26, 27]

Equipment	Cost ($)
Storage Tanks	80,200
Water Phase Mixing Tank	20,100
Oil Phase Mixing Tank	13,500
Bath Sonicator	4,100
Homogenizer	21,000
2 Pumps	5,000
Colloid Mill	15,000
Total	**158,900**

Competitor's Consumer Satisfaction. In order to find β, the competitor's consumer satisfaction needed to be found using our consumer satisfaction model. Using the Cosmetic & Toiletry Formulation Book, the ingredients and concentrations for one of the competitors was found.[28]

A consumer satisfaction of 51% was found for the competitor when the competitor's ingredients and concentrations were plugged into the consumer satisfaction model. The competitor's ingredients and compositions are shown in **Table 11**.

Table 11: Competitors Ingredients and Compositions

Ingredient	Composition
Deionized Water	70.840%
C10-30 Alkyl Acrylate	0.600%
Titanium Dioxide	3.000%
Allantoin	0.200%
PEG	3.000%
Methylparaben	0.150%
Dilaureth-4 Phosphate	3.000%
Cetyl Alcohol	2.000%
Mineral Oil	10.300%
Decyl Oleate	6.200%
Propylparaben	0.050%
TEA	0.360%
Phenoxyehtanol	0.200%
Fragrance	0.100%

Max Profit Product. Using the business model, the consumer satisfaction was found to be 62%. The following table shows which ingredients and their concentrations were chosen.

Table 12: Max Profit Ingredient and Compositions

Ingredient	Composition
Deionized Water	70.000%
Glycerin	10.000%
Petrolatum	1.000%
Isopropyl Palmitate	1.046%
Isostearic Acid	2.000%
Phenoxyethanol	1.000%
Citric Acid	0.004%
Cetearyl Alcohol	13.950%
Malic Acid	1.000%

In order to calculate the ROI and NPW, α was first assumed to be fixed. This was used to determine what price our product should be marketed at. The following figure shows the NPW for a fixed α from 0.1-0.8. It was assumed α is at a maximum at 0.8 due to limitations in the model. The budget and fixed demand model could not converge above 0.8. It was also assumed that α would never reach 1 due to a small percentage of the population that buys based on consumer loyalty; advertisements do not influence their purchasing decisions.

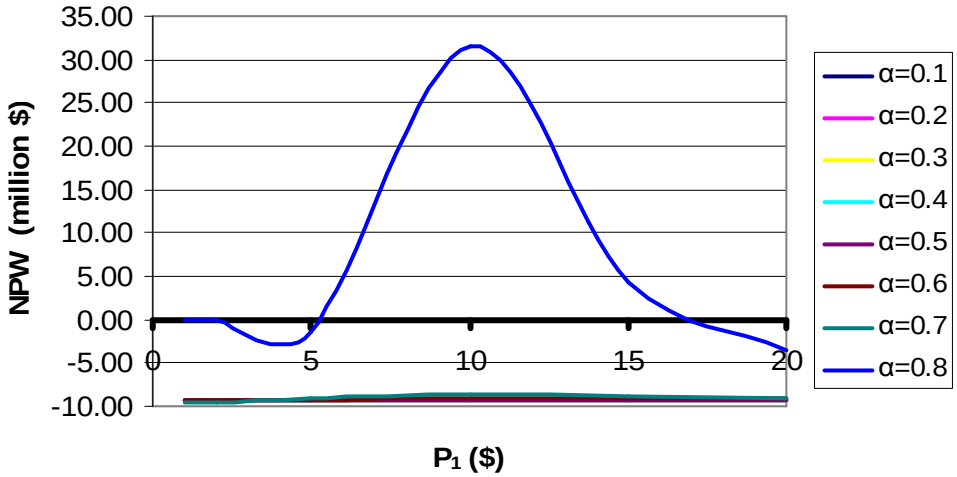

Figure 24. NPW vs. p_1 for α=0.1-0.8

From this graph it is seen that only with an α of 0.8 will the product be profitable. To determine what price to sell our product at, another graph was created showing the NPW for α=0.7-0.8.

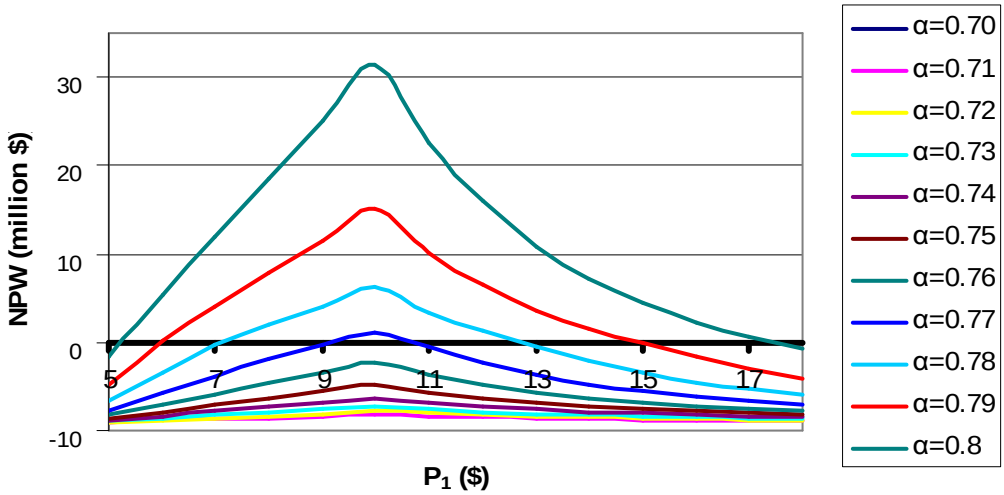

Figure 25. NPW vs. p_1 for α=0.7-0.8

There is a maximum NPW at p_1=\$10. This price was used when considering a variable α over time. The α was adjusted over time to more closely simulate real life. The following figure shows how α was adjusted over time.

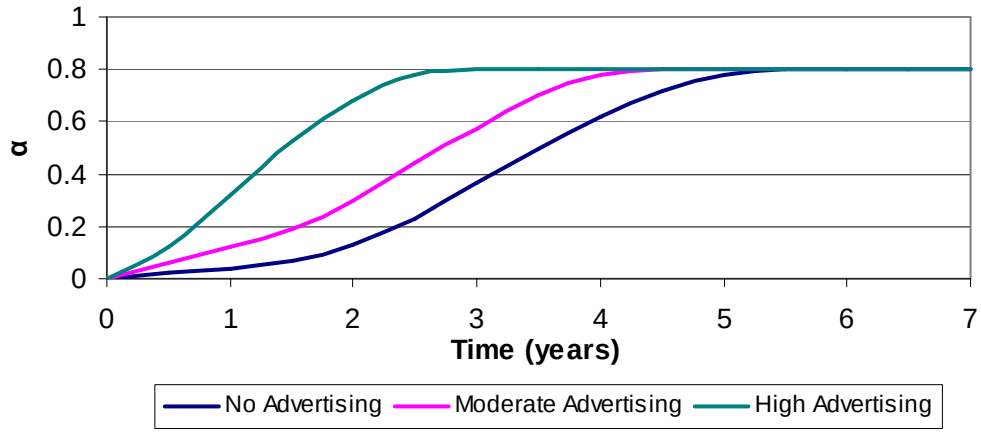

Figure 26. α vs. time at various amounts of advertising.

The advertising used is TV, women's magazines, journals, free samples, and websites. It was assumed that women do a majority of the shopping for the household, so the advertising is targeted towards women. A preliminary estimate on advertising costs showed that moderate advertising would be around \$3.9 million. High advertising would be around \$6.7 million. The following figures show the distribution of the advertising costs.

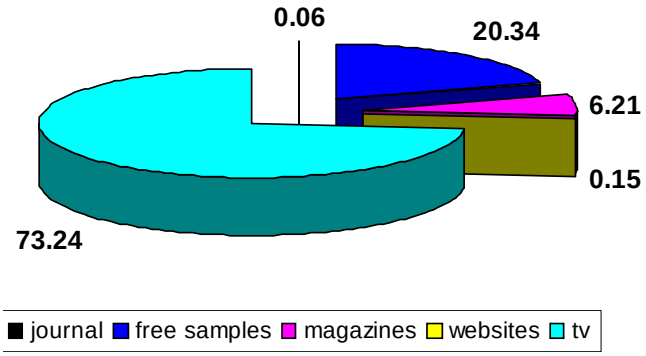

Figure 27. Distribution of moderate advertising costs in percentages[29,30,31,32]

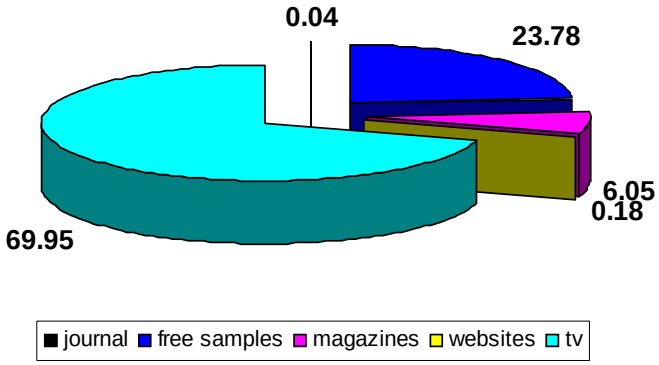

Figure 28. Distribution of high advertising costs in percentages

The pie charts show that the most expensive advertising is tv. The free samples are also a larger percentage of the total costs.

There is clear connection between the advertising and the time it takes to increase α to the maximum. All three scenarios ROI were compared to see how advertising affects the profit.

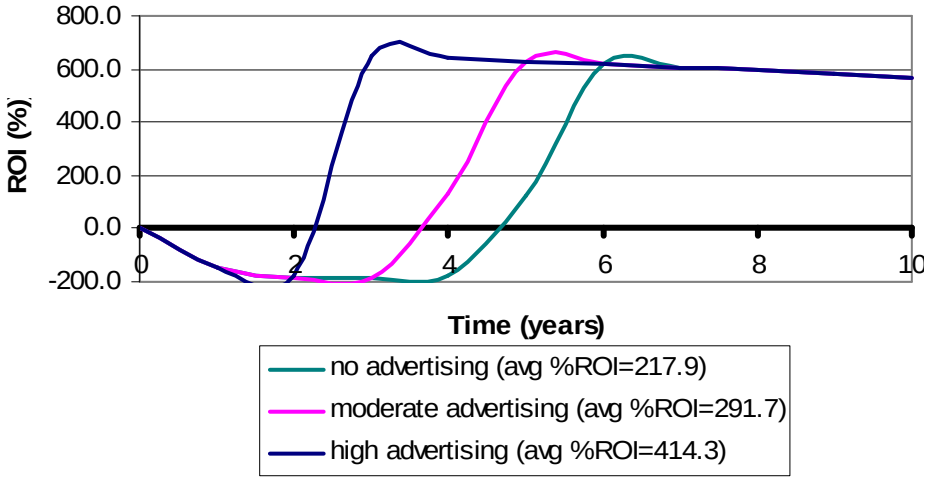

Figure 29. ROI vs. time for various amounts of advertising

Although for approximately the two years the process is not profitable, the average for the ten year span is profitable. As the amount of advertising increase, the time it takes to start making a profit decreases. **Table 13** shows the NPW for the three different scenarios of advertising.

Table 13: NPW for Various Amounts of Advertising.

Amount of Advertising	NPW (million $)
None	5.50
Moderate	9.96
High	19.03

A higher NPW can also be reached with high advertising. **Table 13** and **Figure 29** show that it is important to start advertising the product before it is released to the public.

The raw material costs were looked at over time to see how it is affected by the advertising and demand. As shown in **Figure 30**, the raw material costs depend on the demand which is dependent on α. It is also shown that the raw material costs increase with the amount of advertising.

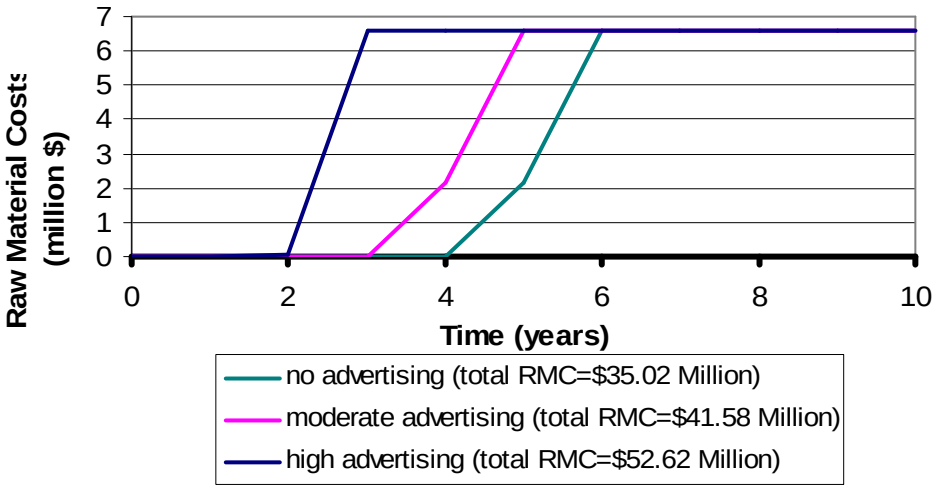

Figure 30. Raw material costs vs. time for varying amounts of advertising.

Conclusions

From the consumer satisfaction model that was created, it was found that a perfect product is not economically feasible. While the consumer satisfaction was found to be 68%, the average ROI was $-5.89*10^6$. A demand model was then created to find a profitable solution. The demand model maximizes NPW while changing the demand as well as the ingredients and their concentrations. **Table 14** compares the economics for the maximum satisfaction and maximum profit products.

Table 14: Economic Values for Maximum Satisfaction and Maximum Profit Product*.

The maximum profit product economics are for changing alpha with high advertising.

	Product	
	Maximum Satisfaction	**Maximum Profit**
Total Capital Investment (10^6)	1.0	1.06
Raw Material Cost (10^6)	49000	52.62
Return on Investment (%)	-5900000	414
Net Present Worth (10^6)	-280000	19.03

While the TCI value is higher with the maximum profit product, the raw material costs are lower and the ROI and NPW are significantly higher.

From the demand model the consumer satisfaction was found to be 62% with an average ROI of 414%. This is still higher than the competitor's satisfaction of 51%.

While the models give a good approximation on the lotion product and process, there are still flaws to be worked out. There are a few ingredients that are in the competitor's lotion, but can only be approximated for the consumer satisfaction model. Only the viscosity of the competitor's lotion is known. In order to have a better comparison between our product and the competitors, the model needs to have more accurate physical properties (i.e. viscosity, surface tension, etc.) for the competitor's ingredients.

Microsoft Excel's Solver was also found to not have the capabilities to completely handle all of the constraints. Some of the calculations had to be manipulated manually instead of Solver going through all of the options. Another software program should be looked into that can better handle the number of constraints and the non-linear equations.

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