Introduction
The Repellent Market

- DEET (N,N-diethyl-m-toluamide) was discovered in 1946
- The market has remained largely unchanged since then
- Consumer pressures have led companies to seek gentler and safer alternatives to DEET
- OFF! and Cutter are the major players in the repellent market
Introduction

The Repellent Market

- The company that can come up with an economically feasible, user-friendly, safe product stands to gain a large share of the market.

- Initial aim: develop a new repellent that will accomplish these objectives
  - Investigate insect repellent interactions
Background

Insect Receptors

Types of Receptors

- Thermoreceptors
- Mechanoreceptors
  - Tactile receptors
  - Sound receptors
- Photoreceptors
- Chemoreceptors
  - Gustatory receptors
  - Olfactory receptors

Source: http://www.mediabum.com/images/mosquito.jpg
Background
Insect Chemoreceptors

- Olfactory chemoreceptors are usually located on the antennae.
- Each antenna is covered in hair-like sensilla containing neurons.
- Each antenna can have as many as 75,000 receptor cells.

Source: http://www.insectscience.org/3.2/ref/fig5.jpg
Background
Chemoreceptor Mechanism

Source: http://www.bioweb.uncc.edu/BIOL3235
Source: http://www.pneuro.com/publications/insidestheneuron
Background
Insects of Interest

How do insects use their receptors to find humans?
- Visual Stimuli: long distances
- Chemical Stimuli: short distances
  - Carbon dioxide from skin and breath
  - Lactic acid from skin
- Temperature Stimuli: very close range

What types of insects are interested in humans?
- Mosquitoes
- Ticks
- Fleas

Source: http://static.howstuffworks.com/gif/mosquito6a.jpg
Background
Repellent Mechanisms

What we need to know

- How insect repellents work
  - “Blockers”- blinds the insect to the presence of its meal
  - “Repellents”- works opposite of an attractant
  - “Alarms”- sends a danger signal to the insect’s brain

- Characteristics of a certain molecule that give it repellent properties
Background
Repellent Mechanisms

- Unfortunately, the true mechanisms of repellents are not known!

- According to Dr. Joel Coats at Iowa State University, “Structure-activity relationships of repellents are unclear, and little definitive work has been done…Vapor pressure is the only parameter significantly related to mosquito repellent activity.”

Figure 1. Structures of several insect repellents.
Source: Coats, Joel, “Insect Repellents- Past, Present, and Future”
Background
A New Pursuit

- Instead of developing a new repellent, we plan to re-engineer an existing repellent.

- Market research is performed to determine which repellents to re-engineer.
Background
Repellents in the U.S. Market

DEET
- The most commonly used insect repellent
- One of few repellents that can be applied to the skin
- Unpleasant scent
- Damages plastic and other synthetic materials

Source: http://en.wikipedia.org/wiki/DEET
Background
Repellents in the U.S. Market

- Picaridin
  - Recently introduced in the US in Cutter Advanced
  - Shown to be as effective as DEET at equal concentrations
  - Recommended by Center for Disease Control (CDC) and World Health Organization (WHO)
  - No scent
  - Does not damage synthetic materials

Source: http://picaridin.com/science.htm
Background
Repellents in the U.S. Market

- Cutter Advanced contains Picaridin at 7% concentration
- DEET is offered at concentrations up to 100%
- There is room in the market for more Picaridin products
Achieving the Objective

- Develop a new repellent formula with Picaridin as the active ingredient
  - Create a utility function to measure the wants and needs of repellent consumers
  - Design a production and distribution model
  - Analyze the economics and maximize the profit of this formula
Caveats

- This is a preliminary model
- Many assumptions made based on educated guesses
The Utility Function

- Describes the satisfaction a consumer receives from using a product:
  \[ U = \sum U_i w_i \]
  
  U is the utility; w is the weighted average of each characteristic of the product that the consumer deems important; i is each characteristic.

- Need to decide w, construct equations for each characteristic.
The Utility Function
Repellent Characteristics

- Maximize utility of each of the following characteristics for an overall maximum utility
  - Effectiveness
  - Durability
  - Feel
  - Form (Lotion or Spray)
  - Toxicity
  - Scent
A sample population was surveyed to determine the preferences of consumers.

Target consumer: campers and hikers

These preferences were used to assign $w_i$ to each physical property (sum = 1).

Assumptions

<table>
<thead>
<tr>
<th>Property</th>
<th>Weight</th>
</tr>
</thead>
<tbody>
<tr>
<td>Effectiveness</td>
<td>0.29</td>
</tr>
<tr>
<td>Durability</td>
<td>0.24</td>
</tr>
<tr>
<td>Feel</td>
<td>0.19</td>
</tr>
<tr>
<td>Form</td>
<td>0.14</td>
</tr>
<tr>
<td>Toxicity</td>
<td>0.09</td>
</tr>
<tr>
<td>Scent</td>
<td>0.05</td>
</tr>
</tbody>
</table>
The Utility Function

Ingredients

- Each ingredient chosen to increase the overall utility
  - To increase effectiveness and durability: *use Picaridin*
  - To improve scent and texture, *add fragrance and aloe*
  - To dissolve ingredients and lower cost, *add ethanol*
The Utility Function

General Method

For each chosen characteristic:
1. Relate utility to levels of the characteristic
2. Relate these levels to results of a consumer test
3. Relate test results to some physical property of the repellent formula
4. Relate utility to repellent physical property for optimization
The Utility Function
Effectiveness

- Industry Standard Test
  - Mosquitoes in a box with a repellent sample on one side
  - Percentage of the population on that side of the box after a certain time shows the repellent’s effectiveness.
The Utility Function

Effectiveness

Effectiveness Utility to "Mosquitoes in a Box" Test

Utility (%)

Effectiveness (% of mosquitoes on repellent side of box)
The Utility Function

Effectiveness

Concentration of Picaridin to Test

Effectiveness (% mosquitoes on repellent side of box) vs. % Picaridin
The Utility Function
Effectiveness

Final Utility to Picaridin Relationship:
\[ U = 1.023\times\%\text{Picaridin} \]
The Utility Function

Durability

- Relate durability utility to levels of durability: 
  *Amount of time repellent stays effective*
The Utility Function

Durability

- Relate time to physical property of formula: *Vapor pressure of the mixture*
  - Model evaporation of repellent off skin as a function of time
  - Calculate the amount of time needed for the concentration of repellent at a certain distance from the skin to fall below a set threshold concentration
The Utility Function

Durability

- Fick’s second law of diffusion

\[ \frac{\partial c_A}{\partial t} = D_{AB} \frac{\partial^2 c_A}{\partial z^2} \]

- \( c_A \) = concentration of component A
- \( D_{AB} \) = diffusion coefficient of component A
- \( t \) = time
- \( z \) = distance from skin, set at 0.3 m
Fick’s second law becomes

\[ \frac{\partial c_A}{\partial t} = \frac{c_{As} \cdot e^{\frac{-z}{4t\sqrt{\pi}D_{AB}t}}}{4t\sqrt{\pi}} \]

where \( C_{As} \) = surface concentration

\[ c_{As} = \frac{p_A}{RT} = \frac{x_A(VP)}{RT} \]

using Raoult’s Law approximation
The Utility Function

Durability

- Set time interval = 10 minutes
- Set initial concentrations of all components
- Start: $C_{As} =$ partial pressure of each component
- Calculate $C_{A}$ of each component at $z = 0.3$ m
- Calculate amount of moles lost from liquid
- Recalculate liquid concentrations
- Recalculate new $C_{As}$ based on new concentrations
- Repeat process until $C_{A}$ of Picaridin reaches 0.05 mol/m³
After correlating durability to several physical properties, initial vapor pressure of the mixture showed the strongest relationship.
After correlating durability to several physical properties, initial vapor pressure of the mixture showed the strongest relationship.

This data was combined with the utility versus durability data to form a relationship between utility and mixture vapor pressure.

\[ U = 100 - 9.664e^{3.72 \times 10^{-4} VP} \]
The Utility Function

Feel

Happiness to Feel

Happiness (%)

Feel (Stickiness Level)

Very Sticky, Somewhat Sticky, Slightly Sticky, Barely Sticky, Nonsticky
Aloe and Fragrance can leave a sticky residue when used in large amounts. After applying a concentration of either component to the underside of the forearm, a 2” by 2” piece of paper is applied. The heaviest paper basis weight that will not fall off is used to describe the contribution of stickiness from each component to the final product.
The Utility Function

Feel

Feel to Amount of Fragrance

Feel to Amount of Aloe
The Utility Function

Feel

- **Feel to Amount of Fragrance**
  
  \[ y = -0.9589x + 100 \]
  
  \[ R^2 = 0.9935 \]

- **Feel to Amount of Aloe**
  
  \[ y = -0.7112x + 100 \]
  
  \[ R^2 = 0.9878 \]
The Utility Function

Feel

- Each ingredient contributes unequally to consumer utility
- Solution: weighted average
  - Each relationship has a y-intercept of 100, but differing rates of change:

\[
U = 100 - (0.9589 \times x_{\text{fragrance}}) - (0.7112 \times x_{\text{aloe}})
\]
Market research data showed that 83% of consumers prefer spray repellent over the lotion form.

A repellent in spray form would give ‘100% happiness’ to 83% of consumers, but less happiness to the other 17%, approximated at 50%.

Thus, a spray repellent would have an overall consumer utility of 92%.
Market research data showed that 83% of consumers prefer spray repellent over the lotion form. A repellent in spray form would give ‘100% happiness’ to 83% of consumers, but less happiness to the other 17%, approximated at 50%. Thus, a spray repellent would have an overall consumer utility of 92%.

Liquids with a kinematic viscosity over 75 centistokes\(^1\) will be too thick to be sprayed by a finger pump.

The relationship between form and utility can then be determined using an “If-Then” statement.

\(^1\)www.jamestowndistributors.com/decoder_epifanestopcoats.jsp
The Utility Function

Toxicity

\[ y = -25x + 125 \]

\[ R^2 = 1 \]
The Utility Function

Toxicity

\[ y = -25x + 125 \]

\[ R^2 = 1 \]

Happiness to Toxicity

Toxicity Descriptions
The Utility Function

Toxicity

\[ y = -25x + 125 \]

\[ R^2 = 1 \]

Happiness to Toxicity

Toxicity Descriptions

Amount of Picaridin to Toxicity
The Utility Function

Toxicity

Happiness to Toxicity

\[ y = -25x + 125 \]

\[ R^2 = 1 \]

Amount of Ethanol to Toxicity

Amount of Picaridin to Toxicity

Amount of Ethanol (% of formulation)

Amount of Picaridin (% of formulation)

Toxicity Descriptions

NFPA Description

Least Slight Moderate High Extreme

Toxicity

Least Slight Moderate High Extreme

0 20 40 60 80 100

0 0.2 0.4 0.6 0.8 1

0 0.5 1 1.5 2 2.5 3 3.5 4 4.5

0 0.5 1 1.5 2 2.5 3 3.5 4 4.5
The Utility Function

Scent

Qualitative scent description and utility
The Utility Function

Scent

Qualitative scent description and utility + % fragrance and qualitative scent description
The Utility Function
Scent

Qualitative scent description and utility + % fragrance and qualitative scent description → utility vs. % fragrance

\[ U = -9.09E-06 x^4 + 2.1507E-03 x^3 - 0.160 x^2 + 2.677 x + 89.6 \]

\[ R^2 = 9.96625E-01 \]
The Utility Function

Scent

Qualitative scent description and utility
The Utility Function
Scent

Qualitative scent description and utility + % ethanol and qualitative scent description
The Utility Function

Scent

Qualitative scent description and utility + % ethanol and qualitative scent description → utility vs. % ethanol

\[ U = 0.0081x^2 - 1.7529x + 96.963 \]
\[ R^2 = 0.9937 \]
The Utility Function
Scent

- One ingredient has a positive effect, one has a negative effect on consumer utility

Solution:

Weighted average:

\[
\frac{U_{\text{ethanol}} \cdot x_{\text{ethanol}} + U_{\text{fragrance}} \cdot x_{\text{fragrance}}}{x_{\text{ethanol}} + x_{\text{fragrance}}}
\]

- Assumptions:

  Picaridin, aloe are essentially odorless
Optimization

Cost Analysis

- Raw Material Costs

- Process Costs
  - All process equipment
  - Buildings
  - Utilities
  - Labor

- Shipping Costs
  - Optimized plant location: Little Rock, AR
  - Products shipped to 16 locations across the U.S.

- Advertising Costs
  - Annual budget set at $1 million
Optimization
The Production Process

- Each Ingredient tank is designed to hold one week’s supply.
- The Mixing tank is designed to hold half a day’s production.
- The Products tank is designed to hold up to two days’ production.
- The Products tank feeds to the Packaging line, which is operated during weekdays only.
Distribution centers were chosen to be able to cover all sections of the US.
Percentage of production sent to each center was allotted to supply each region based on population and perceived need for the product.
Assumptions: consumer utility is the same in each market (same target consumer); relative prices remain constant in each region; budget constraints have constant ratio to prices
# Optimization

## Shipping

<table>
<thead>
<tr>
<th>Distribution Center</th>
<th>Percent of Production Received</th>
<th>Shipping Distance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Eugene, OR</td>
<td>5</td>
<td>1752</td>
</tr>
<tr>
<td>Salt Lake City, UT</td>
<td>5</td>
<td>1144</td>
</tr>
<tr>
<td>Denver, CO</td>
<td>5</td>
<td>1635</td>
</tr>
<tr>
<td>Lubbock, TX</td>
<td>6</td>
<td>767</td>
</tr>
<tr>
<td>Kansas City, MO</td>
<td>7</td>
<td>551</td>
</tr>
<tr>
<td>Indianapolis, IN</td>
<td>7</td>
<td>326</td>
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<td>Jacksonville, FL</td>
<td>7</td>
<td>484</td>
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<td>Albany, NY</td>
<td>7</td>
<td>683</td>
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<td>Sacramento, CA</td>
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<td>Phoenix, AZ</td>
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<td>1142</td>
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<td>Billings, MT</td>
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<td>1132</td>
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<tr>
<td>Baton Rouge, LA</td>
<td>7</td>
<td>304</td>
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<td>St Paul, MN</td>
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<td>706</td>
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<td>Memphis, TN</td>
<td>7</td>
<td>129</td>
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<tr>
<td>Charlotte, NC</td>
<td>7</td>
<td>648</td>
</tr>
<tr>
<td>Pittsburgh, PA</td>
<td>5</td>
<td>779</td>
</tr>
</tbody>
</table>
# Optimization

## Shipping

<table>
<thead>
<tr>
<th>Location</th>
<th>Shipping Costs</th>
</tr>
</thead>
<tbody>
<tr>
<td>Oklahoma City, OK</td>
<td>$25,680</td>
</tr>
<tr>
<td>Lafayette, LA</td>
<td>$26,611</td>
</tr>
<tr>
<td>Shreveport, LA</td>
<td>$26,067</td>
</tr>
<tr>
<td>Jackson, MS</td>
<td>$25,919</td>
</tr>
<tr>
<td>Birmingham, AL</td>
<td>$26,006</td>
</tr>
<tr>
<td>Little Rock, AR</td>
<td>$25,243</td>
</tr>
</tbody>
</table>

Costs shown are per ton of production.

This optimization showed that Little Rock, AR would be the best location for constructing our plant.

Source: uams.edu
Optimization
Economic Analysis

- **Budget Constraint:**
  \[ P_1 D_1 + P_2 D_2 \leq Y \]

  P is price; D is demand; Y is budget constraint; 1 is our product; 2 is the competition

- **Price and Demand:**
  \[ \beta P_1 D_1 = \alpha P_2 D_2 D_1^{\alpha/D_2^\beta} \]

  \( \beta \) is relative utility; \( \alpha \) is relative consumer awareness
Algebraic manipulation and substituting for $D_2$ gives:

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

(LHS) \hspace{1cm} (RHS)

If the other parameters are given, the $D_1$ that makes this equation true is our annual production.
Optimization
Procedure

Demand Equation:

\[ D_1^{1-\alpha} = \left( \frac{\alpha P_2}{\beta P_1} \right) \left( \frac{Y - P_1 D_1}{P_2} \right)^{1-\beta} \]

- \( \alpha \): relative consumer awareness, set at 0.9
- \( \beta \): relative utility = \( U_2 / U_1 \)
  - \( U_1 \): combined utility of our formula
  - \( U_2 \): combined utility of competitor’s formula
- \( Y \): market budget constraint
- \( P_2 \): price of competitor
Optimization Procedure

- Set $P_1$ and $D_1$
- Guess a composition of repellent formula
  - $U_1$ is calculated from this
  - $\beta$ is calculated from $U_1$
- Set up two cells in Excel: LHS and RHS of demand equation
- Enter all economic formulas into Excel, set to automatically calculate based on $D_1$
  - Annual Revenue
  - Annual Return on Investment
- Use Excel Solver to set LHS and RHS cells equal to each other by changing concentration
- Repeat for different $D_1$’s
- Repeat for different $P_1$’s

\[
D_1^{1-\alpha} = \left( \frac{\alpha P_2}{\beta P_1} \right) \left( \frac{Y - P_1 D_1}{P_2} \right)^{1-\beta}
\]
Maximized Utility Product

- When utility is maximized:
  - 93.6% Utility

- Resulting composition:
  - Picaridin: 98%
  - Aloe: 0%
  - Ethanol: 2%
  - Fragrance: 0%

- Cost to break even:
  - Over $60 a pound

Source: http://www.parktudor.pvt.k12.in.us/innell/smiling%20sun.gif
Maximized Utility Product

- We want to make this product profitable.

- From market analysis,
  - Market budget constraint: $25 million per year
  - Competitor: Deep Woods OFF! for Sportsmen
    - 100% DEET
    - $96.00 per pound
Maximized Utility Product

- This product can be profitable!
  - Demand: 125,000 pounds per year
  - Price: $80 per pound ($5 per 1 oz. bottle)
  - Net Income: $310,000 per year

- However, raw material costs are the largest cost, so any deviations in these could have a large effect.
Maximized Utility Product
Risk Analysis

Distribution for Net annual income, post-tax: annually...

Values in Millions

-4 -3 -2 -1 0 1 2 3 4

0.000 0.200 0.400 0.600 0.800 1.000

Mean = 178044.5

38.19% 61.14% .67%
Maximizing Profit

- The previous approach was deemed too risky, so it was decided to develop a product with a larger consumer pool.

- New aim: common repellents
  - Less effective
  - Less expensive

- New market budget constraint: $250 million per year

- New competitor: Cutter Advanced
  - 7% Picaridin
  - $16.00 per pound
Maximizing Profit

Cash Flow versus Demand for Various Product Prices

Net Cash Flow ($ per year)

Demand (pounds per year)
Maximized Profit Product

- Resulting composition
  - Picaridin: 43%
  - Aloe: 1%
  - Ethanol: 55%
  - Fragrance: 1%

- Demand: 5 million pounds per year
- Price: $28 per pound ($10.50 per 6 oz. bottle)
- Net Income: $2.55 million per year

Source: http://www.mobileedproductions.com/images/chem1bandw.gif
Maximized Profit Product
Risk Analysis

- A standard deviation of 20% was assumed in the raw materials costs
- 55% chance of our product being profitable
- Expected profit is -$500,000

Distribution for Net annual income, post-tax: / annually...

Values in Millions

<table>
<thead>
<tr>
<th>Values in Millions</th>
<th>44.96%</th>
<th>54.23%</th>
<th>.81%</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>-80</td>
<td>-60</td>
<td>-40</td>
</tr>
</tbody>
</table>

Mean = 49329.3
Consumer Budget Constraint

Market Research Results: Cost versus Effectiveness of Product

Price per pound

Effectiveness Utility

$0 $13 $25 $38 $50 $63 $75 $88 $100

0 20 40 60 80 100

Known Trend

Outside budget constraint

Our product

Inside budget constraint

Uncertainty in trend begins
Conclusions

- The Safer Choice
  - Market the specialty repellent
    - Less risk involved
    - Less profit possible (millions)

- The More Lucrative Choice
  - Market the common repellent at a higher price
    - Riskier
    - Higher possible profit (10s of millions)
    - Because of uncertainty of budget constraint, further market research should be performed

Source: http://www.oc88.com
Environmental Impact

- Production only involves mixing
  - No gas releases
  - No harmful byproducts
- All ingredients non-toxic
  - Leaks present no serious environmental concerns
- Largest impact is related to shipping (truck emissions)

Source: http://residentialvessels.com/environment.htm
Recommendations for Future Work

- **Marketing Survey**
  - Revise to include “form”
  - Increase sample size
  - Refine budget constraint

- **Production**
  - Investigate synthesis of Picaridin

- **Miscellaneous**
  - Find more accurate costs and physical property data
Any Questions?