Product Design: A Case Study of Slow-Release Carpet Deodorizers/Disinfectants

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In this article, a recently published procedure for product design is applied to the design of carpet deodorizers/disinfectants and expanded to include multiple competitors. The procedure proposes to make a connection between consumer preferences in different markets, plant design, and supply-chain limitations to the characteristics of the product. Exploiting this connection, the procedure proposes to add a price-demand model and maximize the profit by simultaneously changing product characteristics and product price in each market. A consumer-preference model based on disinfectant effectiveness, scent type and intensity, fragrance duration, toxicity, and odor elimination properties was developed to assess consumer choices. Finally, the aforementioned consumer properties are linked to the product basic design parameters, such as slow-release particle diameter, fragrance content, proportion of ingredients, etc. The best product from the consumer point of view turns out not to be the most profitable. This well-known fact from practical experience can now be quantified, and a formal procedure to manage it is available.

Introduction

Carpet deodorizers/disinfectants are used as a dry alternative to cleaning carpets. Carpets can become a refuge for dust mites, mold, mildew, and bacteria. A dry alternative to cleaning carpets is considered because the previously stated pests are benefited by increased humidity. The solution presented is a dry powder that will avoid the use of water to eliminate carpet odors as well as pests. The powder will also include a freshening substance that will generate a pleasant smell.

On an average, a gram of dust may contain 19 000 dust mites, which results in a large production of harmful fecal matter. Molds are microscopic fungi that produce a bad smell as well as floating spores and even lethal mycotoxins. Bacteria produce butyric acid, which has a rancid vomit-like smell. The traditional solution of cleaning carpets through wet processes with shampoo leaves a great amount of water in the carpet, creating a moist environment that benefits some of the problem causing agents.

To address this problem, a dry powder is proposed using three active components: Baking soda is used as an all-purpose humidity retainer, boric acid is used as a disinfectant that kills mites as well as attacks mold, mildew, and bacteria, and, finally, microscopic PLGA spheres filled with linalool are used to slowly release a pleasant lily smell.

In this article, we apply a methodology recently introduced by Bagajewicz[1] that takes into account microeconomics. The major finding of this methodology so far is the confirmation and quantification of the fact that the best product from the consumer-preference point of view is not always the most profitable. Often a compromise between the quality of the product, as perceived by the customer, and profit, needs to be made. This finding directly contradicts the premise used by alternative product design procedures, like the one proposed by Cussler and Moggridge[2] or Seider et al.[3] that advocates the identification of consumer needs first and uses those as targets in the product design procedure. Our methodology is more in agreement with the aforementioned heuristic notion that profitable products are not always the best products from the consumer-preference point of view, providing at the same time the means to manage these connections numerically.

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Table 1. Design Parameters

design parameter	physical model effect
size of the bag for a typical 100 m^2 room	
internal and external radius of PLGA−linalool particles	defines the duration of the scent
proportion of PLGA−linalool particles	defines the scent intensity
proportion of boric acid particles	determines the efficiency of the mite killer
proportion of baking soda particles	defines the amount of freshness obtained

The article is organized as follows. First, a background on carpet pests including dust mites, mold, mildew, and bacteria is given. Then, the consumer-preference model is presented, followed by the determination of the optimal product from the consumer point of view. The production of the complete product starting from the production of double-emulsion scent encapsulation and continuing with the solid handling process related to the boric acid and baking soda is then presented. We then present a simplified business model that allows us to assess a better price, possible demand, and the composition of the most profitable product. We ignore, in this case, complications arising from multiple markets. The supply-chain restrictions are also reduced to transportation costs.

Background

As a result of the physical nature of carpets, these may become a perfect environment for many pests that may have harmful effects as well as generate undesired odors. These pests are basically divided into three main categories: dust mites, mold and mildew, and bacteria.

Dust Mites. Dust mites are microscopic arachnids (400 mm length), which are considered as the most common cause of asthma and allergies.[4] These arachnids feed mainly on dead human cells. An average human can shed about 1.5 grams of dead cells each day. These arachnids also rely on the humidity of the air as their water source because they do not drink water but rather they absorb it from the environment. They require a relative humidity of around 55% to be able to survive.

The main problem with dust mites is that just one mite can produce over 200 fecal particles in 1 week. This particulate

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Table 2. Toxicity of Various Substances

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

Table 3. Weights

characteristic	weight
disinfectant effectiveness	21%
scent intensity	22%
fragrance duration	19%
toxicity	9%
odor elimination	15%
scent type	14%

matter can have noxious effects on humans because they contain enzymes that can cause potential health problems. This amount of particles can be of a very large magnitude when considering the magnitude of mites that may inhabit a given carpet. On average, 1 gram of dust can have 19 000 dust mites.

Molds and Mildew. Molds are another problem that can appear in carpets.[5] These are microscopic fungi of very fast maturation. They require a moist environment to be able to live as well as high humidity to be able to grow. They are responsible for bad odors as well as health-related problems such as the production of floating spores and even the production of lethal mycotoxins. Mildew, a form of mold, can also pose potential problems for carpets due to its musty odor.

Bacteria. 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 its rancid butter or vomit smell. These bacteria are found in the latex backing of the carpet, and they also require moist environments to reproduce.

Proposed Product Description

The proposed product is a fine powder in a sealed container containing three active components: boric acid, baking soda, and small particles containing a scent in liquid form encapsulated in polylactic-co-glycolic acid (PLGA), which is degradable. Other choices, of course, may lead to different conclusions.

Baking soda is selected as a freshener over components such as zeolites, activated carbon, and hydrating salts to complete the task of retaining odor. These first two components retain odor from the environment through adsorption. These are more complex and expensive products and therefore they are not considered. Hydrating salts such as calcium chloride, magnesium chloride, zinc chloride, and the strong base sodium hydroxide can also be used to retain humidity, although they may pose some other problems. The best solution was found to be baking soda because of its ability to absorb humidity at a moderate price.

Boric acid in small-pellet form addresses the disinfectant problem. Boric acid is chosen over other disinfectants such as tannic acid and sodium propionate because this component has the broadest effect over the defined pests. Boric acid may be used to eliminate dust mites, mold, mildew, and bacteria, unlike other components that have a more selective function. Another

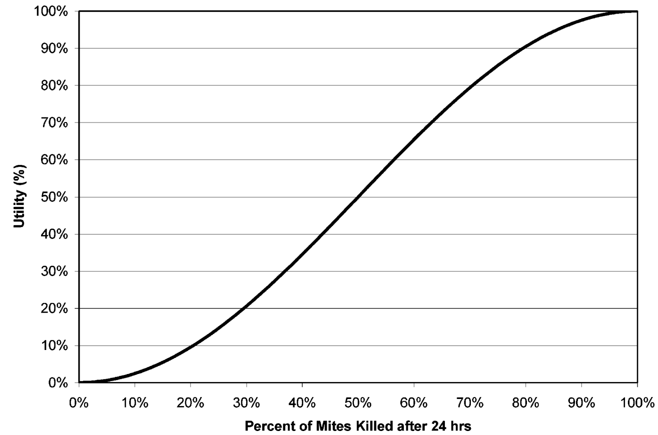

Figure 1. Disinfectant effectiveness utility.

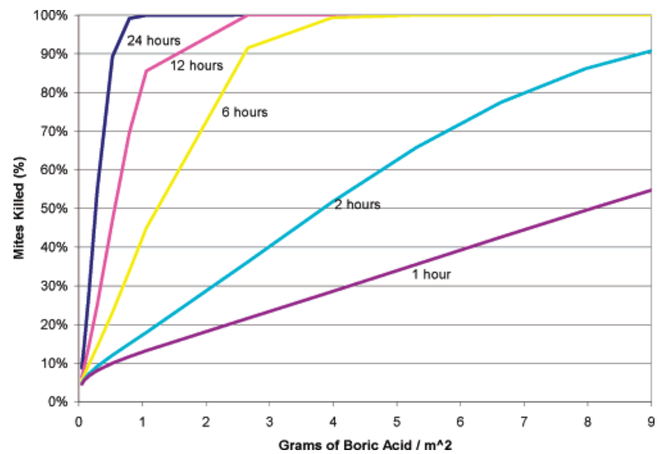

Figure 2. Disinfectant killing rate.

reason for this selection is the ease of incorporating in the product: whereas boric acid can be easily found as a powder, tannic acid is found as a liquid solution.

The proper superficial concentration of boric acid is suggested to the consumer to guarantee that mites are eliminated properly without creating a toxicity hazard for the consumer. The odor problem is taken care of by baking soda in the form of a fine powder because of its hydration capacity. Finally, microscopic PLGA spheres filled with linalool are used to provide a pleasant smell. These particles are formed by a double-emulsion process where linalool is placed in contact with emulsified PLGA to form ~5 micron spheres of radius R_2, with a fragrance (linalool) inside a smaller sphere of radius R_1. The diffusion coefficient of linalool in solid PLGA is very small, and this allows for the slow release.

The three components are mixed in the proper fractions to create the most consumer attractive product.

The design parameters are shown in Table 1. An ideal product should be designed to last a long period of time with the powder remaining in the carpet even after vacuuming the carpet. This is practically impossible because common vacuum cleaners can vacuum particles down to 0.3 μm, and the PLGA pellets that can be manufactured are bigger.

Because of this physical limitation, our product is designed to last until the next vacuum, leaving the use of smaller particles for another design. This assumption does not prevent us from making meaningful conclusions about this product. One solution to this would be to have a PLGA particle that would stick to the carpet. This could be done chemically by adding an adhesive over the particles or mechanically by creating a Velcro-like surface.

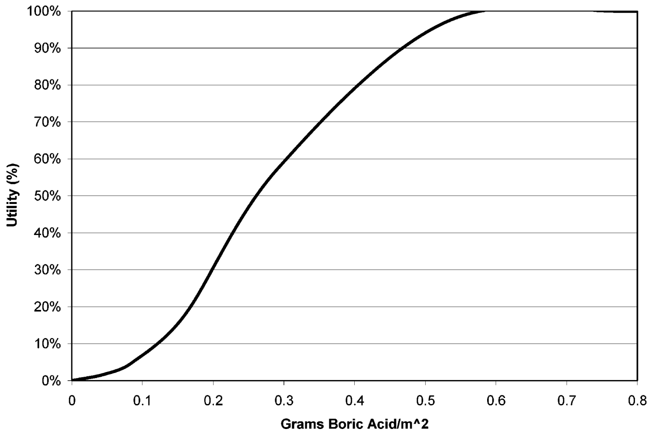

Figure 3. Disinfectant utility.

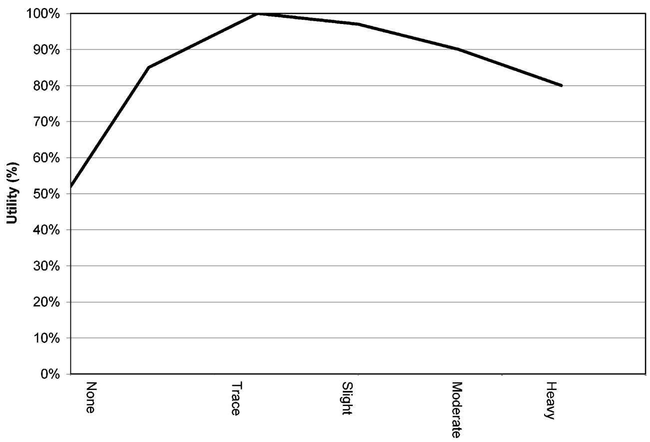

Figure 4. Scent intensity utility.

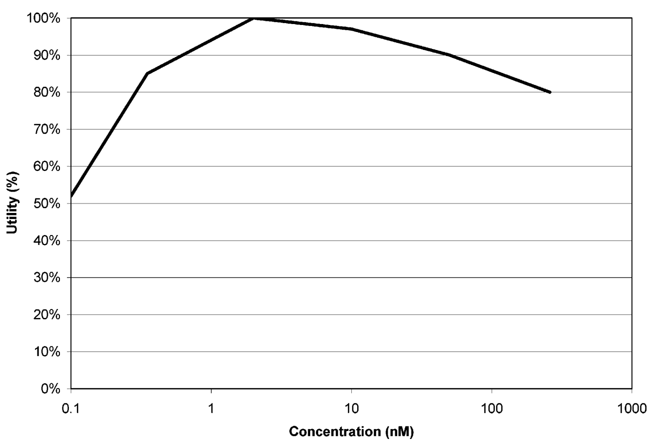

Figure 5. Scent intensity utility.

We now present a consumer-preference model that will allow us to make the connection to the above design parameters.

Consumer-Preference Model

Following Bagajewicz,[1] we use a linear preference function:

$$S_{ik} = \sum_j w_{ikj}\, y_{ikj} \tag{1}$$

where S_{ik} is the preference for product i in market k, y_{ikj} is the score of the product characteristics j for product i in market k, and w_{ikj} is the corresponding weight.

We use the following product characteristics.

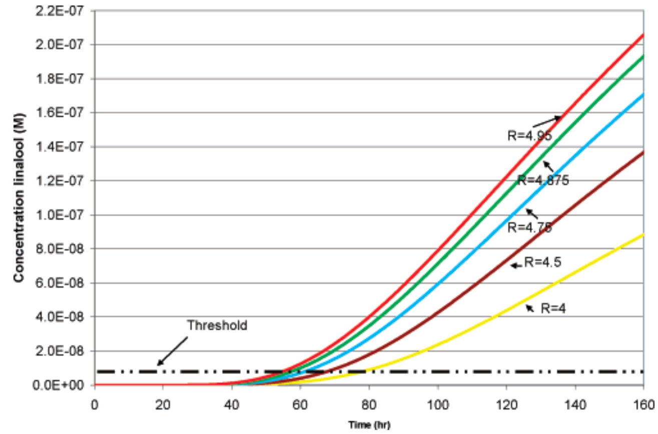

Figure 6. Concentration profiles for different internal radiuses and a superficial concentration of 1 000 000 particles/m^2.

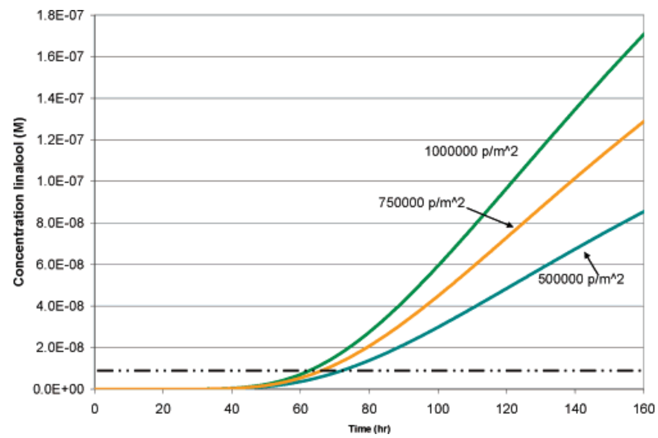

Figure 7. Concentration profiles for different ground concentration of particles ($R_{\text{external}} = 5\ \mu$m, $R_{\text{internal}} = 4.75\ \mu$m).

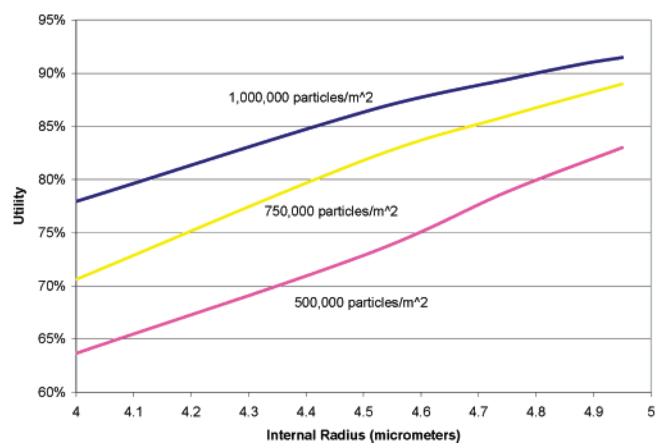

Figure 8. Utility versus the internal radius of PLGA spheres for different ground concentrations.

Scent Intensity and Duration. This can be achieved by varying both the inner and outer radius of the PLGA−linalool particles as well as their superficial concentration on the carpet. The inner radius defines the size of the linalool reservoir. The relation between the two radiuses defines the rate of diffusion from the particle, having therefore an impact on both the intensity of the scent as well as the duration of the scent. We quantify this later.

Disinfectant Effectiveness. The use of boric acid as a mite, mold-mildew, and bacteria killer is controlled by the randomness of the dispersion by the consumer. Because fungi and bacteria are considered to be stationary, boric acid can only act when a

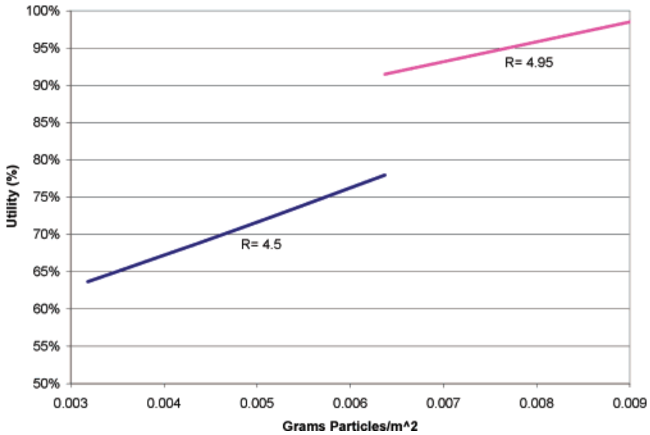

Figure 9. Utility versus the superficial concentration of PLGA−linalool spheres (R in μm).

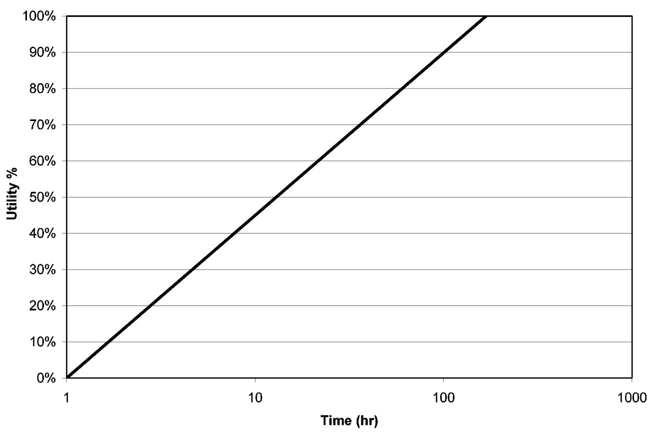

Figure 10. Fragrance duration utility.

particle lands on either of them. The amount of boric acid to be used is controlled by the toxicity of the product as well as by its disinfectant potential. Particle size is restricted on the upper bound by the probabilistic efficiency and in the lower bound by the necessary dosage to be able to kill a mite.

Toxicity. The most toxic component present in our product is boric acid. The toxicity of boric acid is slightly higher than the one of linalool but is less toxic than common substances like aspirin, caffeine, and nicotine. The toxicity is measured according to the well-known LD_{50} criteria in toxicology, which is defined as the amount (in grams per kilogram of body weight) that a a population of given individuals must ingest such that 50% of them die. Table 2 shows the values corresponding to humans weighing 75 kg.

When humans are exposed to high concentrations of boric acid, health issues may appear. When boric acid is inhaled it can cause irritation in the respiratory tract. It can also cause skin irritation but is not significantly absorbed by the skin. On contact with the eyes, it can cause irritation and pain. After exposure for prolonged periods of time, it may cause liver and kidney problems.

Odor Elimination. Because the active component selected to handle this problem is baking soda, which is physically limited to a certain amount of odor to elimination, the superficial concentration is the determining design parameter. The superficial concentration is determined by both the particle fraction in the product itself as well as the recommended use given to the consumer.

Scent Type. Although different scents are available, this parameter was not varied and the most preferable scent from the consumer point of view was chosen.

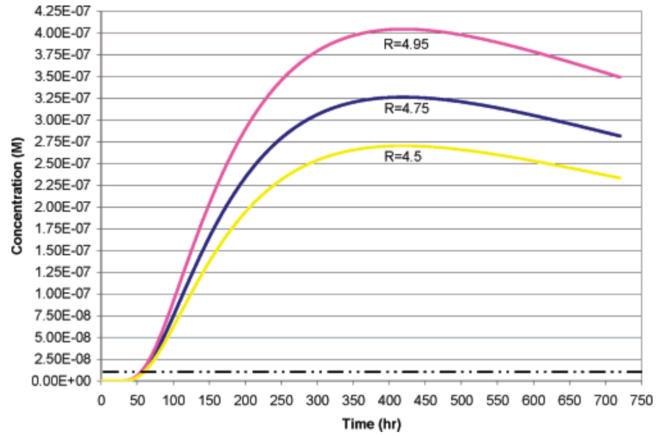

Figure 11. Mass-transfer model results. Concentration at 1.5 m above ground level.

In the polls, the consumers rank some characteristics according to the importance they have on the product. These characteristics go from the essential duty of the product to less important characteristics that the product can fulfill. The results from the consumer polls are used to assign the weight in the utility function. These weights are used to create a relation between the different consumer properties so that they can all be integrated and considered in a product design model. The important characteristics, along with their respective weights, are shown in Table 3 and were obtained using informal surveys.

The issue now is to

(a) Make a scale of the preference for each characteristic and obtain through consumer surveys the form of the characteristic function y_{ikj}, for example, obtain a score y_{ikj} from zero to one as a function of consumer characteristic descriptions. These are described in terms of qualitative assessments. For example, effectiveness can be described in terms of words like very efficient, fairly efficient, poor, etc.

(b) Make a connection between the product qualifiers (very, fair, poor) to some quantitative measure. For effectiveness, one could say the product is very efficient if it kills 99% of mites in a couple of hours.

(c) Make a connection between the quantitative description of the product characteristic to a physical property or product design parameter.

All three steps are presented next, but sometimes steps (a) and (b) are done simultaneously.

Disinfectant Effectiveness. This consumer property relates the percentage of existing mites that are killed to the consumer response. It is assumed that all of the mites that are killed by the product are killed by boric acid and not by any other component of the product. 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 used model presents lower sensibility at the extremes because it may be harder to perceive the effect of the product when few mites are killed or when most are exterminated but completeness cannot be guaranteed.

In turn, the percentage amount of mites killed was related to the amount on particles of boric acid per unit area using a random walk model. The model assumes that boric acid kills the mites by contact and that the boric acid particle does not disappear once it has been effective. The random walk simulation was done by taking an area and dividing it into small squared cells. Then, a certain number of boric acid particles are located randomly in different cells. The simulation for one mite's random walk is started next by using a uniform distribution to generate random numbers between zero and one

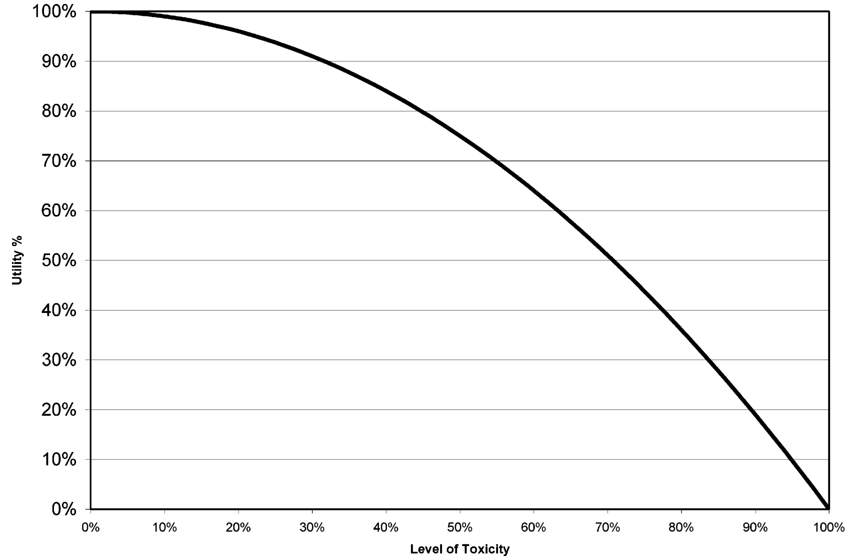

Figure 12. Toxicity utility.

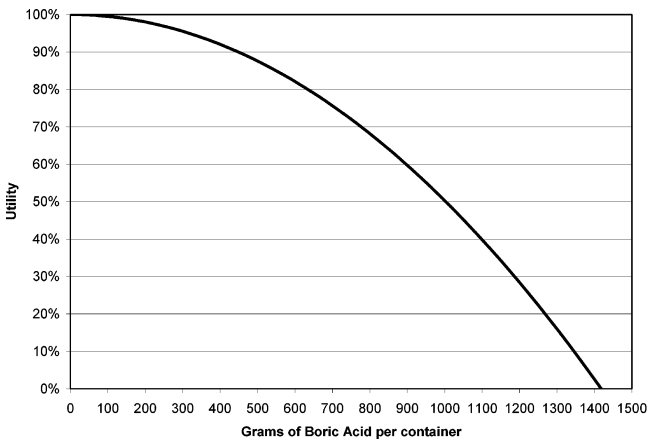

Figure 13. Toxicity versus the amount of boric acid.

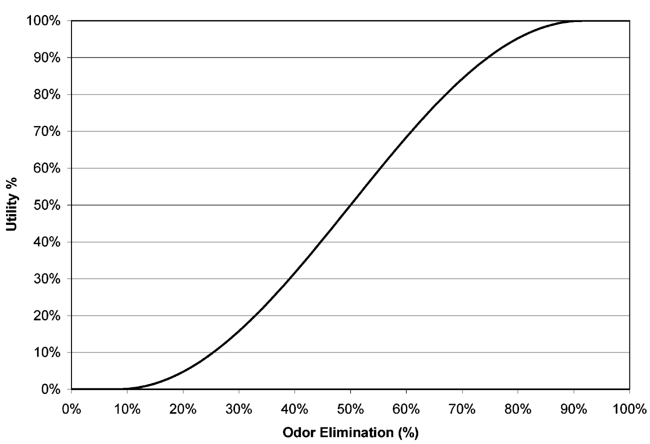

Figure 14. Odor elimination utility.

to indicate the cell to which the mite will travel next (in eight different directions). Once one mite enters a cell with a boric acid it is assumed to die. These simulations where done for different amounts of boric acid particles per unit area. Each simulation was repeated 150 times, recording the time in which the mite dies. Then, the average and standard deviation of these data was taken. Having this information, a normal distribution is assumed for the time of death of an independent mite. With this distribution, the probability of a mite dying in a given time can be obtained for different concentrations of boric acid particles in the carpet, which is used to indicate the percentage of mites that will die in a population at that time. Results are shown in Figure 2. Next, Figures 1 and 2 were combined to obtain the disinfecting utility as a function of the surface particle density (Figure 3). The 24 h line was used as the selection criteria because mites have a short life cycle (20 to 30 days), therefore it is important to be able to exterminate them before they reproduce.

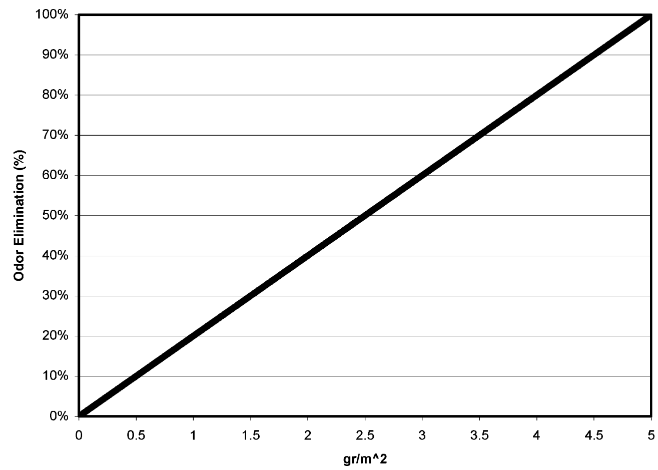

Figure 15. Odor elimination capacity of baking soda.

Scent Intensity. Scent intensity relates the fragrance concentration that can be perceived by the consumer at 1.5 m from the floor level. Figure 4 exhibits the consumer preference is greatest at a *trace* followed closely by *slight*. As the fragrance becomes too strong, the preference reduces linearly to 80%. When no scent is perceived by the consumer, the utility drops to 40%.

Kamadia et al.[6] studied various amounts of linalool and used human subjects to determine the intensity of each sample 1.5 feet away from the sample, 25 min after the sample was prepared. 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 in Table 3. Subjects found that at 0.5 ppm, the linalool reached the threshold, which corresponds to a linalool concentration of 4×10^{-10} M. At 2.5 ppm, the concentration of linalool was at the most pleasant level, corresponding to a concentration of 2×10^{-9} M, and at 312.5 ppm the linalool was overwhelming, corresponding to a concentration of 2.6×10^{-7} M.

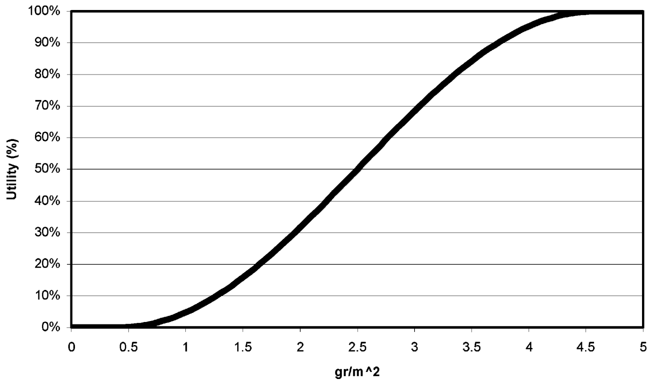

Figure 16. Utility versus baking soda superficial concentration.

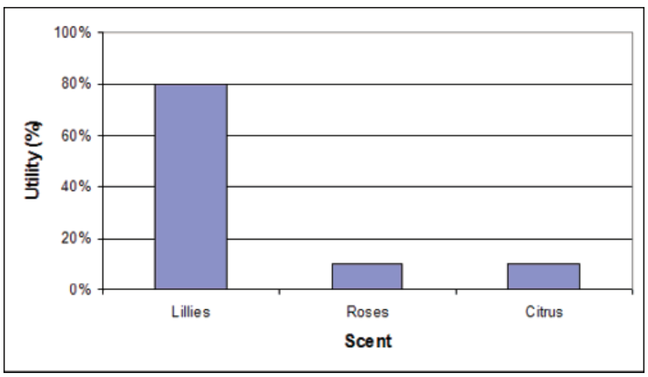

Figure 17. Scent preference score versus scent type.

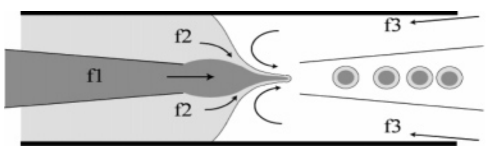

Figure 18. Double-emulsion process.

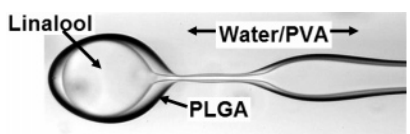

Figure 19. PLGA/Linalool sphere.

Table 3 allows us to make the connection between the consumer score y_{ikj} and the specific concentration at a given height. The different concentrations in the air were related with the *consumer concentrations*, and a concentration of 0 M is considered as no scent. A concentration of 2 nM is considered as a *trace* of fragrance, 10 nM is considered as *slight*, 50 nM as *moderate*, and 260 nM as a *heavy* smell. Figure 5 shows the combination of Figure 4 and the information form is in Table 3.

What is needed now is to make the connection between the diameters and the amount of linalool-filled particles to the scent concentration. Quite clearly, this is a mass-transfer problem. This was assessed using the following well-known mass-transfer model:

$$\frac{\partial C_a}{\partial t} = -D_{a-b}\nabla^2 C_a \qquad (2)$$

The model assumes a uniform distribution of particles laid out through the entire room. The boundary conditions chosen are:

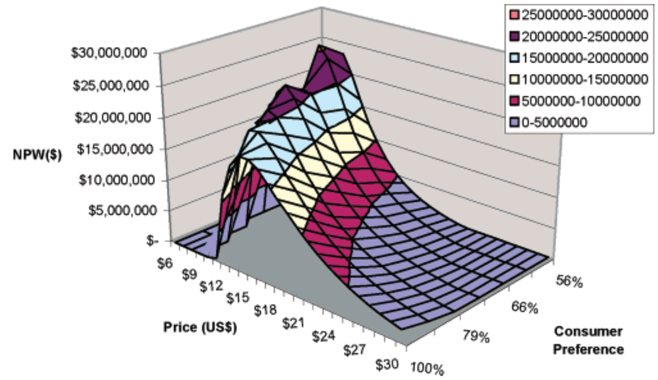

Figure 20. Net present worth versus preference and price.

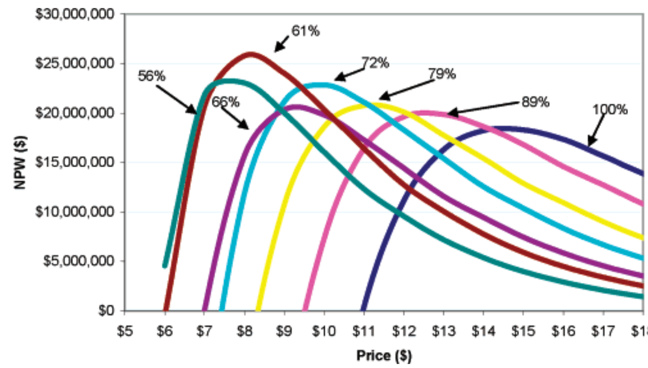

Figure 21. Net present worth as function of price for different preferences.

- Saturated concentration of fragrance in PLGA at the interface of the fragrance and the internal particle surface (R_1).
- Continuity of flux at the particle surface (R_2).
- Henry law at the particle surface.
- No diffusion through the walls of the room.
- Zero concentration (simulating a ventilation stream) at the ceiling.

The model was solved numerically through finite differences. Data for diffusion coefficients were obtained from Kang et al.[7] and adjusted to linalool by molecular weight adjusting for the molecular weight (using direct proportionality).

The design variables that affect the mass-transfer model are basically the concentration of particles on the ground as well as the relation between radiuses R_1 and R_2. The external radius was fixed at 5 μm, whereas the internal radius was varied from 4 to 4.95 μm. Because these particles are big enough to be captured by a vacuum cleaner, the life span of this product is 1 week, which is considered as the time between vacuums. All of the evaluated parameters fulfilled this duration, therefore a greater importance is given to the intensity reached at 1.5 meters above the floor level. Figure 6 shows the effects of both the radius and the superficial concentration. Figure 7 shows the effect of different ground-particle concentrations on the linalool concentration in the air at 1.5 meters.

Because both the radius as well as the superficial concentration are design parameters, they can be used to manipulate the utility of the product. Indeed, Figures 8 and 9 give the final utility as a function of the two parameters.

Fragrance Duration. Fragrance duration relates the application frequency of the product so that a scent concentration close within a range in the air is achieved after a certain time. Figure 10 shows a semilog plot of consumer utility versus duration. Consumer preference increases with an increase in application time; consumers are more satisfied with longer fragrance duration. Once the product lasts a period of approximately 1

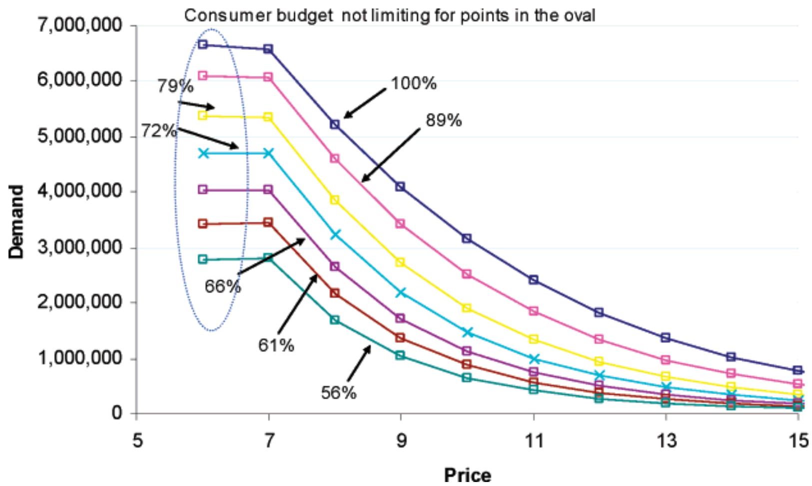

Figure 22. Demand as a function of price and preferences.

Table 4. Linalool Concentration Threshold

linalool (ppm in water) from Kamadia et al.[6]	conc. (nM) at 1.5 feet & 25 min	corresponding consumer perception	corresponding utility (%)
n0	0	none	50
0.5	0.4	light trace	70
2.5	2	trace	100
12.5	10	slight	97
62.5	50	middle rate	90
312.5	260	heavy (overwhelming)	82.5

month, the consumer is completely satisfied and will not become happier if the product lasts longer.

The connection between the duration time and the fragrance-containing particles' diameters R_1 and R_2 and the number of particles were also obtained using the above-described mass-transfer model. The particle sizes that were used are all big enough to guarantee that the scent would last more than a week at an ideal ground concentration. Figure 11 shows that duration should not be a problem and will receive a 100% preference score.

Toxicity. As expected in any product, the consumer prefers it to be nontoxic or to have very low toxicity. As the toxicity increases, the utility drops toward zero. Extreme toxicity can be defined as a function of the LD_{50} of boric acid. The LD_{50} for boric acid is of 202.5 grams. This means that of a population of individuals with a body weight of 70 kg, 50% would die when ingesting 14.18 kilograms of boric acid. Toxicity relates the amount of boric acid per unit area of carpet to the toxicity of the product. Because this component is used by both the competition as well as our product, the toxicity would not interfere in a consumer's decision. The only consideration that could be generated is that the consumer would be happier with a product that is less toxic, and therefore the only utility function that is used as a guideline is the one presented in Figure 12. The user has a high preference for a nontoxic product; as the toxicity increases the happiness decreases. Because the product has a low level of toxicity, the happiness decreases slowly at first and faster at the end.

The level of toxicity is defined based on the LD_{50} measurement. For a 70 kg person, 14.18 kg of boric acid will be lethal with a probability of 50%. Because this is a drastic measure, one tenth of that measure will be defined as a toxic amount of boric acid. Figure 13 shows the final preference score as a function of boric acid particles.

Odor Elimination. Odor elimination relates the amount of odors that can be eliminated generating a feeling of freshness. Freshness is the property of something that smells new and clean. This can be obtained by the use of baking soda. Baking soda is able to fulfill this task with a solid−gas reaction in which the alkaline base reacts with an acidic gas such as hydrogen sulfide. Baking soda also has the property or retaining humidity through a hydration process.

As shown in Figure 14, the consumer utility was directly proportional to the freshness that the product generates. 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 does not generate that freshness feeling (0% = no freshness). The user does not present sensitivity to an elimination of less than 10% or greater than 90%.

Because the amount of freshness feeling that can be accomplished is related to the superficial concentration of baking soda in the carpet, the relation between the amount of odor eliminated and the superficial concentration of baking soda is presented in Figure 15. The linearity of this relation is due to the stoichiometry of the solid−gas reaction where one mole of baking soda has the ability to react with one mole of odor, creating gas and therefore reducing the concentration of that odor. Because the elimination of odor is linearly related to the utility, a utility versus superficial concentration of baking soda can be constructed (Figure 16).

Scent. One of the functions of this product is to produce a pleasant smell that could help cover the unwanted odors produced by the pests. Three different scents were evaluated by a consumer poll, which resulted in a consumer preference for a smell of lilies (Figure 17).

This smell is produced by linalool, which is a naturally occurring terpen alcohol that can be synthesized in large quantities. Linalool is found in many flowers and spice plants and can be found in many household products such as soaps, detergents, and lotions.

Table 5. Preference Scores of Competitors

	weight	Glade Room & Carpet	Borid	Arm & Hammer Baking Soda
disinfectant effectiveness	21%	0%	21%	10%
scent intensity	22%	20%	0%	0%
fragrance duration	19%	13%	0%	0%
toxicity	9%	7%	5%	9%
odor elimination	15%	9%	10%	15%
scent type	14%	13%	0%	0%
total preference score		**62%**	**36%**	**34%**

Table 6. Composition of Product

	u_1						
	100%	89%	79%	72%	66%	61%	56%
PLGA	0.05%	0.04%	0.02%	0.01%	0.01%	-	-
linalool	1.2%	0.85%	0.57%	0.34%	0.24%	-	-
boric acid	32.9%	33.0%	33.1%	33.2%	33.2%	32.7%	30.0%
baking soda	65.8%	66.1%	66.3%	66.4%	66.5%	67.2%	70.4%
material cost	$10.72	$9.28	$8.12	$7.17	$6.80	$5.81	$5.52

Pricing Model

Bagajewicz[1] proposed to use the following model, which has a constant elasticity of substitution.

$$p_1 d_1 = \left(\frac{\alpha}{\beta}\right)^{\rho} p_2 \left[\frac{Y - p_1 d_1}{p_2}\right]^{1-\rho} d_1^{\rho} \tag{3}$$

In this expression, d_1 and d_2 are the demands of the new product and the existing products, respectively, and p_1 and p_2 are the corresponding prices. In turn, α is the awareness function (zero when consumers are not aware of the new product and one when they are fully aware), and β is the product superiority function, which is the ration of the consumer preferences ($\beta = S_2/S_1$). Finally, ρ is a parameter (related to the elasticity). Bagajewicz[1] also discussed in detail the advantages and shortcomings of the above model in view of other alternatives. We will consider $\alpha = 1$ for simplicity and we will examine the results.

We also consider here the possibility of multiple competitors. In such a case, we reformulate the consumer utility function as follows:

$$u(d_1, d_2,..., d_n) = \left(\sum_i (d_i\, u_i)^{\rho}\right)^{1/\rho} \tag{4}$$

Performing the maximization subject to the budget constraint, one gets

$$d_j = \beta_j^{\rho/(1-\rho)} \left(\frac{p_1}{p_j}\right)^{1/(1-\rho)} d_1 \; j \neq 1 \tag{5}$$

(($\beta_j = u_j/u_1$), which with the help of the (active) budget constraint,

$$\sum_j p_j d_j = Y \tag{6}$$

provides the different demands as a function of all of the prices. Both equations are solved for a different process p_1, and if the sum of the demands is larger than the natural maximum demand D (in our case the total number of households that could use some carpet deodorizer) then the demands are no longer driven by the consumer budget and are only driven by preferences, in which case the consumer-preference function is maximized subject to the demand constraint ($\sum_i d_i = D$).

Production Process

The production process for this product has two basic steps: the first one is the production of the linalool-filled PLGA particles and the second is the mixing of the components to obtain a homogeneous powder ready to use.

Linalool encapsulated by the polymer PLGA is produced by a double-emulsion technique, 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. Figure 18 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.

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 (Figure 19).

Maximum Consumer Preference

The competition that was considered for this example is composed of Glade Room & Carpet, Borid, and Arm & Hammer Baking Soda. Their preference function scores are shown in Table 5. Glad Room & Carpet is not a disinfectant like Borid. In turn, Borid and Arm & Hammer have no scent-associated utility.

Table 6 shows the product composition for different preference values for the proposed carpet deodorizer/disinfectant. Table 6 also lists the cost of the product. We point out that, unlike in other cases, a maximum 100% preference score for our product is possible in this case.

Optimization

Using the consumer-preference model and the pricing model, the following procedure was used to optimize the product. The price of the proposed product price p_1 and its quality was varied to identify the optimum product and its selling price. The prices for the competition were set at $p_2 = \$10$, $p_3 = \$7.50$, and $p_4 = \$6$. Finally, the profit was calculated for each price p_1 and corresponding product composition using the following expression:

$$Profit = \sum_t df_t(p_1 - o_1)d_1 - FCI(d_1) \tag{7}$$

le;1.0qResults are shown in Figure 20. An optimal is found at a consumer preference around 61% with a selling price of $8.00 US$. This gives a net present worth (NPW) of $25 million US$ for a 10 year lifespan of the product. Figure 21 shows the same results but now parametrically in preference. Finally, Figure 22 shows the demand as a function of price. We note that only for the smallest price tried ($6), we obtain that the consumers have enough of a budget and therefore their consumption is driven by preferences only, not preferences and price anymore.

We point out that the best product ($u_1 = 100\%$), if chosen as suggested by other methodologies,[2,3] would have to be sold between $14 and $15 and would give an NPW of around $18 million US$.

Conclusions

We have applied a recently developed methodology (Bagajewicz[1]) to the case study of a slow-release carpet deodorant and disinfectant, extending the method to consider more than one competitor. This methodology makes use of microeconomics to determine the most appropriate product. As is the case in many products, the most profitable one is not the best product. This contradicts the results of methodologies that make use of sequential steps, determining consumer *needs*, and using them as targets for design,[2,3] without looking at the consumer response. We also look at needs and preferences, but we assess through microeconomics how much we want to meet the needs. In the particular example we study, a perfect product (100% preference score) is possible, but it is not as profitable as another one that actually does not have fragrance.

Another issue of importance is that there is uncertainty associated with many of the parameters used in the pricing model as well as in assessing the costs of raw materials and manufacturing. This is an important issue that can only be addressed in a design under an uncertainty framework that was not attempted here, as the main objective is to illustrate the deterministic model. The deterministic model will be extended to consider uncertainty in future work.

In conclusion, we reinforce the well-known fact that the best product from the consumer point of view is not the most printable, by providing a numerical framework to make decisions. This is, we believe, the major contribution.

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