

DESIGN II – CHE 4273

2007

SLOW RELEASE FRAGRANCE AND DISINFECTANT FOR CARPET

Authors:

Carrie Street

University of Oklahoma

Chemical, Material, and Biological Engineering

Justin Woody

University of Oklahoma

Chemical, Material, and Biological Engineering

Presented to:

Dr. Bagajewicz

University of Oklahoma

Chemical, Material, and Biological Engineering

Executive Summary

Carpet can serve as a haven for dust mites, mold, mildew, and bacteria. A freshening and disinfecting powder product was designed to address these problems and provide a long lasting fragrance. The product includes baking soda to absorb moisture, boric acid to serve as a disinfectant, and linalool (lily) fragrance in PLGA (polymer) particles to provide a long lasting scent.

The following consumer utilities were considered in the design of this product: disinfectant effectiveness, scent intensity, fragrance duration, toxicity, odor elimination, and scent type. Disinfectant effectiveness related the percentage of mites killed by the product to the amount of boric acid per unit area of carpet. A mass transfer model allowed for the relation of fragrance particle dimensions to the scent intensity, or concentration of linalool at a plane five feet above the carpet, and the fragrance duration. The toxicity and odor elimination utilities allowed for the determination of the amount of boric acid and baking soda per unit area of carpet, respectively.

The FCI (Fixed Capital Investment), working capital, and TCI (Total Capital Investment) were estimated to be \$252,000; \$126,000; and \$378,000; respectively. Maximizing the utility gave a product composed of 0.1% linalool, 0.2% PLGA, 20.06% boric acid, and 79.1% baking soda. With the utility maximized, the product could not be sold at any price to have a positive NPW (Net Present Worth). Maximizing the NPW gave a product composed of 0.01% linalool, 0.02% PLGA, 17.9% boric acid, and 80% baking soda. Strauss plots and Monte Carlo simulations demonstrated that the NPW was most sensitive to changes in boric acid and baking soda prices.

Extended Summary

Carpet can serve as a haven for dust mites, mold, mildew, and bacteria. On average, one gram of dust includes 19,000 dust mites, which results in significant amounts of harmful fecal matter. Dust mites require a moist environment and humidity above 55% because they do not drink water but absorb it from the air. Dust mites' main food source is dead human skin cells. Humans shed about 1.5 grams of skin cells per day, aiding in dust mite growth and reproduction. Molds are microscopic fungi which mature rapidly and require moist areas and high humidity for growth. They produce an identifiable smell which can be overwhelming and, most importantly, produce health hazards, such as floating spores and even lethal mycotoxins. Bacteria produce butyric acid, which is known for a rancid butter or vomit smell. Shampooing carpets leaves up to 20% of the water in the carpet, creating the moist environment in which dust mites, mold, mildew, and bacteria thrive. A dry freshening and disinfecting powder product was designed to address the problems of dust mites, mold, mildew, and bacteria, as well as provide a long lasting fragrance. The product includes baking soda to absorb moisture, boric acid to serve as a disinfectant, and linalool (lily) fragrance in PLGA (polymer) particles to provide a long lasting scent. Baking soda is an all-purpose absorbent. Boric acid is a non-toxic insecticide effective against dust mites, fungus, mold, mildew, and bacteria. PLGA allows for the controlled release of linalool, a natural fragrance.

A utility function method allows for the quantification of consumer preference. In polls, consumers list product characteristics they consider essential and rank the characteristics in order of importance. The following consumer utilities were considered in the design of this product: disinfectant effectiveness, scent intensity, fragrance

duration, toxicity, odor elimination, and scent type. The budget constraint for the price and demand model was found to be 54 million dollars from market analysis. Disinfectant effectiveness related the percentage of mites killed by the product to the amount of boric acid per unit area of carpet. A mass transfer model allowed for the relation of fragrance particle dimensions to the scent intensity, or concentration of linalool at a plane five feet above the carpet, and the fragrance duration. Consumer preference was greatest for a scent intensity between “Trace” and “Slight.” Consumer preference increased with increasing fragrance duration; consumers preferred a product with an infrequent application requirement. The toxicity and odor elimination utilities allowed for the determination of the amount of boric acid and baking soda per unit area of carpet, respectively. The relationship between the toxicity and the amount of boric acid (the most toxic component of the product) per unit area of carpet was determined by examining the LD₅₀ of boric acid versus various other chemicals. The relationship between the odor elimination and the amount of baking soda per unit area of carpet was determined by examining the odor elimination quality of existing products. Consumers preferred a lily scent when given a choice of lily, rose, and citrus scents. The production process involves preparation of the fragrance particles by double emulsion and mixing the fragrance particles with boric acid and baking soda.

Cost analysis and optimization were performed utilizing a price and demand model. For preliminary analysis, consumer awareness, diminishing marginal utility, and Borid 16 oz. product price were 0.9, 0.8, and \$10.00, respectively, and remained constant throughout the analysis. Distribution center locations were chosen such that they were evenly distributed throughout the continental United States. The population and average

humidity of each distribution center city were utilized to assign the relative amounts of production that would be sent to each distribution center. The optimum plant location was determined to be Oklahoma City, OK. The FCI (Fixed Capital Investment), working capital, and TCI (Total Capital Investment) were estimated to be \$252,000; \$126,000; and \$378,000; respectively.

Maximizing the utility gave a product composed of 0.1% linalool, 0.2% PLGA, 20.06% boric acid, and 79.1% baking soda. With the utility maximized, the product could not be sold at any price to have a positive NPW (Net Present Worth). Maximizing the NPW gave a product composed of 0.01% linalool, 0.02% PLGA, 17.9% boric acid, and 80% baking soda. This composition resulted in a NPW of \$1,730,000. Strauss plots and Monte Carlo simulations demonstrated that the NPW was most sensitive to changes in boric acid and baking soda prices.

Table of Contents

Introduction.....	- 1 -
Utilities.....	- 5 -
Disinfectant Effectiveness	- 7 -
Scent Intensity and Fragrance Duration.....	- 10 -
Mass Transfer Model	- 12 -
Toxicity	- 21 -
Odor Elimination	- 23 -
Scent Type	- 25 -
Production Process.....	- 26 -
Cost Analysis	- 29 -
Shipping and Distribution Model.....	- 32 -
TCI and NPW	- 33 -
Raw Materials Pricing.....	- 34 -
Operating Labor and Utilities	- 34 -
Equipment Sizing and Pricing	- 34 -
Optimization	- 35 -
Risk Analysis	- 37 -
Future Considerations	- 44 -

Introduction

Every time someone walks into a home they are hit by “the smell.” This wave of smell is pleasant some of the time, but most of the time it is very unpleasant. Women and men from all walks of life perform numerous tasks to defend against such odors. Their tactics include lighting candles, spraying air fresheners, and tossing carpet powders 2-3 times a week in 4-5 rooms. These methods can add a significant burden to a family’s budget when the product cost and frequency of application is taken into account. Another problem these consumers face is that current products only mask the odor for a few days without eliminating the cause. There is a growing need and a potential market for a product which not only could be applied once every few months, but also would eliminate dust mites, mold, mildew, and the odor produced by bacteria. Such a product would have to produce a lasting scent for a much longer time than the present products on the market. With existing technologies, these goals can be accomplished in an affordable manner for the consumer.

In designing such a product, a desirable goal would be to eliminate pests such as dust mites, mold, and mildew, as well as do away with the odor produced by bacteria. Each of these problems has a preferential environment which must be understood in the hopes of irradiation. Dust mites, which are considered to be the most common cause of allergies and asthma, are microscopic arachnids (400 μm length) that are globular in shape. In 10 weeks, just one of the millions of dust mites that inhabit a given carpet will produce over 2000 fecal particles and even more enzyme infested dust particles that can cause potential health problems.¹ These particles are also easily suspended in the air for long periods of time. On average, one gram of dust includes 19,000 dust mites, which

results in significant amounts of harmful fecal matter.² Dust mites require a moist environment and humidity above 55% because they do not drink water but absorb it from the air. Dust mites' main food source is dead human skin cells. Humans shed about 1.5 grams of skin cells per day, aiding in dust mite growth and reproduction.

Molds also pose many health problems, as well as unpleasant odors. Molds are microscopic fungi which mature rapidly and require moist areas and high humidity for growth. They produce an identifiable smell which can be overwhelming and, most importantly, produce health hazards, such as floating spores and even lethal mycotoxins. Mildew, a form of mold, can also pose potential problems for carpets due to its musty odor.^{3,4}

Bacteria have also been found to cause a substantial problem for carpets. Researchers have found that most carpets contain large quantities of anaerobic bacteria which emit a chemical called butyric acid. Butyric acid is known for a rancid butter or vomit smell. These bacteria are found in the latex backing of the carpet, and they also require moist environments to reproduce.⁵

While shampooing carpets provides a means for cleaning stains and removing dirt from carpets, this process can produce some problems. Up to 20% of the water used for carpet cleaning can remain in the carpet, creating the moist environment in which dust mites, mold, mildew, and bacteria thrive. This situation is analogous to shampooing one's hair and not rinsing it; a soapy, sticky residue is left behind that clings to any dust particle that is present.

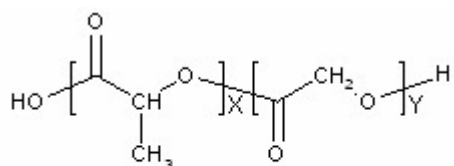
The current leading carpet products on the market include, but are not limited to, Arm & Hammer, Borid, and Capture Clean. Arm & Hammer contains around 99%

sodium bicarbonate or baking soda and around 1% fragrance. This product absorbs odors and provides a fresh smell for a few days. Borid is approximately 100% boric acid and is designed to eliminate dust mites, mold, mildew, and bacteria. However, Borid does not provide a scent to mask the odors these pests create. Capture Clean is around 100% baking soda and absorbs smells leaving carpets fresh.^{6,7,8,9} These products, however, do not confront both the problems of odor and the causes of the odors, nor do they last a considerable length of time. A design is needed that will address both of these issues.

The challenge involved in the development of a novel product lies in designing a freshening and disinfecting powder. The powder must contain an element to absorb odors, kill pests, and most of all create a scent that will last for weeks. A potential chemical to absorb odors is sodium bicarbonate or baking soda,¹⁰ to kill dust mites is boric acid or tannic acid,¹¹ to kill mold and mildew is boric acid or sodium propionate,¹² and to neutralize smell from bacteria is baking soda.^{13,11} Potential fragrances that could be used in the design include citral which smells like lemons, geraniol which smells like roses, or linalool which smells like lilies.^{14,15,16}

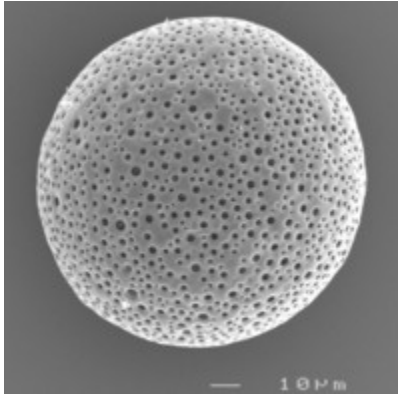
The chosen design was a product composed of baking soda, boric acid, linalool, and a slow release polymer, PLGA, to encapsulate the linalool. Baking soda, which is sodium bicarbonate, is a white solid alkaline crystalline powder and is produced by the solvay process with around 100,000 tons produced each year. It is an all-purpose adsorbent which can be used in the refrigerator, carpet, microwave oven, etc. It can also be used for pest control, cosmetics, and even as a cleaning agent.¹⁷ Boric acid is a mild acid which is used as an insecticide, antiseptic, and a flame retardant. Boric acid, which exists as a colorless crystalline or white powder, is mainly used as a non-toxic insecticide

for cockroaches, fleas, dust mites, fire ants, and termites. The small boric acid crystalline particles cling to the insects' legs and cause fatal chemical burns. Boric acid can also be used exterminate fungus, mold, and mildew making it a great component in this product design.^{18,10,11,12,13} The fragrance linalool is a naturally occurring terpene alcohol which can also be synthesized in large quantities. Linalool is found in many flowers and spice plants and is used in many household products such as soaps, detergents, and lotions.¹⁴ To utilize the fragrance linalool effectively for slow release, the polymer PLGA will be used. PLGA, or poly(lactic-co-glycolic acid) is a polymer micro sphere (10 μm diameter) which has been approved by the FDA and has been used in a variety of slow release applications. Many of its uses result from its biocompatibility, as well as biodegradability. PLGA degrades by hydrolysis of the ester linkages in the presence of moisture and can be composed in different ratios of copolymers (x and y shown below) allowing for more control of the degradation time. PLGA degrades to the original monomers, lactic acid and glycolic acid.



x - Number of units of Lactic Acid
y - Number of units of Glycolic Acid

Fully immersed in water, PLGA can last up to 2 months and much longer with the lower levels of moisture found in carpets.¹⁹ PLGA allows liquids (medical and commercial) to be stored and released slowly over time and will be designed to encapsulate the fragrance linalool. An example of a micro sphere is shown below:²⁰



PLGA particle

Utilities

The utility function allows for the quantification of consumer preference. The utility equation is given by:

$$U = \sum U_i w_i$$

U = utility w = importance weight

i = characteristic

In polls, consumers list product characteristics they consider essential and rank the characteristics in order of importance. The consumer poll results can be used to assign weights to the important characteristics such that the sum of the weights equals one. The weights allow for each characteristic to be considered in relation to the other characteristics during the product design. The important characteristics, along with their respective weights appear in Table 1.

Table 1

Characteristic	Weight
Disinfectant Effectiveness	0.21
Scent Intensity	0.22
Fragrance Duration	0.19
Toxicity	0.09
Odor Elimination	0.15
Scent Type	0.14

Tests are then performed to measure the happiness of the consumer. Test results allow for the relation of desired product characteristics to physical properties of the product.

The budget constraint, Y, is given by the following equation:

$$Y = P_1 D_1 + P_2 D_2$$

where P and D refer to the price and demand, respectively, and 1 and 2 refer to our product and the competitor's product, respectively. Utilizing the equation above with a P_2 and D_2 equal to \$10.00 and 5,400,000, respectively, the budget constraint, Y, is equal to \$54,000,000. Likewise, this budget constraint correlates well with the size of the carpet disinfectant market which has also been shown to be approximately 54 million dollars.

Disinfectant Effectiveness

Disinfectant effectiveness relates the percentage of mites killed by the product to the amount of boric acid per unit area of carpet. The first step in determining this utility was to relate the utility of the consumer to the percentage of mites killed.



Figure 1 Utility versus Disinfectant Effectiveness (% of mites killed)

As shown in Figure 1, consumer utility was directly proportional to the percentage of mites killed. The consumer would be completely satisfied with 100% of the mites killed, and the consumer would be completely dissatisfied with 0% of the mites killed. The relationship between percentage of mites killed and the amount of boric acid per unit area of the carpet could be found utilizing a statistical method, such as a random walk generator as shown below in Figure

2. The complex nature of boric acid and the way in which it kills different insects (eating the crystals versus only having to touch the crystal) results in an exponential function due to mathematical description of the random walk. This was used in correlation with an assumed 20% of the formulation of the competitor killing 90% of the mites^{21,22} and is shown in Figure 3. This corresponds to the amount of boric acid the competitor, Borid, has in their formulation, which is near 0.1 g/ft². The relationship between utility and amount of boric acid per unit area is shown in Figure 4. Because the utility is a linear function of effectiveness, the relationship between utility and amount of boric acid per unit

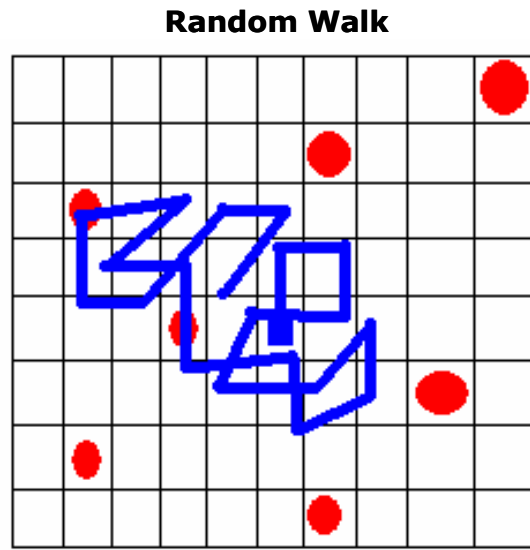


Figure 2 Random Walk Schematic

area, shown in Figure 4, resembles the relationship between effectiveness and the amount of boric acid per unit area.

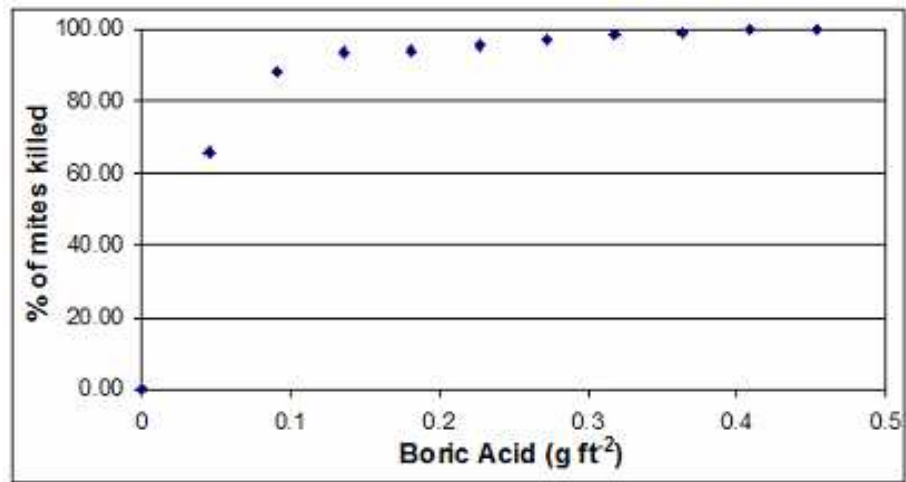


Figure 3 Amount of Boric Acid g/ft⁻² vs. % of mites killed

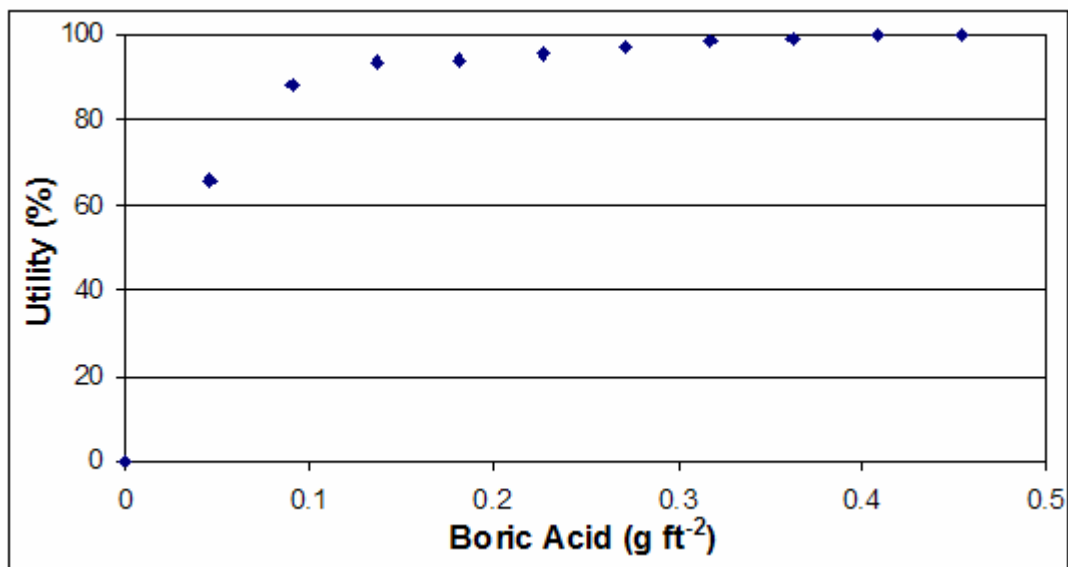


Figure 4 Utility versus amount of boric acid per unit area.

Scent Intensity and Fragrance Duration

Scent intensity relates the fragrance concentration to the number of fragrance particles per unit area of carpet. From Figure 5, consumer preference is greatest for a “Trace” scent intensity. Utility subsequently decreases with increasing scent intensity;

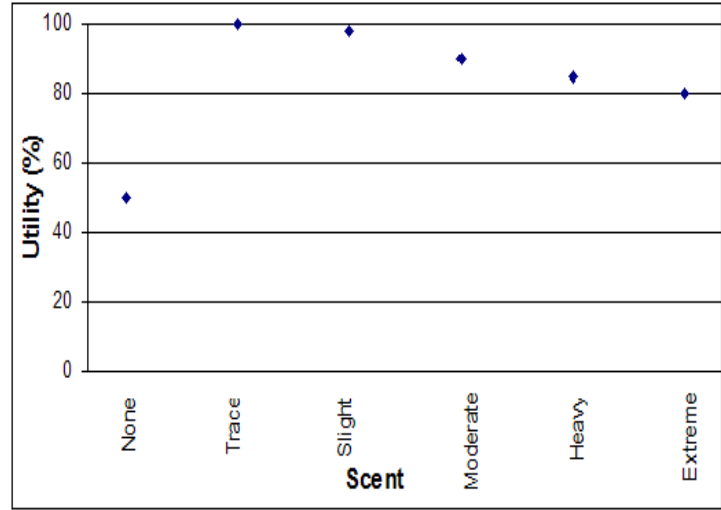


Figure 5 Utility versus Scent Intensity

consumers are increasingly displeased as the scent intensity approaches “Extreme.”

A research article by Kamadia, Yoon, Schilling, and Marshall in the Journal of Food Science²³ allowed for the quantification of the concentration of linalool detectable by the human nose (threshold) and the concentration at which the linalool fragrance becomes overwhelming. Kamadia, et al. studied various amounts of linalool and used human subjects to determine the intensity of each sample 1.5 feet away from the sample, 25 minutes after the sample was prepared. Fick’s second law of diffusion for a flat plate is shown below:

$$\frac{\partial c_a}{\partial t} = D_{ab} \frac{\partial^2 c_a}{\partial z^2}$$

where C_a is the concentration of linalool, t is time, D_{ab} is the diffusion coefficient of linalool in air, and z is the distance at which the linalool is smelled. The solution to the equation is given by:

$$C_a = C_{as} - (C_{as} - C_{ao}) \operatorname{erf} \left(\frac{z}{2\sqrt{D_{ab}t}} \right)$$

where C_{as} is the concentration at the surface and C_{ao} is the concentration infinitely away from the source. Using the equation above, the concentration at 1.5 feet and 25 minutes after the sample was prepared was found. The researchers found certain samples from which the scent was just at threshold and samples from which the scent was overwhelming. The results are shown below:

Table 2

Linalool (ppm in water) from Research Paper	Conc. (M) at 1.5 feet & 25 mins	Conc. (nM) at 1.5 feet & 25 mins	Utility from polled consumers
0	0	0	50
0.5	4E-10	0.4	70
2.5	2E-9	2	100
12.5	1E-8	10	99
62.5	5E-8	50	90
312.5	2.6E-7	260	82.5

Subjects found that at 0.5 ppm, the linalool reached the threshold which corresponds to a linalool concentration of 4E-10 M. At 2.5 ppm, the concentration of linalool was at the most pleasant level corresponding to a concentration of 2E-9 M, and at 312.5 ppm the linalool was overwhelming corresponding to a concentration of 2.6E-7 M. These values serve as a reference point for scent intensity utility quantification.

Fragrance duration relates the application frequency to the amount of linalool in the fragrance particles. Figure 6 shows consumer utility versus application time. Consumer

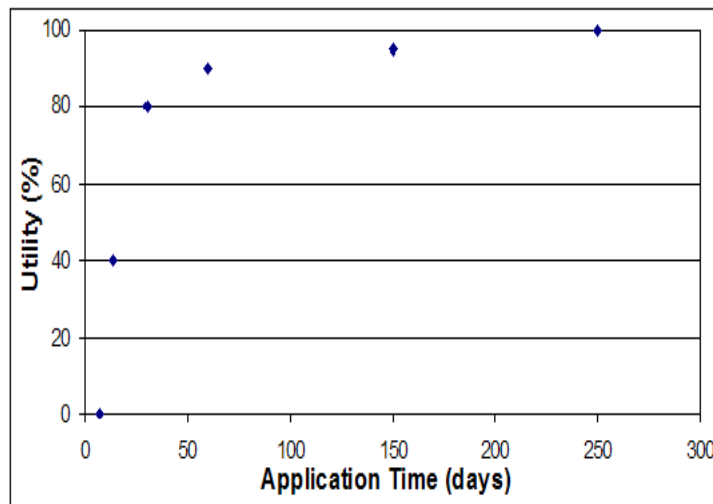


Figure 6 Utility versus Application Time (days)

preference increases with increase in application time; consumers are more satisfied with longer fragrance duration.

Mass Transfer Model

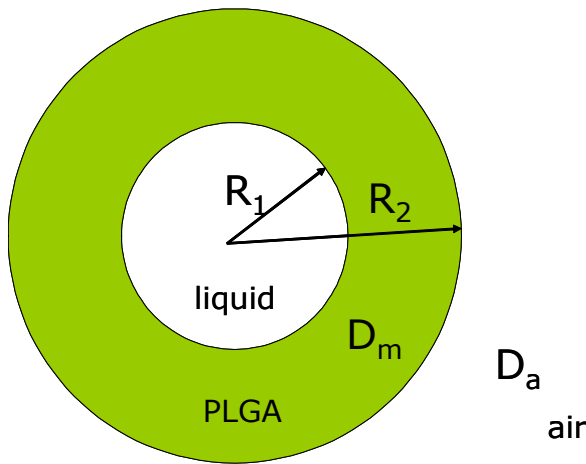


Figure 7 Fragrance Particle Schematic

Mass transfer quantifies the relationship between the scent intensity and fragrance duration utilities and fragrance particle characteristics. In a fragrance particle, liquid linalool is coated with the polymer PLGA. A fragrance particle schematic appears in Figure 7, where R_1 is the inner radius, R_2 is the

outer polymer boundary, D_m is the diffusion coefficient of linalool in PLGA, and D_a is the diffusion coefficient of linalool in air.

The available fragrance particle design parameters are the number of particles per unit area (n) and the amount of fragrance in each particle (L). Figure 8 shows a schematic

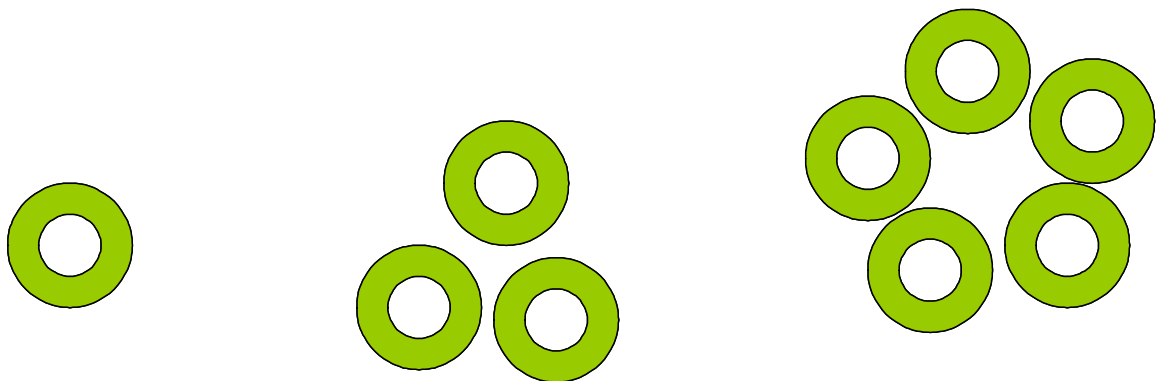


Figure 8 Number of particles per unit area (n) representation

representation of the number of particles per unit area, which is related to the scent intensity utility. In the evaluation of the scent intensity utility, the amount of linalool in each particle (L) is fixed, and the number of particles per unit area (n) is varied. Figure 9 shows a schematic representation of the amount of linalool in the fragrance particles (L), which is related to the fragrance duration utility. In the figure, the amount of linalool increases from left to right, and the polymer thickness coating the linalool core decreases from left to right.



Figure 9 Amount of linalool in particles (L) representation

Figure 10 shows the expected trends in linalool concentration for variations in these design parameters. For a fixed amount of fragrance in each particle (L), the linalool concentration would increase with increasing numbers of particles per unit area (n). For a fixed number of particles per unit area (n), the duration time would decrease with increase in amount of fragrance in each particle (L). As the amount of fragrance in each particle is increased, the layer of PLGA separating the liquid fragrance core and the surrounding air would be thinner, and the liquid fragrance would be able to diffuse rapidly out of the particles.

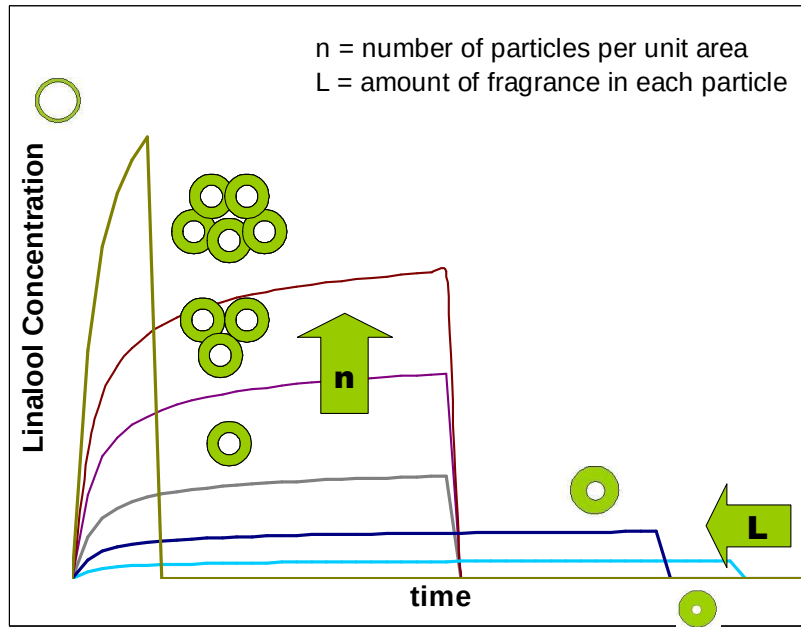


Figure 10 Trends expected with fragrance particle design variations

The mass transfer model involved diffusion of linalool from a single fragrance particle. The following assumptions allowed

for analysis of the mass transfer of linalool out of a fragrance particle. Diffusion from the particle was assumed to be radially symmetrical. The surrounding air was assumed to be semi-infinite; the concentration of linalool at r equal to infinity was assumed to be zero. Linalool was assumed not to degrade within the particle. The PLGA coating was assumed not to degrade appreciably during the fragrance duration.

As long as liquid linalool remains in the inner cavity, the concentration at the inner radius (R_1) is equal to the saturation concentration, and linalool diffusion through the PLGA coating does not change with time. Diffusion from the outside polymer surface is diffusion into a semi-infinite medium.

The diffusion coefficient of a small hydrophobic probe in PLGA was determined by Kang as $(3-10) \times 10^{-12} \text{ cm}^2/\text{s}$ ($(1-3.6) \times 10^{-12} \text{ m}^2/\text{hr}$).²⁴ The diffusion coefficient of linalool in PLGA was determined by adjusting for the molecular weight using the following equation:

$$D_m = \frac{MW_{probe}}{MW_{linalool}} D_{probe}$$

where D_m is the diffusion coefficient of linalool in PLGA, MW_{probe} is the molecular weight of the small hydrophobic probe used by Kang, $MW_{linalool}$ is the molecular weight of linalool, and D_{probe} is the diffusion coefficient of the small hydrophobic probe used by Kang in PLGA. The diffusion coefficient of linalool in PLGA used in the mass transfer model was $3.6 \times 10^{-10} \text{ m}^2/\text{hr}$.

Fick's second law in spherical coordinates for steady state is given by:

$$\frac{d}{dr} \left(r^2 \frac{dC}{dr} \right) = 0$$

where C is the concentration of linalool (mol/L) and r is radial position (m). Integrating twice yields:

$$C = b - \frac{a}{r}$$

where a and b are constants. The concentration of linalool is equal to the saturation concentration given by Raoult's law at the inner polymer boundary (R_1). The second boundary condition is given by setting the flux of linalool out of the particle equal to the flux of linalool into the air at the polymer boundary (R_2). The concentration of linalool outside of the polymer boundary was described by diffusion into a semi-infinite medium in spherical coordinates, where C^* is the concentration of linalool in the air surrounding a fragrance particle. The boundary conditions are given below.

$$C = c^{sat} \quad \text{at} \quad r = R_1$$

$$D_m \frac{dC}{dr} \Big|_{r=R_2} = D_a \frac{dC^*}{dr} \Big|_{r=R_2}$$

$$r > R_2 \quad C^* = C_{\infty}^* + (C^*(R_2) - C_{\infty}^*) \frac{R_2}{r} \operatorname{erfc} \left(\frac{r - R_2}{2\sqrt{D_a t}} \right)$$

Using the boundary conditions, the concentration profile of linalool is given by:

$$C(r) = c^{sat} - \frac{R_2}{R_1} \frac{D_a}{D_m} C(R_2) + \frac{R_2}{r} \frac{D_a}{D_m} C(R_2)$$

The concentration profile can be used to determine the concentration of linalool at the polymer boundary (R_2), which is given by:

$$C(R_2) = \frac{c^{sat}}{1 + \frac{R_2}{R_1} \frac{D_a}{D_m} - \frac{D_a}{D_m}}$$

Application of the concentration profile of linalool and the equation describing linalool diffusion into a semi-infinite medium allowed for the determination of the concentration profile during the time liquid linalool remained in the fragrance particle. After the entire amount of liquid linalool had been released from the particle, Fick's second law was solved again for diffusion into a semi-infinite medium with the initial condition equal to the concentration profile at the time when all of the liquid linalool had just evaporated from the fragrance particle and the boundary condition of the concentration at the polymer boundary, $C(R_2)$, equal to zero.

To examine the scent intensity as a function of time, a plane of interest was defined at r equal to 5 ft. Each particle was assumed to have a total diameter of 10 microns. The amount of linalool in each particle (L) was fixed at 90% of the total particle. The concentration at 5 ft as a function of time for a range of number of particles per unit area (n) of carpet for the first mass transfer model appears in Figure 11. The concentration of linalool increased with increasing number of particles per unit area.

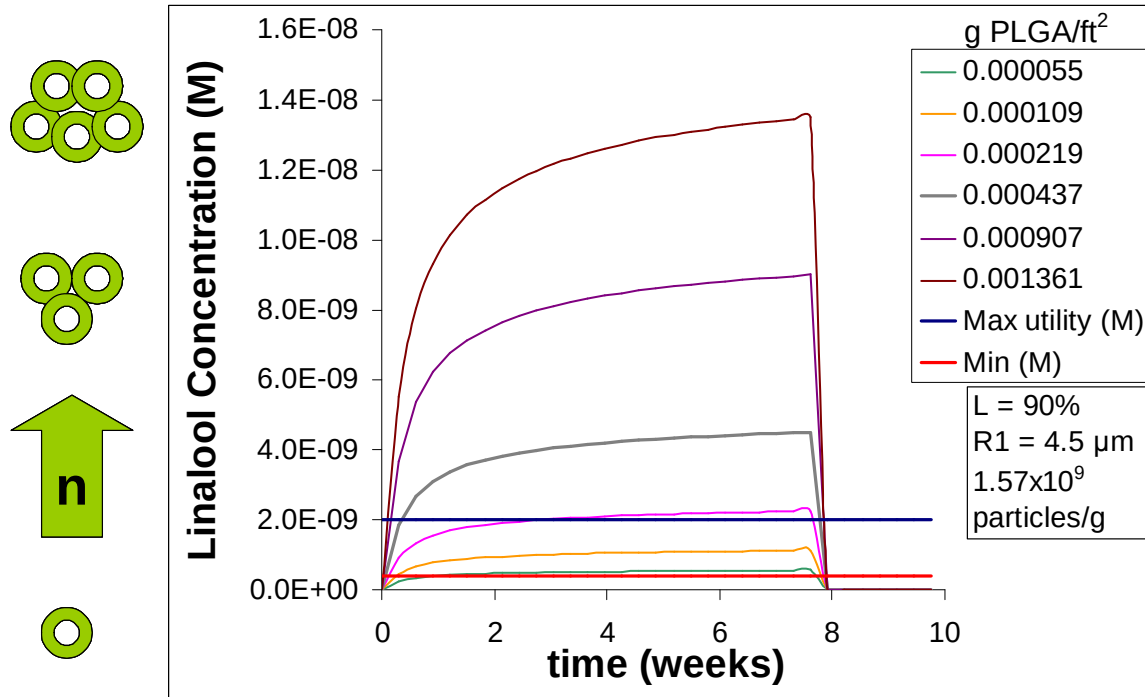


Figure 11 Linalool concentration versus time at r equal to 5ft for a range of number of particles per unit area (n)

From Figure 11, the linalool concentration for 0.00219 g of particles per ft² most closely matched the maximum consumer utility for the greatest length of time. The mass transfer model allowed for the relationship between consumer utility and number of particles per unit area (n) shown in Figure 12.

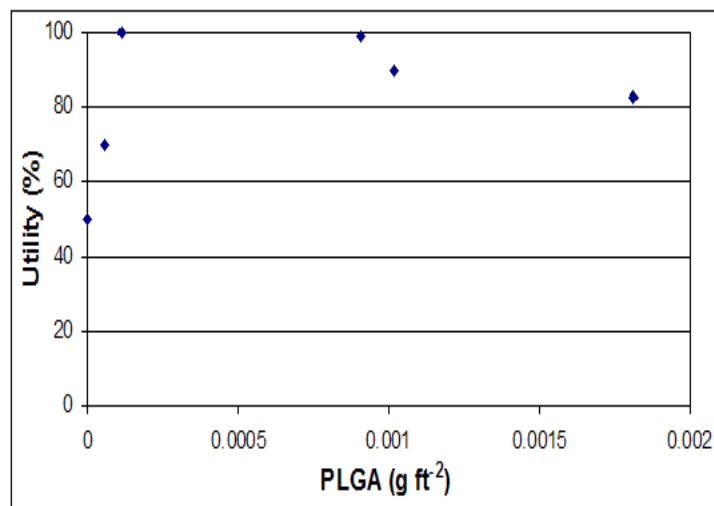


Figure 12 Utility versus Number of fragrance particles per unit area (n) (g ft⁻²)

The total time of fragrance duration is given by integrating the concentration profile from time equal to zero to t*, the total time of fragrance duration.

$$\int_0^{t^*} D_m \frac{dC}{dr} = m$$

The total time is given by:

$$t^* = \frac{c^{sat} R_1^3}{3D_a C(R_2) R_2}$$

The total time of fragrance duration was determined using the same number of particles per unit area (n) and varying the amount of fragrance in each particle (L). The linalool concentration as a function of time at a plane five feet from the surface of the carpet for various inner particle radii appears in Figure 13. As the inner radius increased, the fragrance was able to diffuse rapidly out of the fragrance particles.

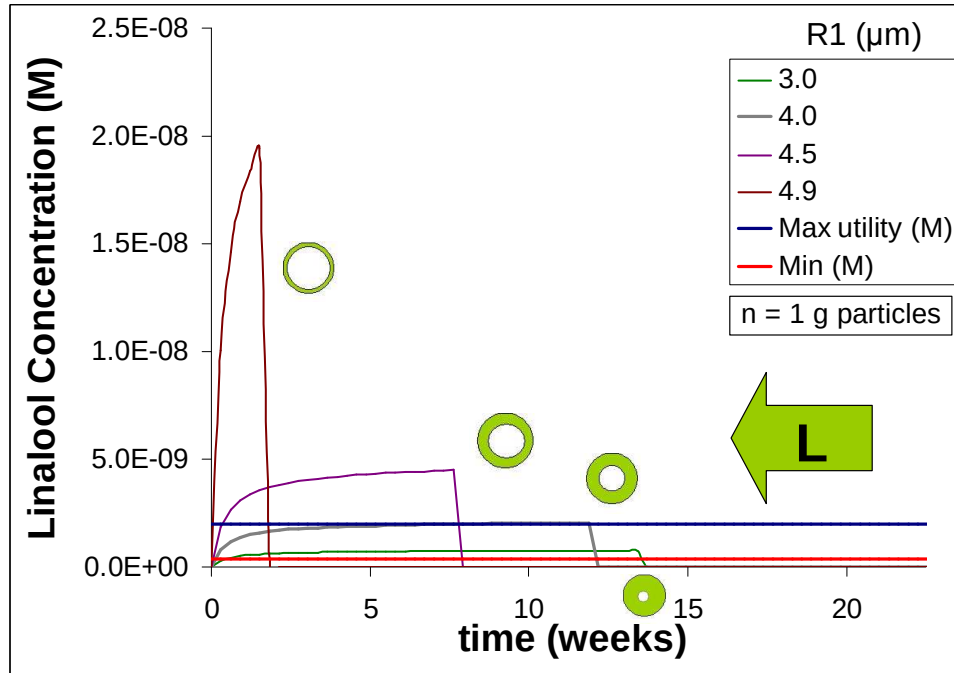


Figure 13 Linalool concentration at five feet for various inner radii

Mass transfer calculations related to the total time of fragrance duration allowed for the relationship between fragrance duration and the amount of linalool in the particles spread

over a unit area of carpet. Figure 14 shows the total time of fragrance duration versus the amount of linalool in the particles. The duration increases with increase in amount of linalool in the particles spread over a unit area of carpet until the duration time reaches a maximum. The duration time subsequently decreases with increase in amount of linalool in particles spread over a unit area of carpet because the thickness of the polymer coating the liquid fragrance decreases and allows the fragrance to diffuse rapidly out of the particles.

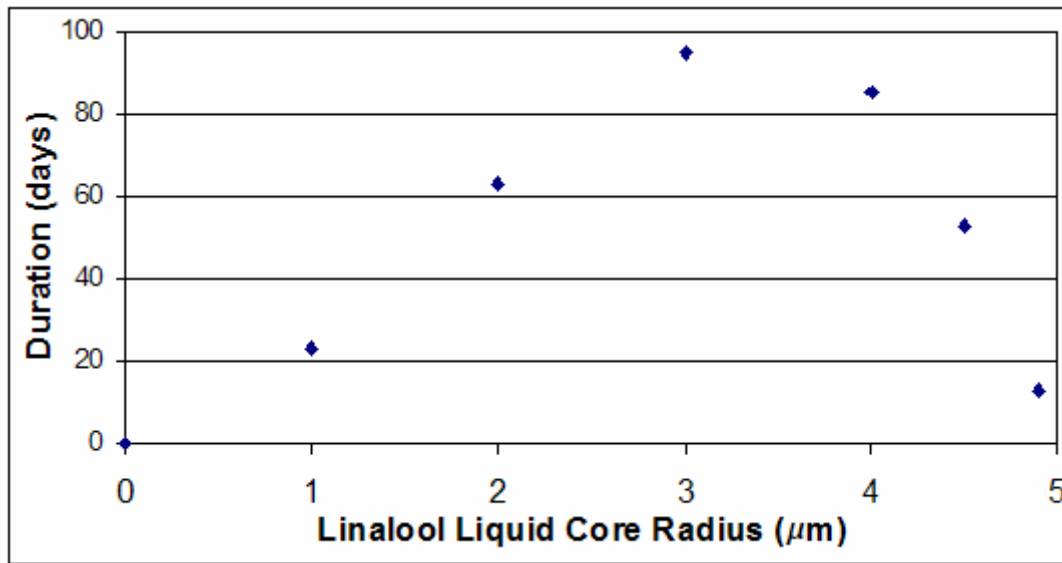


Figure 14 Total time of fragrance duration versus amount of linalool in fragrance particles spread over a unit area of carpet

The mass transfer model provides a conservative estimate of total time for fragrance duration. In reality, diffusion would be directed upward from a plane containing a number of fragrance particles. The concentration profile from one fragrance particle would be influenced by nearby particles. The total time for scent duration using the

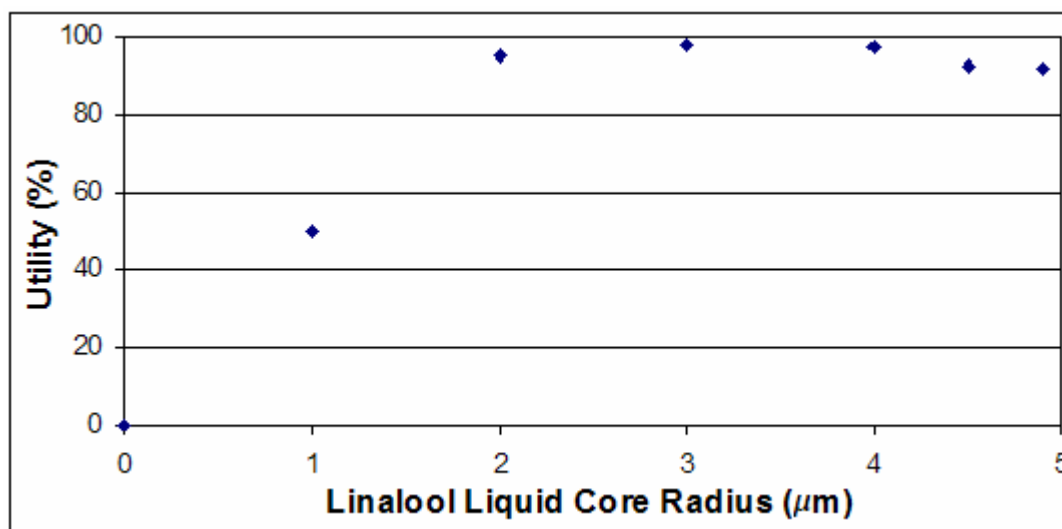


Figure 15 Utility versus amount of linalool in fragrance particles spread over a unit area of carpet

model was calculated assuming the fragrance diffused through 100%, 75%, and 50% of the particle surface area for a particle containing with a 4.5 μm inner radius (an amount of fragrance (L) equal to 90%). A comparison of total times for fragrance duration appears in the following table.

Table 4

Diffusion Area	Duration
100% Particle Surface Area	7.6 weeks
75% Particle Surface Area	10 weeks
50% Particle Surface Area	15 weeks

Toxicity

Toxicity relates the amount of boric acid per unit area of carpet to the toxicity of the product. As shown in Figure 16, the consumer utility was directly proportional to the toxicity of the product. The consumer would be completely

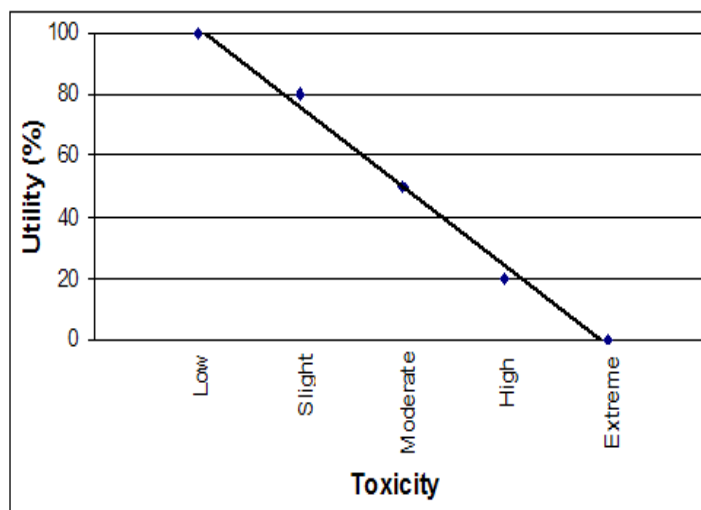


Figure 16 Utility versus Toxicity

satisfied with a product that has a low toxicity, and the consumer would be completely dissatisfied with a product that has an extreme toxicity. The relationship between the toxicity and the amount of boric acid (the most toxic component of the product) per unit area could be determined by examining the LD₅₀ of boric and various other chemicals shown in Table 5 to the right. The

Table 5

Substance	LD ₅₀ (g)
Nicotine	3.75
Caffeine	14.40
Aspirin	75.00
Tannic Acid	169.50
Boric Acid	202.50
Linalool	221.30
Table Salt	225.00
Benzoyl Benzoate	300.00
Baking Soda	315.00
Grain Alcohol	1050.00

LD₅₀ is a quantitative way to determine the toxicity of a chemical. It is the amount, in grams, that would kill 50%

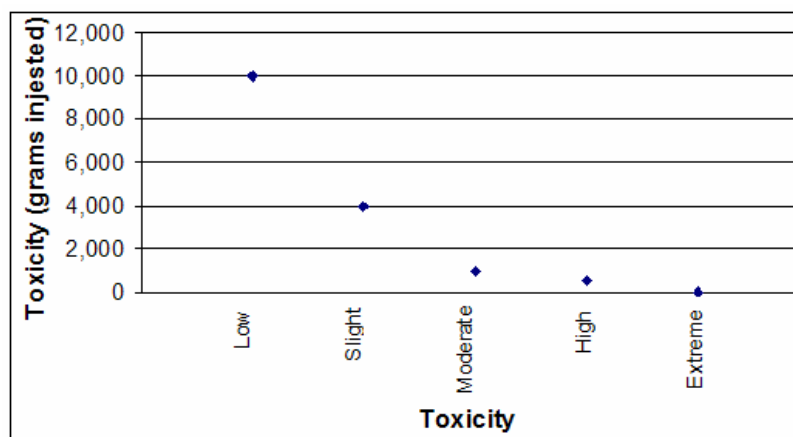


Figure 17: Toxicity standard

of human subjects weighing 165 lbs. Utilizing the LD₅₀ of the various chemicals, a standard can be established to determine the toxicity of boric acid based on its LD₅₀. However, this standard is unnecessary because both the competitor's product and our product are using the same chemical with the same toxicity. If this were not the case, Figure 16 and 17 could be used to calculate the resulting utility shown in Figure 18.

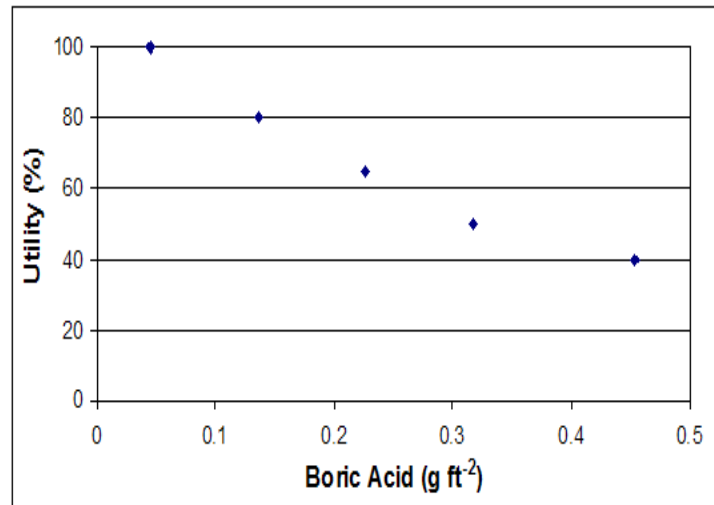


Figure 18 Utility versus Boric Acid (g ft⁻²)

Odor Elimination

Odor elimination, or freshness, relates the amount of baking soda per unit area to the freshness of the product. Freshness is the property of something that smells new and clean; baking soda does this in a solid-gas reaction of the alkaline

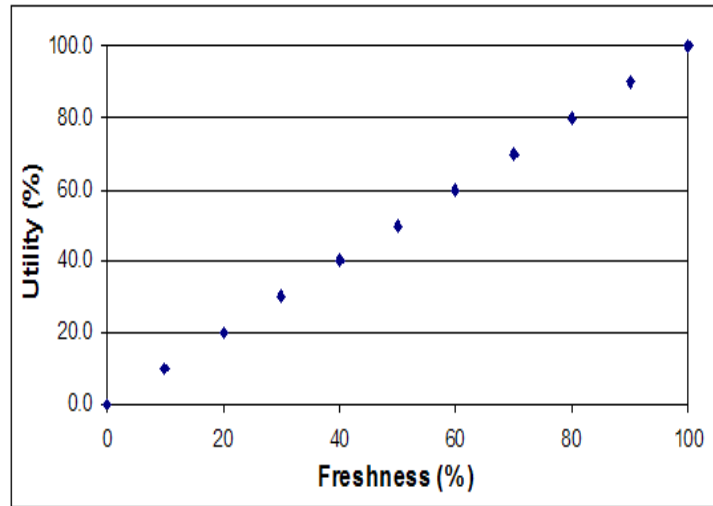


Figure 19 Utility versus Freshness Scale

base with an acidic gas such as hydrogen sulfide, rotten egg smell. As shown in Figure 19, the consumer utility was directly proportional to the freshness of the product. The consumer would be completely satisfied with a product that has a high freshness (100% = completely fresh), and the consumer would be completely dissatisfied with a product that is not fresh at all (0%=no freshness). The relationship between freshness

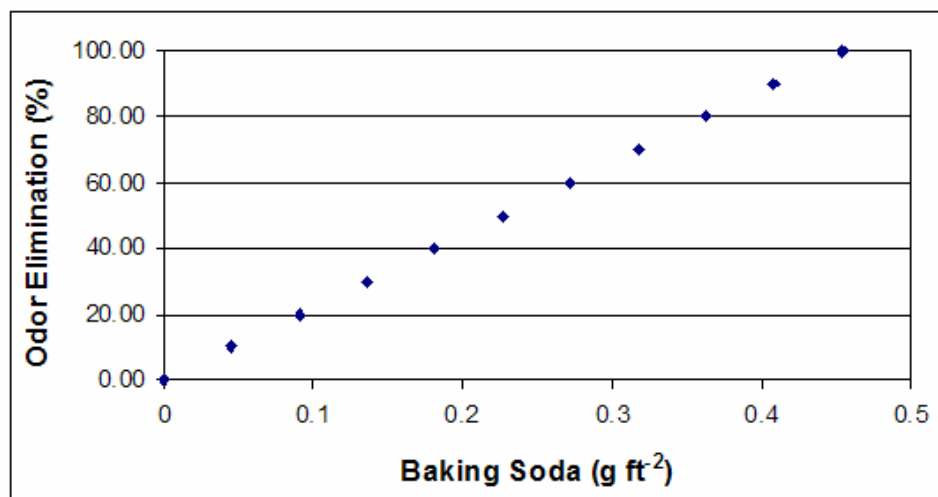


Figure 20: Odor Elimination versus amount of baking soda per unit area. and the amount of baking soda per unit area was determined by calculating the odor

absorption of baking soda for specific amounts as shown in Figure 20. The function is linear due to the kinetics of the solid-gas reaction in which the reactants (odor and baking soda) are in a 1:1 molar ratio. The graph depicts that as one mole of baking soda reacts with the acidic gas, one mole of odor is eliminated. Odor elimination is a depiction of how effective baking soda is at neutralizing odor; therefore, in Figure 20 the effective percentage is the percentage of odor neutralized. Because the utility is a linear function of freshness, the relationship between utility and the amount of baking soda per unit area is exactly the same as the relationship between freshness and amount of baking soda per unit area and is shown below:

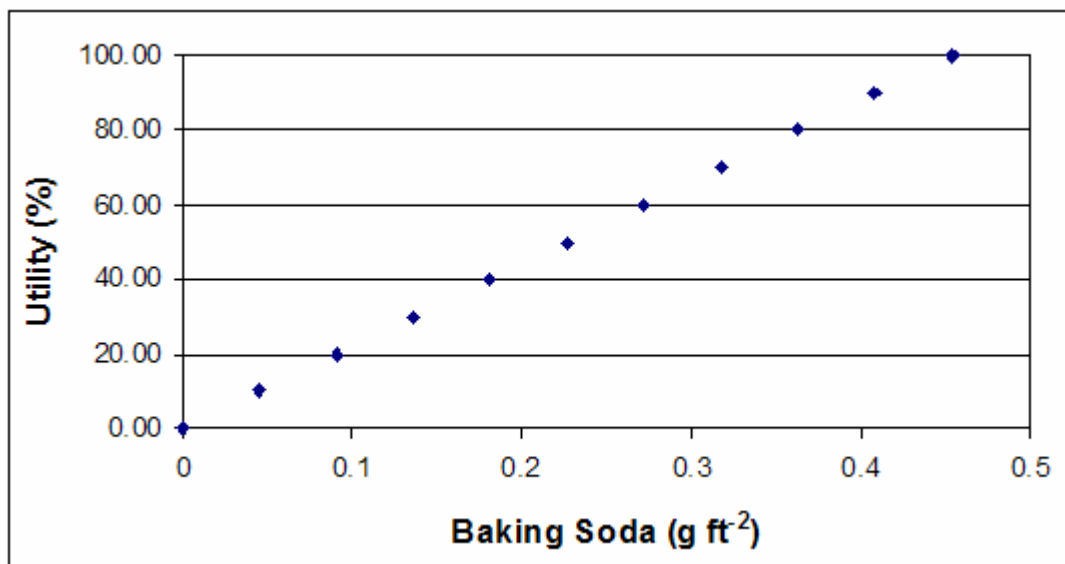


Figure 21: Toxicity standard

Scent

The best scent was determined by polling consumers as to which scent they would prefer out of citral which smells like lemons, geraniol which smells like roses, and linalool which smells like lilies. The graph below shows the results:

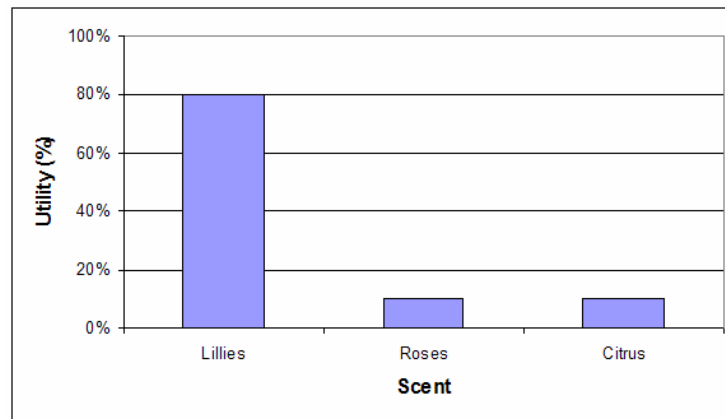


Figure 21 Utility versus Scent Type

According to the graph above, consumers preferred to have the product smell like lilies.

Production Process

The production process involves preparation of the fragrance particles by double emulsion and mixing the fragrance particles with boric acid and baking soda. A basic schematic of the production process appears in Figure 22.

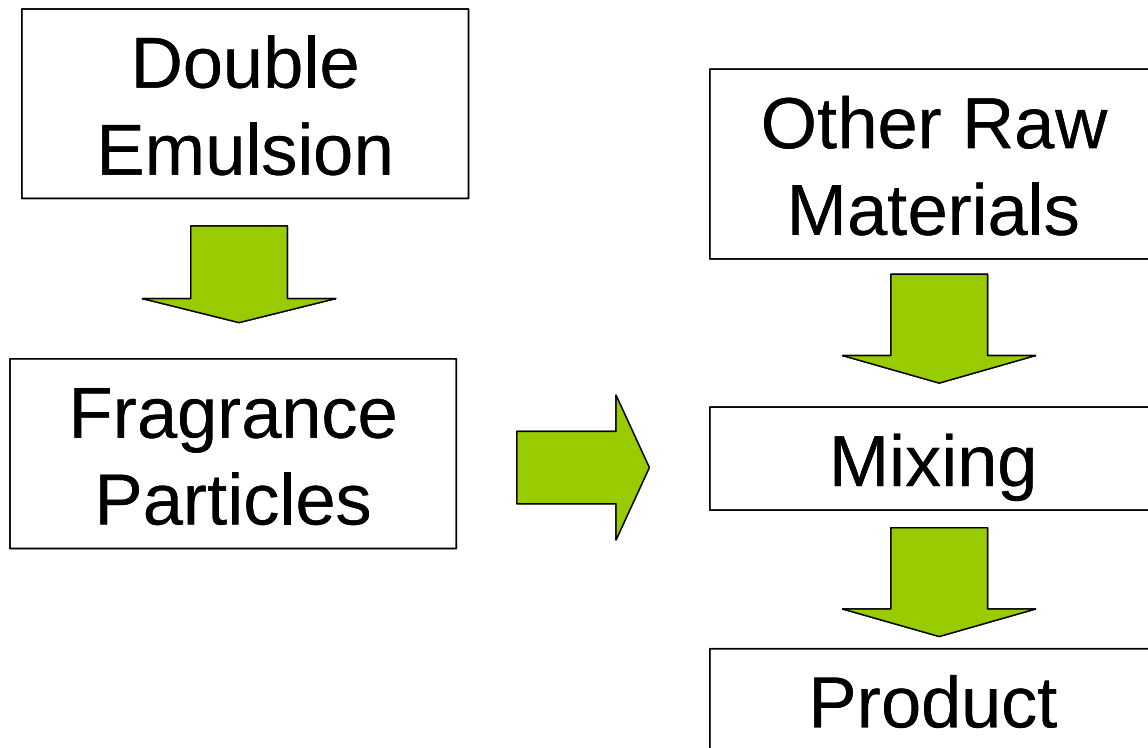


Figure 22 Schematic of Production Process

Linalool encapsulated by the polymer PLGA is produced by a double emulsion technique, specifically water/oil/water double emulsion. Aqueous linalool is emulsified in organic methylene chloride containing the polymer PLGA, creating the primary emulsion or the water/oil emulsion. The diagram below represents the primary emulsion, where f1 is the aqueous linalool and f2 is the methylene chloride/PLGA solution. The primary emulsion can then be fed through a nozzle to break the colloid into many particles or can be sonicated on a larger scale.

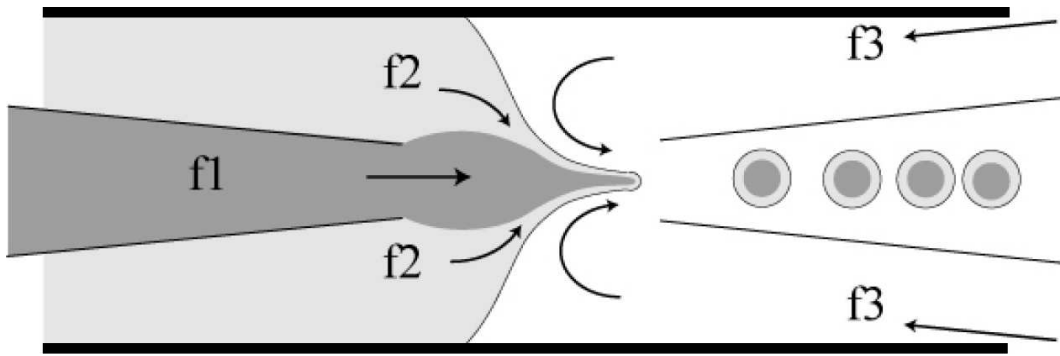


Figure 23 Double Emulsion Process Illustration

Once the primary emulsion is complete, the emulsion is transferred to an aqueous solution of water and PVA, an emulsifying agent. This solution is now a water/oil/water double emulsion. The PVA ensures that the small colloids stay at that small spherical size instead of collecting together as thermodynamically expected. The water/oil/water solution is then placed in a rotary evaporator to evaporate the volatile organic methylene chloride, leaving a water/PVA solution and PLGA encapsulating the linalool as shown below:

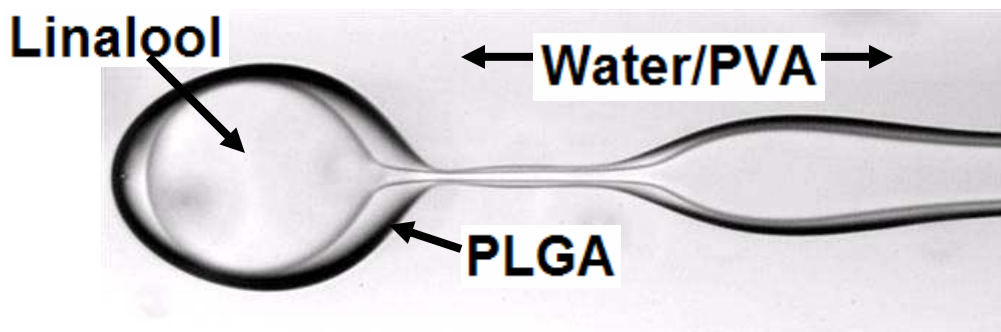


Figure 24 Double Emulsion Process Illustration

The solution can then be centrifuged to collect the PLGA that encapsulates the linalool resulting in the micro spheres seen in Figure 25:

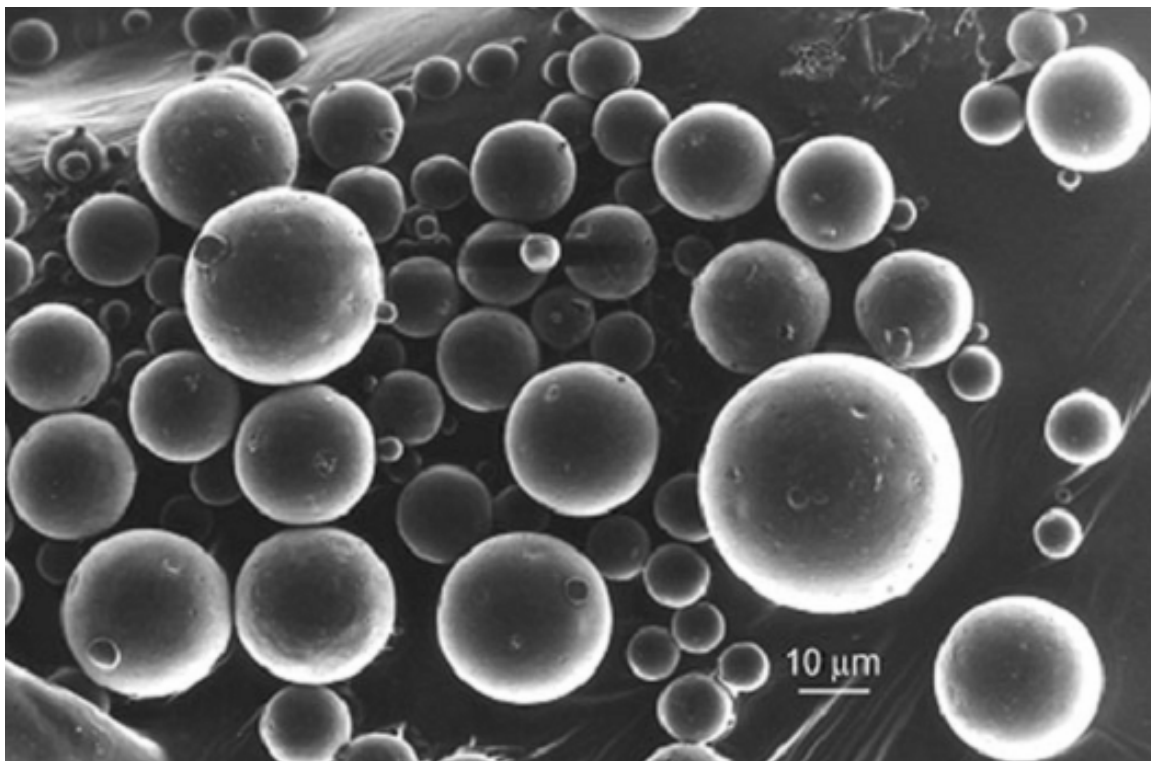


Figure 25 PLGA Microspheres

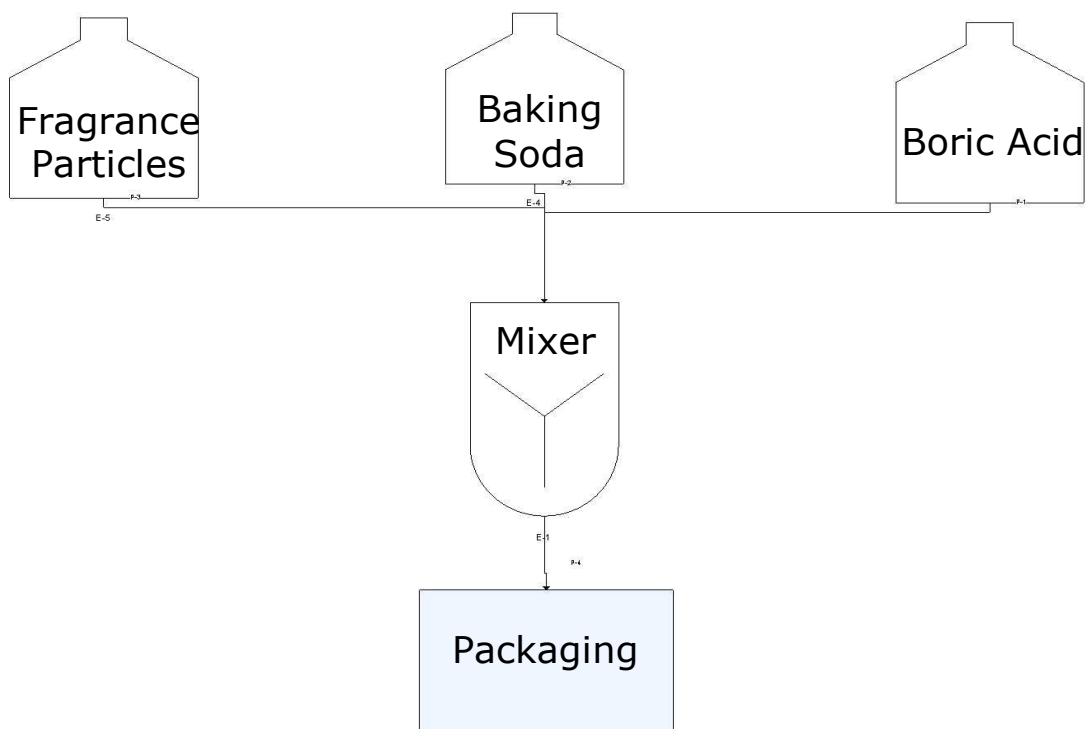


Figure 26 Process Flow Diagram

A schematic of the mixing process appears in Figure 26.

Cost Analysis

Cost analysis and optimization were performed utilizing a price a demand model shown below:

$$0 = P_1 D_1 - \left(\frac{\alpha}{\beta} \right)^\rho P_2 \left(\frac{Y - P_1 D_1}{P_2} \right)^{1-\rho} D_1^\rho$$

where P is the price, D is the demand, Y is the budget constraint, α is the consumer awareness, β is the superiority function, and ρ is the diminishing marginal utility. The subscripts 1 and 2 refer to our design and the competitor's design, respectively. The budget constraint, Y , introduced earlier, was determined by finding the product of the competitor's price and demand, which also agreed with the analysis of the disinfectant market's size. The consumer awareness, α , is a function of time and advertising. An example illustration is shown in Figure 27.

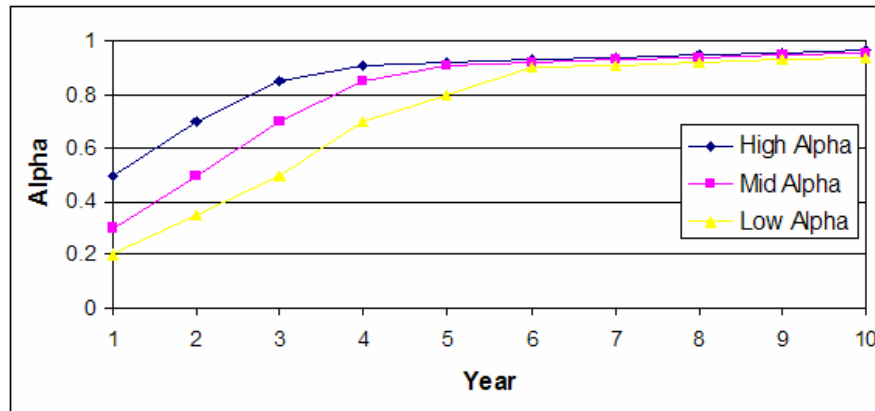


Figure 27 Alpha versus Year

The awareness of a new product will be relatively low during the first few years of its introduction to the market. Consumer awareness will increase with time until it reaches a maximum. The illustration above also depicts the differences in advertising. A high α value corresponds to a company which advertises heavily and a low α corresponds to a

company which advertises very little. With more advertising, the consumer awareness increases more quickly, which allows a company's product to earn a larger profit. The amount of money spent on advertising in the price and demand model was directly proportional to the demand (amount of the market possessed by our company). For a demand of 1, \$5,000,000 was spent on advertising, and for a demand of 0, no money was spent on advertising as shown below:

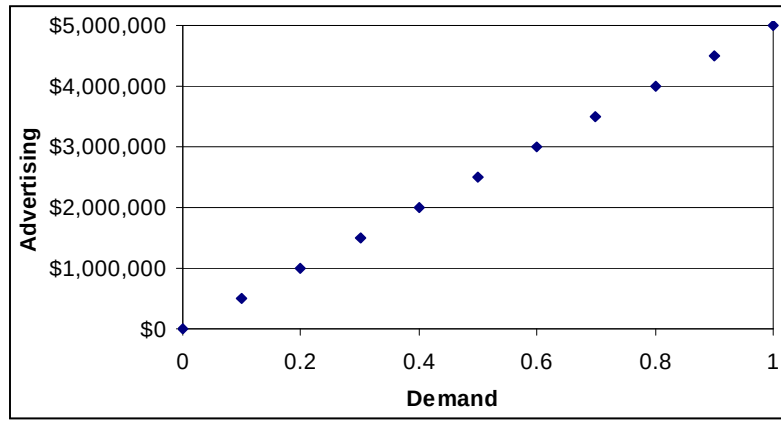


Figure 28 Advertising versus Demand

All other demands received advertising money in a linear fashion as shown above.

The superiority function, β , relates the competitor's utility or preference to our utility or preference as shown below:

$$\beta = \frac{U_2}{U_1}$$

where U_2 and U_1 are the utility of our competitor's product and the utility of our product, respectively. Utilizing the utility functions, U_2 was found to be 62. The diminishing marginal utility, ρ , is a variable introduced to ensure concavity to the price and demand model. It ensures that the model reflects the realistic situation in which as the consumer buys more of a product, they do not continue to be as happy with the product.

For preliminary analysis, the budget constraint, consumer awareness, the diminishing marginal utility, and Borid 16 oz. product price were found to be \$54,000,000, 0.9, 0.8, and \$10.00 respectively, and remained constant throughout the analysis. Utilizing these numbers and a β found from our product composition in the price and demand model, the demand could then be found for a given price which we as the product designers can set at any price we choose. An illustration of this is shown below at a variety of α values:

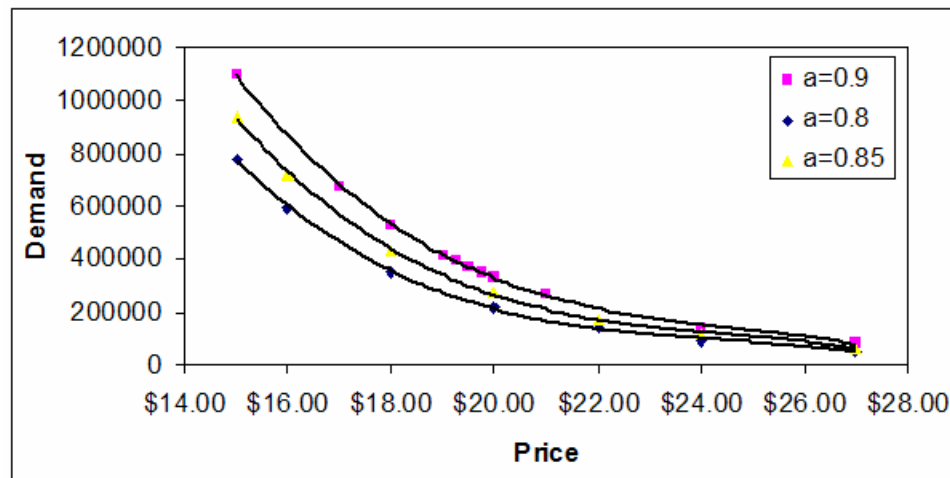


Figure 29 Demand versus Price for various alpha values

The figure above illustrates how the demand is a function of the price. As the price decreases, the demand increases to 1 (100% of the market), and as the price becomes higher the demand decreases to 0 (0% of the market). The effect that the consumer awareness has on the price and demand is also shown. As the consumer awareness decreases, the trends shift further to the left indicating that the product must be sold for much less to have the same amount of the market. This low consumer awareness and product price could be detrimental for a company's profit and will be seen later in the risk analysis section.

Shipping and Distribution Model

A preliminary model was utilized to estimate costs associated with shipping the product and to determine an optimum plant location. The product was assumed to be shipped by truck. Product composition, price, demand and budget constraint were assumed to be constant for every region of the continental United States. Distribution center locations were chosen such that they were evenly distributed throughout the continental United States. The distribution centers are listed in Table 6 and shown in Figure 30.

Table 6

Distribution Center Locations	
Olympia, WA	Albany, NY
Salt Lake City, UT	Sacramento, CA
Denver, CO	Phoenix, AZ
Austin, TX	Helena, MT
Jefferson City, MO	Baton Rouge, LA
Indianapolis, IN	St Paul, MN
Tallahassee, FL	Nashville, TN
Columbia, SC	Harrisburg, PA



Figure 30 Distribution Center Locations

The population and average humidity of each distribution center city were utilized to assign the relative amounts of production that would be sent to each distribution center. Five possible plant locations were chosen in the southeast and south central regions of the United States. The possible plant locations were chosen for their high

productivity per dollar invested.²⁵ The potential plant locations and the costs to ship the product to each appear in Table 7. The optimum plant location was Oklahoma City, OK.

Table 7

Plant Location	Cost per gal
Montgomery, AL	\$ 304
Jackson, MS	\$ 289
Atlanta, GA	\$ 304
Little Rock, AR	\$ 260
Oklahoma City, OK	\$ 250

TCI and NPW

The net present worth, NPW, over the course of the ten year project is shown by the following formula:

$$NPW = \sum_{k=1}^{n-1} \frac{CF_k}{(1+i)^k} + \frac{CF_n + V_s + I_w}{(1+i)^n} - TCI$$

where n is the year, CF is the cash flow for year n, k is the first year, V_s is the salvage value of the equipment, I_w is the working capital, and TCI is the total capital investment.

A spreadsheet that was used for the calculation is shown below:

Yr	Sales	Costs	Annual Cash Flow	d	r	[(er-1)/r]e-rj	Present Worth
1	\$7,300,396.28	\$6,809,171.87	\$320,076.67	\$780.80	\$0.00	0.93	\$299,439.14
2	\$7,519,408.17	\$7,013,423.60	\$329,670.77	\$780.80	\$0.00	0.81	\$268,157.45
3	\$7,744,990.42	\$7,223,802.89	\$339,552.69	\$780.80	\$0.00	0.71	\$240,144.35
4	\$7,977,340.13	\$7,440,493.55	\$349,731.08	\$780.80	\$0.00	0.61	\$215,058.22
5	\$8,216,660.33	\$7,663,684.93	\$360,214.81	\$780.80	\$0.00	0.53	\$192,593.16
6	\$8,463,160.14	\$7,893,572.05	\$371,013.06	\$780.80	\$0.00	0.46	\$172,475.25
7	\$8,717,054.95	\$8,130,355.79	\$382,135.25	\$780.80	\$0.00	0.40	\$154,459.20
8	\$8,978,566.59	\$8,374,243.04	\$393,591.11	\$780.80	\$0.00	0.35	\$138,325.36
9	\$9,247,923.59	\$8,625,446.91	\$405,390.64	\$780.80	\$0.00	0.30	\$123,877.05
10	\$9,525,361.30	\$8,884,186.89	\$417,544.16	\$780.80	\$0.00	0.27	\$110,938.14
10end	\$0.00	\$0.00	\$0.00	\$0.00	\$24,192.00	0.24	\$5,806.08
						Sum	\$1,921,273.42
			NPW				
			\$1,735,801.42				
	16 oz cont	Revenue		TCI	FCI	ROI=Np,avg/TCI	PBP (yrs)
	375000	\$19.47		\$185,472.00	\$161,280.00	1.98	0.37

Raw Materials Pricing

The price of PLGA was found to be \$5300/lb.²⁶ The price of linalool was found to be \$16/lb.²⁷ The price of boric acid was found to be \$1.62/lb.²⁸ The boric acid market was estimated as 5% of the total consumption used for disinfectant purposes.²⁹

Operating Labor and Utilities

Operating labor was calculated based on Figure 6-9 in Peters, et al.³⁰ Ten processing steps and 300 operating days per year were assumed. The average wage of \$19.05 per hour for chemical process operators was utilized in this calculation.³¹ Utilities were estimated as 110% of the power required to operate a 12 hp ribbon mixer capable of processing 50 ft³ of solid material, adjusted for the necessary capacity.³²

Equipment Sizing and Pricing

Equipment sizes and prices were calculated as a function of two weeks production. Solids storage tanks were priced using the carbon steel data from Figure 12-52 in Peters, et al.³³ The double emulsion process equipment, including the sonicator, rotary evaporator, centrifuge, and freeze dryer, was determined to be adequate up to 100% plant capacity. The sonicator, Misonix Sonicator[®] S3000, was priced from Structure Probe, Inc.³⁴ The rotary evaporator, Rotovap BUEVP-E-150, was priced from Analytical Instrument Recycle, Inc.³⁵ The centrifuge, C-3 Select Centrifuge, was priced from Lab Essentials, Inc.³⁶ The freeze dryer, Virtis Benchmark Freeze Dryer, was priced from Surplus Lab, Inc.³⁷ The process mixer was priced using the mixer data from Figure 12-52 in Peters, et al.³⁸

All other pricing utilized data from Table 6-9 in Peters, et al. The FCI, working capital, and TCI were estimated to be \$252,000; \$126,000; and \$378,000; respectively.

Optimization

The optimization of the design began with optimizing both the utility and the NPW. The utility was optimized by varying the four product amounts to maximize the utility or preference, β , of the product for the consumer. Solver was used in Microsoft Excel to vary all compositions simultaneously to determine a maximum β for the product. The following table includes six different product scenarios found by Solver:

Table 8

Product (% of Formulation)				
Linalool	PLGA	Boric Acid	Baking Soda	β
0.0050%	0.0109%	21.24%	78.75%	0.86
0.0100%	0.0217%	17.86%	82.11%	0.82
0.0200%	0.0434%	17.31%	82.63%	0.76
0.0557%	0.1208%	19.20%	80.62%	0.74
0.0750%	0.1628%	20.06%	79.70%	0.735
0.1000%	0.2170%	20.56%	79.12%	0.68

Maximizing the utility gave a product composed of 0.075% linalool, 0.1628% PLGA, 20.06% boric acid, and 79.70% baking soda. In optimizing the utility, it is understood that at such high utilities and low β the product may be unreasonable to produce due to its high raw materials cost, which is the case in this situation. With the utility maximized, the product cannot be sold at any price to maintain a profitable NPW.

Next, the NPW was maximized using Solver to vary all the product compositions simultaneously to find the optimum NPW. Much care was taken to ensure that only scenarios which would be realistic (that would have a scent above the threshold) were

analyzed. The following graph shows different product scenarios and thus different β values with the resulting NPW:

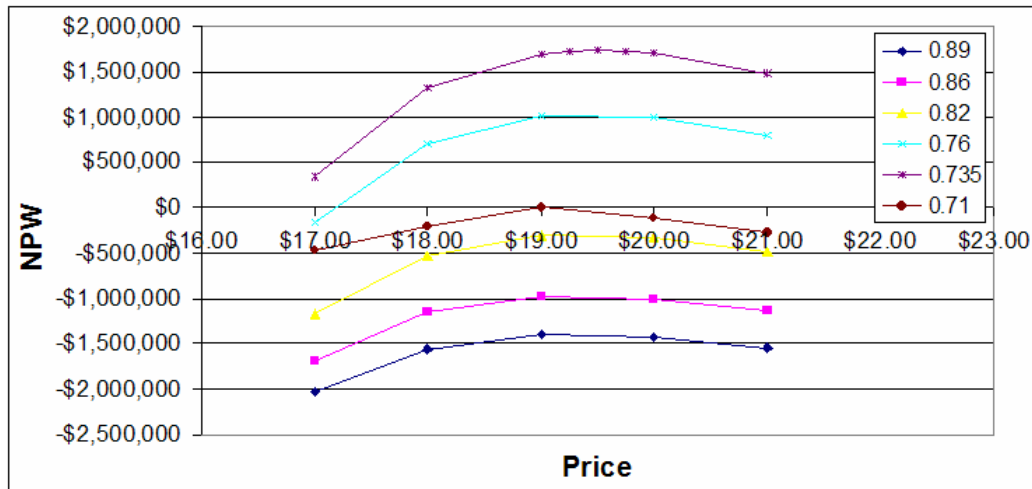


Figure 31 NPW versus Price

The β that maximized the NPW was 0.735, which corresponds to a product with a composition of 0.01% linalool, 0.0217% PLGA, 17.86% boric acid, and 82.11% baking soda. This composition resulted in a NPW of \$1,730,000 and the graph shown below illustrates how the NPW is a function of β :

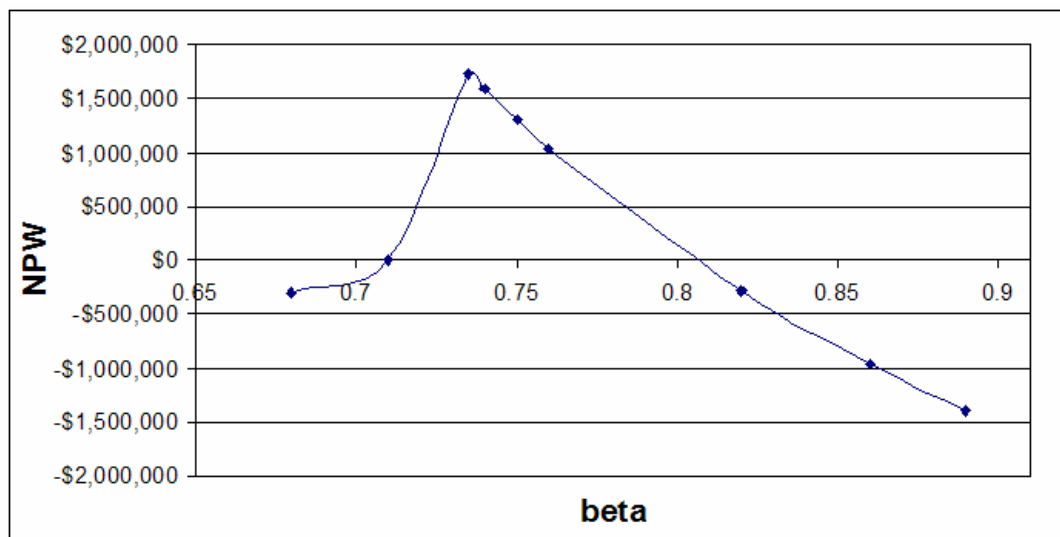


Figure 32 NPW versus β

At a very low β (0.68) the product satisfies the customer greatly, yet it is too costly to produce. As the β increases the product becomes more cost effective ($\beta = 0.735$) maximizing the NPW. As β increases even more the product's low utility ($\beta = 0.9$) results in the consumer's unhappiness with the product, and the product loses money.

Risk Analysis

Risk analysis was performed to determine what effect variations on the raw materials cost would have on the NPW of the product. Two types of risk analyses were performed, which included Strauss plots and Monte-Carlo simulations. The Strauss plots examined how sensitive NPW of the product was to each raw material by varying the raw material cost 20% of its 2007 mean; whereas, the Monte-Carlo simulation varied all the raw materials costs 20% of their 2007 mean simultaneously, giving a much more accurate economic depiction of the product NPW. The graph below shows a Strauss plot for baking soda:

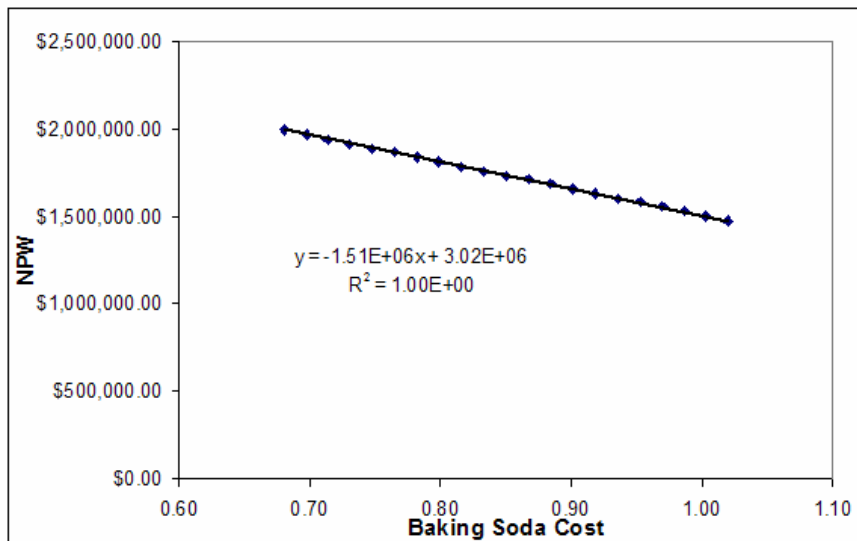


Figure 33 NPW versus Baking Soda Cost

The graph which has a slope of -1,500,000 indicates how sensitive the NPW is to the baking soda cost. The following table illustrates the sensitivity of each component:

Table 9

Component	Slope/Sensitivity
Linalool	-150
PLGA	-400
Boric Acid	-300000
Baking Soda	-1000000

The table indicates that fluctuations of the linalool and PLGA raw material costs will not affect the NPW as much as boric acid and baking soda. It should be addressed also that this analysis used an assumption of \$19.44 per container, which resulted in a 450,000 demand. If the demand increased substantially so too would the sensitivity of the components as shown below:

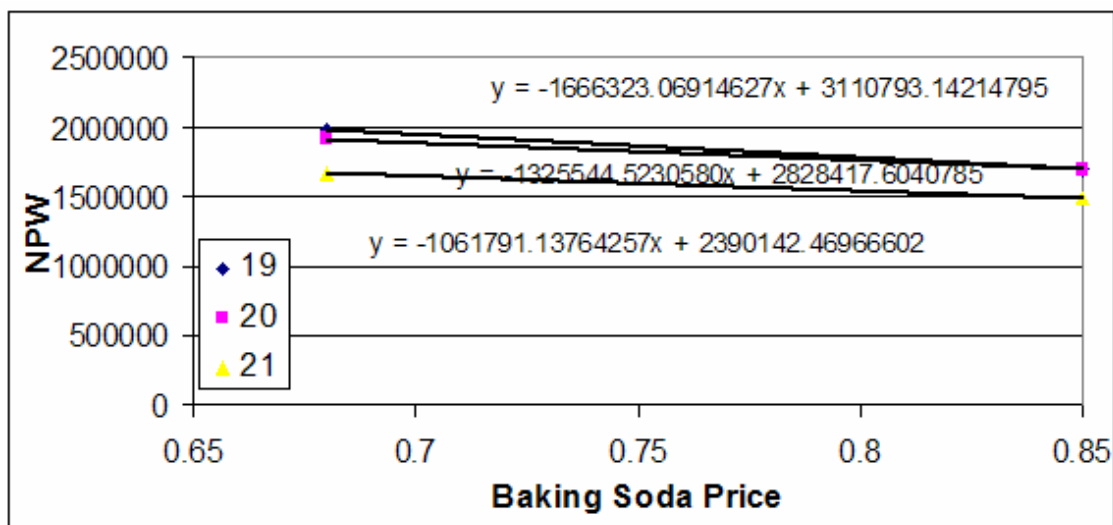


Figure 34 NPW versus Baking Soda Price for various Prices per container

As seen in the graph, as the price decreases, the demand increases. This increase in demand would require much more raw materials, and subsequently the sensitivity of raw

material price would go up as seen above for baking soda. The sensitivity of the baking soda raw material cost goes from -1,000,000 when the price per container is \$21.00 and the demand is 1,600,000 to -1,700,000 when the price per container is \$19.00 and the demand is a much higher 2,000,000. It can be inferred from this analysis that if the price dropped lower and the demand went any higher, it could have drastic effects on any price fluctuation in the raw materials cost. The table below shows this trend in more detail for each of the four components of the product:

Table 10 (Slope in hundreds)

Price per container	Linalool	PLGA	Boric Acid	Baking Soda
\$19	-9	-3	-8000	-16,000
\$20	-7	-3	-6000	-13,000
\$21	-4	-2	-3000	-10,000

As the product price drops for each component, the sensitivity of the raw material cost on the NPW increases. It can also be inferred from the table that the sensitivity is a function of the composition. This product has a composition of 0.01% linalool, 0.0217% PLGA, 17.86% boric acid, and 82.11% baking soda. The trends in sensitivity are also in accordance with the composition, the baking soda has the highest percentage of formulation and also the highest sensitivity. Therefore, if the composition is changed so too would the sensitivity of each component.

Monte-Carlo simulations were also performed to analyze risk; however the simulations varied all raw materials cost simultaneously instead of individually. The simulation consisted of 500 scenarios and was performed at a variety alpha values as shown below:

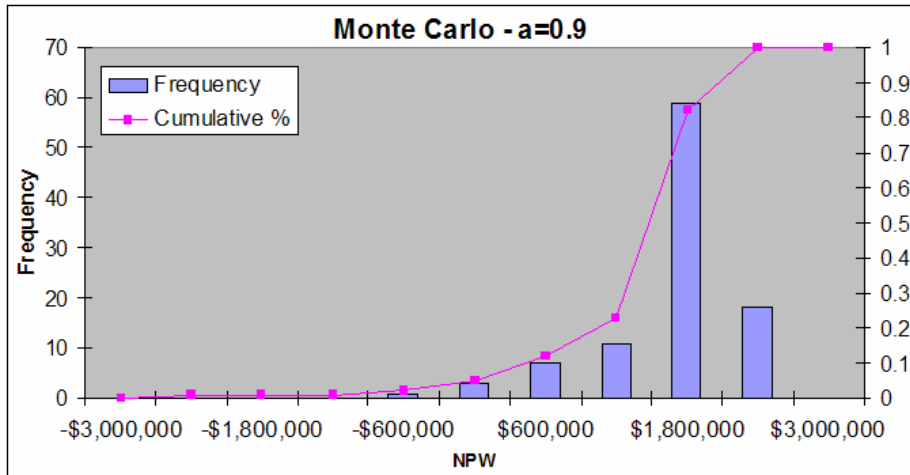


Figure 35 Monte Carlo, $\alpha=0.9$, 54 million dollar budget constraint.

With a budget constraint of 54 million and an alpha of 0.9 there is a 5% chance of losing money and a 95% chance of making money.

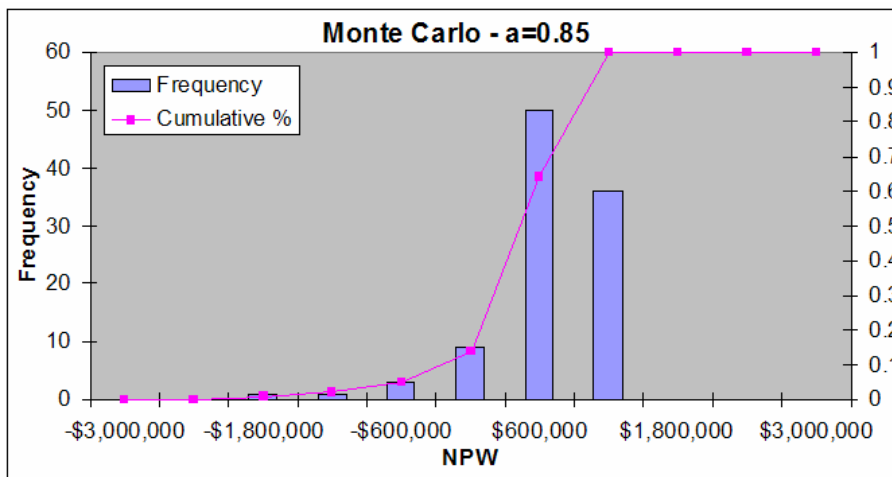


Figure 36 Monte Carlo, $\alpha=0.85$, 54 million dollar budget constraint.

With a budget constraint of 54 million and an alpha of 0.85 there is a 14% chance of losing money and an 86% chance of making money.

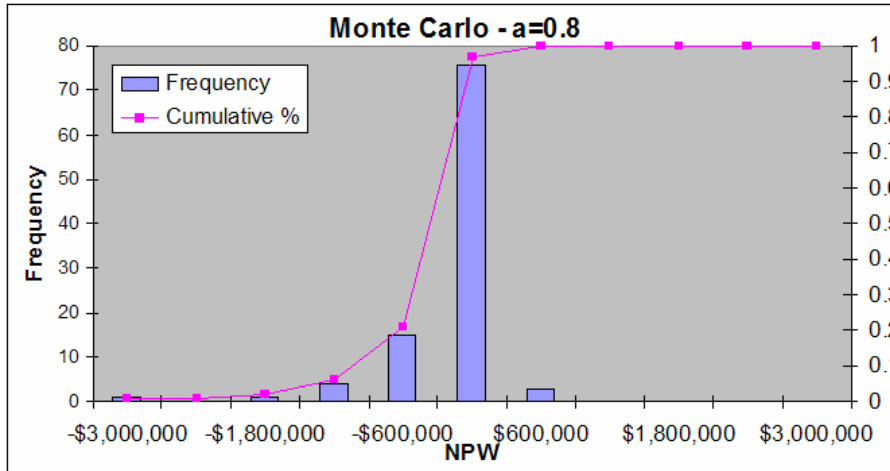


Figure 37 Monte Carlo, $\alpha=0.8$, 54 million dollar budget constraint.

With a budget constraint of 54 million and an alpha of 0.8 there is a 99% chance of losing money and a 1% chance of making money.

All calculations have been based of budget constraint of 54 million dollars which is the size of the disinfectant market. If the air freshener market size is taken into an account the budget constraint grow to 152 million giving a NPW around 13 million dollars. Most likely these two markets will overlap due to the product sharing qualities from both. Due to this fact an average of the two markets should be used for budget constraint's analysis. Another alternative is polling consumers as to how much they will spend, within their budget, for a product with qualities such as twice the duration, effectiveness, freshness, safety, and more pleasant scent than the competitor's product. The results are shown to the below:

16oz - 10\$ container	
2x Duration	\$2.14
More Effective	\$2.03
Fresher	\$1.58
Safer	\$1.23
Better Scent	\$1.01
Increase	\$17.99
Initial Demand	5400000
New Budget Constraint	\$97,000,000.00

Utilizing the new 97 million dollar budget constraint a NPW of \$6,800,000 was found

which is the more reasonable number. Therefore Monte-Carlo simulations were also ran with this budget constraint to determine the risk involved as shown below:

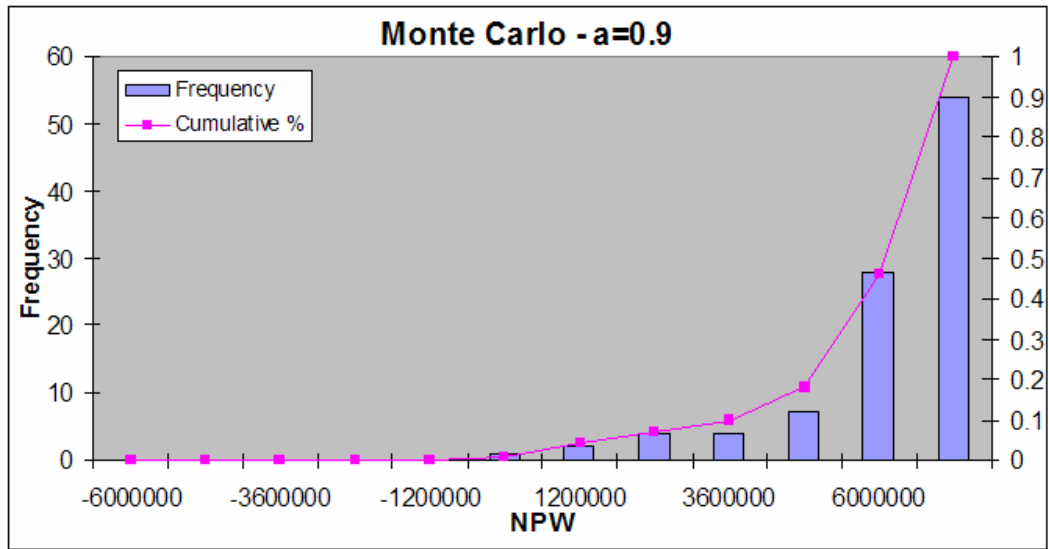


Figure 38 Monte Carlo, $\alpha=0.9$, 98 million dollar budget constraint.

With a budget constraint of 97 million and an alpha of 0.9 there is a 1% chance of losing money and a 99% chance of making money.

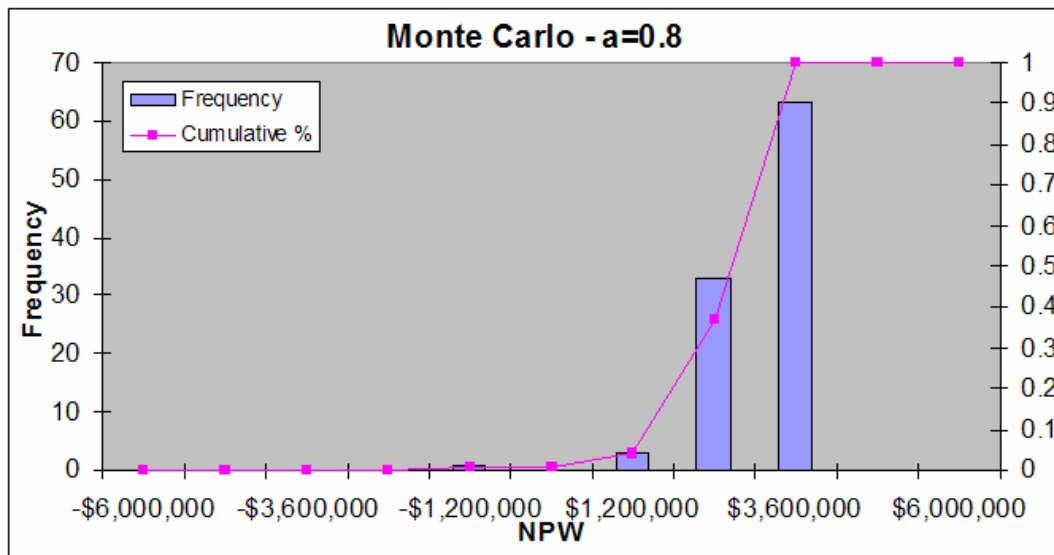


Figure 39 Monte Carlo, $\alpha=0.8$, 98 million dollar budget constraint.

With a budget constraint of 97 million and an alpha of 0.8 there is a 1% chance of losing money and a 99% chance of making money.

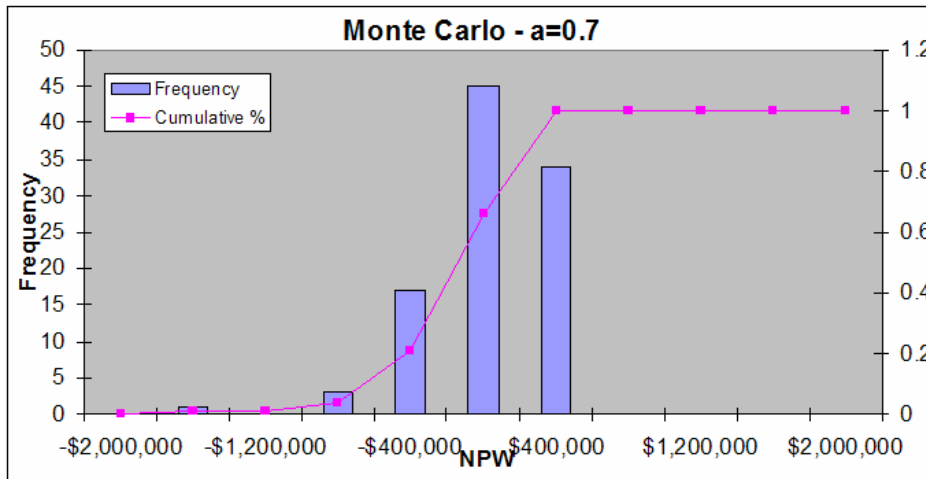


Figure 40 Monte Carlo, a=0.7, 98 million dollar budget constraint.

With a budget constraint of 97 million and an alpha of 0.7 there is a 66% chance of losing money and a 34% chance of making money.

It is reasonable to assume that the actual results would be closer to the last two graphs due to the product being relatively new and unknown.

Future Considerations

Future considerations include solving the time dependent mass transfer model, utilizing PLGA particles for the disinfectant portion of the product, varying all price and demand parameters, and performing a more detailed shipping and distribution estimate with different budget constraints for different regions of the United States.

References

- ¹ “House Dust Mite.” <http://hgic.clemson.edu/factsheets/hgic2551.htm> (1.pdf)
- ² American College of Allergy, Asthma, and Immunology. <http://www.acaai.org/public/advice/dust.htm> (2.pdf)
- ³ “Mold.” <http://www.epa.gov/mold/moldguide.html> (3.pdf)
- ⁴ “Asthma and Allergy Prevention.” <http://www.niehs.nih.gov/airborne/prevent/mold.html> (3.pdf)
- ⁵ “Mystery Stench Explained.” <http://www.niehs.nih.gov/airborne/prevent/mold.html> (5.pdf)
- ⁶ “Dry Carpet Cleaning.” <http://www.thecleanchoice.com/page/page/2322618.htm> (6.pdf)
- ⁷ “Arm&Hammer Household Products.” <http://www.churchdwright.com/Conprods/Household/index.asp> (7.pdf)
- ⁸ “Borid.” <http://www.pestproducts.com/borid.htm> (8.pdf)
- ⁹ “About Capture.” <http://www.captureclean.com/captureclean/topnavigation/aboutcapture> (9.pdf)
- ¹⁰ “Pure Baking Soda.” <http://www.armandhammer.com/basics/magic/> (11.pdf)
- ¹¹ “Chemicals for Dust Mite Control.” http://allergynursing.com/solutions/nas/chemicals_mites.html (10.pdf)
- ¹² “Soda-Boric Acid-Glycine Mixture.” <http://micro.magnet.fsu.edu/featuredmicroscopist/modderman/sodaboricacidglycinesmall.html> (12.pdf)
- ¹³ “Boric Acid MSDS.” ScienceLab.com (13.pdf)
- ¹⁴ “Citral.” http://www.chemie.fu-berlin.de/chemistry/oc/terpene/citral_en.html (14.pdf)
- ¹⁵ “Geraniol.” <http://www.phytochemicals.info/phytochemicals/geraniol.php> (15.pdf)
- ¹⁶ “Linalool.” <http://www.inchem.org/documents/sids/sids/78706.pdf> (16.pdf)
- ¹⁷ “Sodium Bicarbonate.” <http://www.solvaychemicals.us/static/wma/pdf/6/7/5/9/SODBICARB.pdf> (17.pdf)
- ¹⁸ “Boric Acid.” <http://www.natbat.com/docs/boron.htm> (18.pdf)
- ¹⁹ “PLGA.” http://www.debio.com/e/pdf/plga_e.pdf (19.pdf)
- ²⁰ Department of Pharmaceutical Studies Dr. Chris Van der Walle <http://spider.science.strath.ac.uk/PharmSci/showPage.php?u=eas03150&includePage=staffDetails.php> (20.pdf)
- ²¹ “CB Boric Acid Dust.” <http://www.domyownpestcontrol.com/cb-borid-boric-acid-dust-p-205.html> (21.pdf)

-
- ²² “Clover Mites.” <http://muextension.missouri.edu/explore/agguides/pests/g07358.htm> (22.pdf)
- ²³ Kamadia, et al., “Relationships between Odorant Concentration and Aroma Intensity.” Institute of Food Technologies, 2006. (23.pdf)
- ²⁴ Kang, Jichao and Steven P. Schwendeman. Determination of Diffusion Coefficient of a Small Hydrophobic Probe in Poly(lactide-co-glycolide) Microparticles by Laser Scanning Confocal Microscopy. *Macromolecules*, **36** (4), 1324 -1330, 2003. <http://pubs.acs.org/cgi-bin/abstract.cgi/mamobx/2003/36/i04/abs/ma021036+.html>>
- ²⁵ Peters, Max S., Klaus D. Timmerhaus and Ronald E. West. *Plant Design and Economics for Chemical Engineers*. 5th edition. Boston: McGraw-Hill, 2003.
- ²⁶ “US Pricing and Ordering Information.” <http://www.durect.com/> (24.pdf)
- ²⁷ “Aromatic Chemicals.” <http://www.handafc.demon.co.uk/aroma.htm> (25.pdf)
- ²⁸ “Boric Acid.” TheChemistryStore.com (26.pdf)
- ²⁹ Lyday, Phillis A. “Boron.” (27.pdf)
- ³⁰ Peters, Max S., Klaus D. Timmerhaus and Ronald E. West. *Plant Design and Economics for Chemical Engineers*. 5th edition. Boston: McGraw-Hill, 2003.
- ³¹ U.S. Department of Labor Bureau of Labor Statistics http://www.bls.gov/oes/current/oes_nat.htm#b00-0000
- ³² Perry, Robert H. and Don W. Green. *Perry’s Chemical Engineers’ Handbook*. 7th edition. New York: McGraw-Hill, 1997.
- ³³ Peters, Max S., Klaus D. Timmerhaus and Ronald E. West. *Plant Design and Economics for Chemical Engineers*. 5th edition. Boston: McGraw-Hill, 2003.
- ³⁴ Structure Probe, Inc. http://www.2spi.com/catalog/misc_lab/cell4.shtml
- ³⁵ Analytic Instrument Recycle, Inc. <http://aironline.com/equipment/category/EVP.html>
- ³⁶ Lab Essentials, Inc. <http://www.labessentials.com/centrifuge.htm>
- ³⁷ LabX Scientific Marketplace <http://www.labx.com/v2/newad.cfm?catID=85>
- ³⁸ Peters, Max S., Klaus D. Timmerhaus and Ronald E. West. *Plant Design and Economics for Chemical Engineers*. 5th edition. Boston: McGraw-Hill, 2003
- ³⁹ *ICISpricing*. Reed Business Information Limited. 2006. <<http://www.icispricing.com/>>