Engineering Wine

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ChE 4273
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Overview

• Problem Definition
• Process Overview
• Consumer Satisfaction and Preference
• Application of Model
• Business Model
• Conclusions
• Recommendations
Problem Definition

History of Wine

- Predates recorded history
- Fables of medicinal uses
- Integral role in cultures
- Safe alternative to drinking water
Problem Definition

Wine of Today

- Unique product
- Evolved into an experience
  - Past: Quality defined by producer
  - Present: Consumer holds buying power

- Tasks of Producer
  - Identification of consumer wants
  - Adjustment of Product or Price
Problem Definition

Quality

- Outsourced for Evaluation
  1. Laboratories
  2. Competitions

- Problems
  - Increased Cost
  - Defined Post Bottling
  - Adjustment: Selling Price
Problem Definition

Solution

- Quality can be found before bottling
- Engineered to reach desired quality
- Profit can be maximized

Method

- Identification of Consumer Utility
- Adjustment to Process
- Competitor Comparison
Process Overview
Process Overview

1. Harvest Grapes
2. Crush Grapes
3. Add SO2
4. Add Yeast
5. Mix Juice, Skins, Stems, and Seeds (Must)
6. Ferment
7. There are options for fermentation techniques.
8. Extract color, tannins, and flavor compounds.
Fermentation Techniques

- Time on Skins
- Extraction Method
- Temperature
- Fermentation Tank
- Yeast Type
- Barrel Fermentation

The shorter the time spent in skins, the lighter the wine, e.g. blush and light reds.

Go directly to storage in Oak Barrels.
Engineering Wine

Process Overview

1. Press
2. Free Run or Pressed Fractions
   (Combine or Separate)
3. With/without Malo-lactic fermentation
4. Clarity and Stabilize
5. Store
6. Stainless Steel Tanks or Oak Barrels
7. Prepare for Bottling
8. Bottle
9. Mature in Bottle
Consumer Utility and Preference
Consumer Utility and Preference

Theory

- Quantification of Consumer Satisfaction

\[ S = d_1^\alpha + d_2^\beta \]

\( \alpha = \text{Inferiority Function} \)
- Knowledge of product
- Function of Time

\( \beta = \text{Superiority Function} \)
- Consumer preference
- Comparison to competition
Consumer Utility and Preference Theory

- By Maximizing Satisfaction (S)

\[ \beta d_1 p_1 = \alpha d_2 p_2 d_1^\alpha / d_2^\beta \]

- Relation of Consumer Budget (Y)

\[ Y = d_1 p_1 + d_2 p_2 \]
Consumer Utility and Preference

Theory

- $\beta$ is ratio of consumer preference

$$\beta = \frac{H_2}{H_1}$$

- Happiness Function

$$H_i = \sum w_i y_i$$

$w_i$ = weight
- Based on consumer preference
- Fraction of 1

$y_i$ = satisfaction score
- Based on consumer evaluation
- Manipulated by process
Consumer Utility and Preference

Formation and Integration

1. Identification of Characteristics
2. Quantification of Consumer Perceptions
3. Relation to Physical Properties
4. Assignment of Weight
5. Integration into Process

Limitations

*Estimations used to generate consumer expectations.*
Consumer Utility and Preference

Characteristics

- Clarity
- Color
- Bouquet
- Acidity
- Sweetness
- Bitterness
- Body/Texture
- Finish/Aftertaste
## Consumer Utility and Preference

### Weights of Characteristics

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>$w_i$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Clarity</td>
<td>0.15</td>
</tr>
<tr>
<td>Color</td>
<td></td>
</tr>
<tr>
<td>Hue</td>
<td>0.08</td>
</tr>
<tr>
<td>Brightness</td>
<td>0.08</td>
</tr>
<tr>
<td>Bouquet</td>
<td>0.30</td>
</tr>
<tr>
<td>Acidity</td>
<td>0.08</td>
</tr>
<tr>
<td>Sweetness</td>
<td>0.08</td>
</tr>
<tr>
<td>Bitterness</td>
<td>0.08</td>
</tr>
<tr>
<td>Body/Texture</td>
<td>0.15</td>
</tr>
</tbody>
</table>
## Consumer Utility and Preference

<table>
<thead>
<tr>
<th>Clarity</th>
<th>Turbidity (NTU)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Crystal Clear</td>
<td>0.10 - 0.5</td>
</tr>
<tr>
<td>Clear</td>
<td>0.50 - 1.0</td>
</tr>
<tr>
<td>Slightly Blurred</td>
<td>1.0 - 1.8</td>
</tr>
<tr>
<td>Blurred</td>
<td>1.8 - 3.0</td>
</tr>
<tr>
<td>Milky, Cloudy</td>
<td>3.0 - 4.0</td>
</tr>
<tr>
<td>Sediment Present</td>
<td>&gt;4</td>
</tr>
</tbody>
</table>
Consumer Utility and Preference

The graph shows the relationship between clarity and utility/happiness. The x-axis represents the level of clarity ranging from Sediment Present to Crystal Clear, and the y-axis represents the percentage of happiness. The graph demonstrates an increasing trend from Sediment Present to Crystal Clear, indicating a higher level of utility/happiness as clarity improves.
Consumer Utility and Preference

The graph shows the relationship between Clarity and Turbidity (NTU). As turbidity increases, the clarity decreases. The clarity categories include Crystal Clear, Clear, Slightly Blurred, Blurred, Milky, Cloudy, Sediment Present, with turbidity ranging from 0 to 4 NTU.
Consumer Utility and Preference

Clarity

- Utility Function
  \[ y_{\text{clarity}} = -0.25x_{\text{turbidity}} + 1 \]

- Manipulation
  - Bentonite
    - Binds to proteins
    - Cost: $7 / 8 ounces
    - 0.25-1.3 g/L of 5% Aqueous Solution
Consumer Utility and Preference

Color

- Hue
  - Shade of color
  - Ranges from brown to red

- Brightness
  - Intensity of color
  - Ranges from dull to bright
Consumer Utility and Preference

![Graph showing the relationship between hue and % happiness.](image-url)
Consumer Utility and Preference

![Graph showing the relationship between brightness and consumer utility and preference. The Y-axis represents Y (%Happiness) ranging from 0 to 1, and the X-axis represents brightness ranging from 'Dull' to 'Bright'. The graph displays an increasing trend as brightness increases.]
Consumer Utility and Preference

Color

- **Hue**
  - **Measurement**
    \[
    \text{Absorbance Ratio} = \left( \frac{D_{420}}{D_{520}} \right)
    \]
    - Red: < .44
    - Crimson: 0.44-1.0
    - Brown: > 1.0

- **Brightness**
  - **Measurement**
    \[
    \% \text{Brightness} = D_{420} + D_{520}
    \]
    - 0 (Dull)
    - 1 (Bright)
Consumer Utility and Preference

Color

- **Hue**
  
  Utility Function
  
  \[ y = -x_{D420/D520}^2 + 2x_{D420/D520} \]

- **Brightness**

  Utility Function

  \[ y = x_{\text{Brightness Fraction}} \]

- **Manipulation**
  
  - Increase cold soak time
  
  - Alters flavor and aroma profiles
Consumer Utility and Preference

Bouquet

- Olfactory characteristics of wine due to processing
- Result of tannins, esters, and other compounds
- Measured by solid-phase micro-extraction
- Analyzed based on number of components
- Complexity in bouquet is desired
Consumer Utility and Preference

\[ y = 0.02x \]

Graph showing the relationship between the number of aromatic compounds and happiness.
Consumer Utility and Preference

Body/Texture

- Feeling of wine in the mouth
- Depth and round feature
- Measured by \% alcohol
  - Range: 8-16 \%
  - Optimum: 12\%
Consumer Utility and Preference

![Graph showing the relationship between body texture and happiness. The y-axis represents happiness percentage, and the x-axis represents body texture, ranging from rough, course, clumsy to slightly heavy.]
Consumer Utility and Preference
Consumer Utility and Preference

Body/Texture

- Utility Function

\[ y_{Body/Texture} = -625 x_{alcohol}^2 + 150x_{alcohol} - 8 \]

- Manipulation
  
  - Fermentation Time
  
  - Increase time, increase alcohol
Consumer Utility and Preference

Figure 1

Taste Sensor Locations

BITTER
SOUR
UMAMI
TRIGEMINAL
SALT
SWEET
SALT
SOUR
Consumer Utility and Preference

Flavor

- Analyzed based on three attributes
  - Sweetness
  - Acidity
  - Bitterness

- Balance is necessary
Consumer Utility and Preference

y (% Happiness) vs Acidity

- Tart, Vinegary
- Slightly High
- Balanced
- Slightly Low
- Flabby, Insipid
Consumer Utility and Preference

The graph illustrates the relationship between sweetness and happiness. The x-axis represents different levels of sweetness: Lacking, Slightly Lacking, Balanced, Slightly Sweet, and Sweet. The y-axis represents happiness, with values ranging from 0 to 1. The curve shows that happiness peaks at the balanced level of sweetness, declining as sweetness deviates from this balance.
Consumer Utility and Preference

The graph illustrates the relationship between bitterness and perceived happiness. As bitterness increases from balanced to harsh, happiness decreases, indicating a negative correlation between bitterness and consumer preference.
Consumer Utility and Preference

Acidity

- **pH Level**
  - Full Range: 2.9-4.9
  - Optimum: 3.0-3.4

- **Manipulation**
  - Malolactic Fermentation
  - Acid Blend ($5/6ounces)
  - 1 teaspoon/gallon
Consumer Utility and Preference

Sweetness

- Residual Sugar
  - Full Range: 0 – .2wt%
  - Optimum: .1 wt%

- Manipulation
  - Decrease fermentation time

Bitterness

- Tannin Content
  - Full Range: 0 – 3 g/L
  - Optimum: 0 g/L

- Manipulation
  - Increase aging
  - Polyclar
Consumer Utility and Preference

\[ y_{acidity} = -x_{pH}^2 + 6.4x_{pH} - 9.24 \]

\[ y_{sweetness} = -100x_{\%Residual\ Sugar}^2 + 20x_{\%Residual\ Sugar} \]

\[ y_{bitterness} = e^{-2x(\text{tannin content})} \]

**SUM OF SQUARES EMPLOYED FOR ERROR**

\[ y_{balance} = (y_{acidity} + y_{sweetness} + y_{bitterness}) - \]
\[ \{(y_{average} - y_{acidity})^2 + (y_{average} - y_{sweetness})^2 - (y_{average} - y_{bitterness})^2\} \]

**ACCOUNTS FOR EFFECTS ON BALANCE**
Consumer Utility and Preference

Finish/Aftertaste

- Final step of wine evaluation
- Based on length of time on palate
- Measured by residence time on palate
- Cannot manipulate process to alter
- Will not be used in overall function
Consumer Utility and Preference

Effects of Aging

- Largest influential factor of process
- Varies by type, time, and toasting effects
- Toasting method: pyrolysis of oak
- Ranges: Light – Dark
### Consumer Utility and Preference

<table>
<thead>
<tr>
<th>Toast Level</th>
<th>TIME (min)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0</td>
</tr>
<tr>
<td>Light</td>
<td>24</td>
</tr>
<tr>
<td></td>
<td>24</td>
</tr>
<tr>
<td></td>
<td>22</td>
</tr>
<tr>
<td>Medium</td>
<td>22</td>
</tr>
<tr>
<td></td>
<td>23</td>
</tr>
<tr>
<td></td>
<td>22</td>
</tr>
<tr>
<td>Heavy</td>
<td>23</td>
</tr>
<tr>
<td></td>
<td>22</td>
</tr>
<tr>
<td></td>
<td>21</td>
</tr>
</tbody>
</table>

![Graph showing temperature over time for different toast levels: Light, Medium, Heavy.](image)
Temperature profile of medium toast.
Consumer Utility and Preference

[Graph showing various sensory attributes of wine, including TIA, Fruity, Complexity, Creamy, Vanilla, Oaky, Toasty, and Coconut, with different markers for different wine characteristics such as 2mm, 6mm, 10mm, and 14mm.]
Consumer Utility and Preference

Complications

- Consequences of Manipulations
- More data is necessary
  - Diffusivity
  - Profile
  - Correlations of relationships
## Perfect Bottle of Wine

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>$x_i$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Clarity (NTU)</td>
<td>0</td>
</tr>
<tr>
<td>Color</td>
<td></td>
</tr>
<tr>
<td>Hue ($D_{420}/D_{520}$)</td>
<td>1</td>
</tr>
<tr>
<td>Brightness (%Brightness)</td>
<td>1</td>
</tr>
<tr>
<td>Bouquet (#Aromatic Compounds)</td>
<td>60.00</td>
</tr>
<tr>
<td>Acidity (pH)</td>
<td>3.2</td>
</tr>
<tr>
<td>Sweetness (wt% Residual Sugar)</td>
<td>0.2</td>
</tr>
<tr>
<td>Bitterness (g/L Tannins)</td>
<td>0</td>
</tr>
<tr>
<td>Body/Texture (%Alcohol)</td>
<td>0.12</td>
</tr>
</tbody>
</table>
Application of Model
Application of Model

1. Harvesting the grapes
2. Crushing
   - Mixture of juice, skins & seeds (termed Must)
3. Fermentation
4. Pressing
5. Fermentation
6. Clarification and stabilisation
7. Storage
8. Bottling
9. Maturation in the bottle
## Application of Model

### Process - Crushing / Destemming & Cold Soaking

<table>
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<tr>
<th>Physical Properties of Must</th>
<th>Initial</th>
<th>Final</th>
</tr>
</thead>
<tbody>
<tr>
<td>Clarity (NTU)</td>
<td>600</td>
<td>600</td>
</tr>
<tr>
<td>Color (absorbance fraction)</td>
<td>0</td>
<td>0.3</td>
</tr>
<tr>
<td>Color (brightness fraction)</td>
<td>0</td>
<td>0.5</td>
</tr>
<tr>
<td>Bouquet (# of aromatic compounds)</td>
<td>0</td>
<td>15</td>
</tr>
<tr>
<td>Acidity (pH)</td>
<td>3.6</td>
<td>3.2</td>
</tr>
<tr>
<td>Sweetness (wt% sugar)</td>
<td>22</td>
<td>22</td>
</tr>
<tr>
<td>Bitterness (g Tannin/L wine)</td>
<td>0</td>
<td>0.2</td>
</tr>
<tr>
<td>Body (wt% alcohol)</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td><strong>Calculated Happiness (H₁)</strong></td>
<td>0.20</td>
<td>0.39</td>
</tr>
</tbody>
</table>
Application of Model

Grapes from Vineyard

Grapes

Crusher Destemmer 11 ton/hr

Stems

Must

Flexible Impeller Pump 120 gal/min

CO₂

Potassium Metabisulfite (K₂S₂O₅)

Sugar

CO₂

Closed Tank Cold Soaking 20000L

Refrigeration Coils

Refrigeration Water (Brine) In

Refrigeration Water (Brine) Out

3" Butterfly Drain Valve

P-13

Flexible Impeller Pump 120 gal/min

Tartaric Acid

CaCO₃

Calcium Carbonate (CaCO₃)

Tartaric Acid

Sugar

K₂S₂O₅

Potassium Metabisulfite (K₂S₂O₅)

CO₂

Must

Grapes
Application of Model

Crusher Destemmer 11 ton/hr

CO₂
Potassium Metabisulfite (K₂S₂O₅)
Sugar
Tartaric Acid
Calcium Carbonate (CaCO₃)

Grapes
Must
Stems

Flexible Impeller Pump 120 gal/min

CO₂
Sugar
K₂S₂O₅
Tartaric Acid

3" Butterfly Drain Valve
Refrigeration Coils

Closed Tank Cold Soaking 20000L
Refrigeration Water (Brine) In
Refrigeration Water (Brine) Out
Flexible Impeller Pump 120 gal/min
Application of Model

Grapes

Crusher Destemmer 11 ton/hr

Must

Flexible Impeller Pump 120 gal/min

CO₂

Potassium Metabisulfite (K₂S₂O₅)

Sugar

Tartaric Acid

Calcium Carbonate (CaCO₃)

Refrigeration Water (Brine) In

Refrigeration Water (Brine) Out

Closed Tank Cold Soaking 20000L

Cold Soaking

3" Butterfly Drain Valve

Refrigeration Coils

Stems

Sugar

K₂S₂O₅

Tartaric Acid

Calcium Carbonate (CaCO₃)
Application of Model

Grapes

Crusher Destemmer 11 ton/ hr

Stems

Flexible Impeller Pump 120 gal / min

Must

CO₂

Potassium Metabisulfite (K₂S₂O₅)

Sugar

Tartaric Acid

Calcium Carbonate (CaCO₃)

CO₂

Sugar

K₂S₂O₅

Tartaric Acid

Must to Fermentation

Closed Tank Cold Soaking 20000L

Refrigeration Coils

Refrigeration Water (Brine) In

Refrigeration Water (Brine) Out

3" Butterfly Drain Valve

P-13

P-14

Flexible Impeller Pump 120 gal / min

Must
Application of Model

- Harvesting the grapes
- Crushing
- Mixture of juice, skins & seeds (termed Must)
- Fermentation
- Pressing

- Fermentation
- Clarification and stabilisation
- Storage
- Bottling
- Maturation in the bottle
## Application of Model

<table>
<thead>
<tr>
<th>Physical Properties of Must</th>
<th>Initial</th>
<th>Final</th>
</tr>
</thead>
<tbody>
<tr>
<td>Clarity (NTU)</td>
<td>600</td>
<td>600</td>
</tr>
<tr>
<td>Color (absorbance fraction)</td>
<td>0.3</td>
<td>1</td>
</tr>
<tr>
<td>Color (brightness fraction)</td>
<td>0.5</td>
<td>1</td>
</tr>
<tr>
<td>Bouquet (# of aromatic compounds)</td>
<td>15</td>
<td>18</td>
</tr>
<tr>
<td>Acidity (pH)</td>
<td>3.2</td>
<td>3.2</td>
</tr>
<tr>
<td>Sweetness (wt% sugar)</td>
<td>22</td>
<td>10</td>
</tr>
<tr>
<td>Bitterness (g Tannin/L wine)</td>
<td>0.2</td>
<td>2.6</td>
</tr>
<tr>
<td>Body (wt% alcohol)</td>
<td>0</td>
<td>0.07</td>
</tr>
<tr>
<td>Calculated Happiness ($H_1$)</td>
<td>0.39</td>
<td>0.40</td>
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</tbody>
</table>
Application of Model

Potassium Metabisulfite ($K_2S_2O_5$)

Covered Fermentation Tank (Outside) 9000L

Refrigeration Plates

Refrigeration Water (Brine) In

Refrigeration Water (Brine) Out

3" Butterfly Drain Valve

P-15

Pasteur Red Yeast

Diammonium Phosphate (DAP)

Flexible Impeller Pump 120 gal / min

P-19

Must

Membrane Press 7 tons / hr

Skins, Seeds, & Stems

Wine

Flexible Impeller Pump 120 gal / min
Application of Model

Potassium Metabisulfite ($K_2S_2O_5$)

Covered Fermentation Tank (Outside) 9000L

Refrigeration Plates

Refrigeration Water (Brine) In

Refrigeration Water (Brine) Out

3" Butterfly Drain Valve

Flexible Impeller Pump 120 gal / min

Membrane Press 7 tons / hr

Flexible Impeller Pump 120 gal / min

Wine

Must from Cold Soaking

Must
Application of Model

Potassium Metabisulfite ($K_2S_2O_5$)

Covered Fermentation Tank (Outside) 9000L

Refrigeration Plates

Refrigeration Water (Brine) In

Refrigeration Water (Brine) Out

Yeast

$K_2S_2O_5$

DAP

3" Butterfly Drain Valve

P-15

P-19

Flexible Impeller Pump 120 gal / min

Membrane Press 7 tons / hr

Flexible Impeller Pump 120 gal / min

Wine

Skins, Seeds, & Stems

Pasteur Red Yeast

Must

Primary Fermentation
**Potassium Metabisulfite**

(K₂S₂O₅)

**Covered Fermentation Tank**

(Outside)

9000L

**Refrigeration Plates**

**Pasteur Red Yeast**

**Diammonium Phosphate (DAP)**

**Skins, Seeds, & Stems**

Wine

Grape Solids To Waste

**Pressed Wine to Secondary Fermentation**

Must

**Membrane Press**

7 tons / hr

**Flexible Impeller Pump**

120 gal / min

**3" Butterfly Drain Valve**

**Refrigeration Water (Brine) In**

Refrigeration Water (Brine) Out
Engineering Wine

Application of Model

1. Harvesting the grapes
2. Crushing
3. Mixture of juice, skins & seeds (termed Must)
4. Fermentation
5. Pressing
6. Fermentation
7. Clarification and stabilisation
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10. Maturation in the bottle
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<td>600</td>
</tr>
<tr>
<td>Color (absorbance fraction)</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Color (brightness fraction)</td>
<td>1</td>
<td>1</td>
</tr>
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<td>18</td>
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</tr>
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<td>Acidity (pH)</td>
<td>3.2</td>
<td>3.8</td>
</tr>
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<td>Sweetness (wt% sugar)</td>
<td>10</td>
<td>0.2</td>
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<td>2.6</td>
<td>2.6</td>
</tr>
<tr>
<td>Body (wt% alcohol)</td>
<td>0.07</td>
<td>0.12</td>
</tr>
<tr>
<td><strong>Calculated Happiness (H₁)</strong></td>
<td>0.40</td>
<td>0.43</td>
</tr>
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Application of Model

- CO₂
- Potassium Metabisulfite (K₂S₂O₅)
- Refrigeration Coils
- Refrigeration Water (Brine) In
- Refrigeration Water (Brine) Out
- 2" Butterfly Drain Valve
- 2" Butterfly Racking Valve
- Viniflora Oenos Malolactic (ML) Bacteria
- Lees
- ML Bacteria
- K₂S₂O₅
- Wine
- Closed Fermentation Tank 20000L
Application of Model

- CO₂
- Potassium Metabisulfite ($K_2S_2O_5$)
- Closed Fermentation Tank 20000L
- Refrigeration Coils
- Refrigeration Water (Brine) In
- Refrigeration Water (Brine) Out
- 2" Butterfly Drain Valve
- 2" Butterfly Racking Valve
- Lees
- ML Bacteria ($K_2S_2O_5$)
- Racking Elbow
- Viniflora Oenos Malolactic (ML) Bacteria

Pressed Wine from Primary Fermentation
Application of Model

Secondary Fermentation

- CO₂
- Potassium Metabisulfite (K₂S₂O₅)
- Viniflora Oenos Malolactic (ML) Bacteria
- Refrigeration Coils
- Refrigeration Water (Brine) In
- Refrigeration Water (Brine) Out
- 2" Butterfly Drain Valve
- 2" Butterfly Racking Valve
- Racking Elbow
- Wine
- Lees
- Closed Fermentation Tank 20000L
- ML Bacteria
- K₂S₂O₅
Application of Model

Malolactic Fermentation

CO₂

Potassium Metabisulfite (K₂S₂O₅)

Closed Fermentation Tank 20000L

Refrigeration Coils

Refrigeration Water (Brine) In

Refrigeration Water (Brine) Out

Viniflora Oenos Malolactic (ML) Bacteria

Wine

Wine

2" Butterfly Racking Valve

Racking Elbow

2" Butterfly Drain Valve

CO₂

Lees

K₂S₂O₅

Viniflora oenos Bacteria
Decanted Wine to Hot and Cold Stabilization

Viniflora Oenos Malolactic (ML) Bacteria

Wine

CO₂

Potassium Metabisulfite (K₂S₂O₅)

Lees

ML Bacteria K₂S₂O₅

2" Butterfly Drain Valve

Refrigeration Coils

Refrigeration Water (Brine) In

Refrigeration Water (Brine) Out

2" Butterfly Racking Valve

Wine

Closed Fermentation Tank 20000L

Racking Elbow

Sediments to Waste
Application of Model

- Harvesting the grapes
  - Crushing
    - Mixture of juice, skins & seeds (termed Must)
      - Fermentation
        - Pressing
  - Fermentation
    - Clarification and stabilisation
      - Storage
        - Bottling
          - Maturation in the bottle
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<th>Initial</th>
<th>Final</th>
</tr>
</thead>
<tbody>
<tr>
<td>Clarity (NTU)</td>
<td>600</td>
<td>50</td>
</tr>
<tr>
<td>Color (absorbance fraction)</td>
<td>1</td>
<td>0.9</td>
</tr>
<tr>
<td>Color (brightness fraction)</td>
<td>1</td>
<td>0.97</td>
</tr>
<tr>
<td>Bouquet (# of aromatic compounds)</td>
<td>18</td>
<td>18</td>
</tr>
<tr>
<td>Acidity (pH)</td>
<td>3.8</td>
<td>3.2</td>
</tr>
<tr>
<td>Sweetness (wt% sugar)</td>
<td>0.2</td>
<td>0.2</td>
</tr>
<tr>
<td>Bitterness (g Tannin/L wine)</td>
<td>2.6</td>
<td>2.6</td>
</tr>
<tr>
<td>Body (wt% alcohol)</td>
<td>0.12</td>
<td>0.12</td>
</tr>
<tr>
<td>Calculated Happiness ($H_1$)</td>
<td>0.43</td>
<td>0.45</td>
</tr>
</tbody>
</table>
Application of Model

- **Potassium Metabisulfite** ($K_2S_2O_5$)
- **Wine Filter Frame**
- **Rough Polish** (7 Micron)
- **Wine Flexible Impeller Pump** 43 gal / min
- **Closed Tank**
  - Hot & Cold Stabilization 20000L
  - Bentonite (Hot)
  - Refrigeration Water (Brine) In
  - Refrigeration Coils
  - Refrigeration Water (Brine) Out
  - Filter Frame
    - Rough Polish (7 Micron)
  - Flexible Impeller Pump 43 gal / min
  - Racking Elbow
- **Lees**
- **2" Butterfly Racking Valve**
- **2" Butterfly Drain Valve**
Application of Model

[Diagram showing the process flow of wine production, including stages such as potassium metabisulfite addition, Bentonite treatment, refrigeration, and filtration.]

Decanted Wine from Secondary Fermentation
Application of Model

Potassium Metabisulfite ($K_2S_2O_5$)

Wine

Filter Frame Rough Polish (7 Micron)

Flexible Impeller Pump 43 gal / min

Bentonite (Hot)

Wine

Refrigeration Water (Brine) In

Refrigeration Water (Brine) Out

Racking Elbow

Closed Tank Hot & Cold Stabilization 20000L

Wine

2" Butterfly Racking Valve

Lees

2" Butterfly Drain Valve

Bentonite

Wine

Flexible Impeller Pump 43 gal / min

Filter Frame Rough Polish (7 Micron)
Application of Model

Potassium Metabisulfite ($K_2S_2O_5$)

Wine Filter Frame Rough Polish (7 Micron)

Flexible Impeller Pump 43 gal / min

Closed Tank Hot & Cold Stabilization 20000L

Bentonite (Hot)

Wine

Refrigeration Water (Brine) In

Refrigeration Water (Brine) Out

Bentonite

2" Butterfly Racking Valve

2" Butterfly Drain Valve

Racking Elbow

Refrigeration Coils

20000L Wine

Filter Frame Rough Polish (7 Micron)

Hot and Cold Stabilization
Application of Model

Potassium Metabisulfite ($K_2S_2O_5$)

Wine Filter Frame Rough Polish (7 Micron)

Wine Flexible Impeller Pump 43 gal / min

Closed Tank Hot & Cold Stabilization 20000L

Bentonite (Hot)

Refrigeration Water (Brine) In

Refrigeration Water (Brine) Out

Bentonite (Hot)

2" Butterfly Racking Valve

Racking Elbow

2" Butterfly Drain Valve

Lees

Refrigeration Coils

Flexible Impeller Pump 43 gal / min

Filter Frame Rough Polish (7 Micron)

Refrigeration (Cold)
Application of Model

Potassium Metabisulfite ($K_2S_2O_5$)

Wine Filter Frame Rough Polish (7 Micron)

Flexible Impeller Pump 43 gal / min

Closed Tank Hot & Cold Stabilization 20000L

Bentonite (Hot)

Flexible Impeller Pump 43 gal / min

Refrigeration Water (Brine) In

Refrigeration Water (Brine) Out

Bentonite

2" Butterfly Racking Valve

Racking Elbow

Lees

2" Butterfly Drain Valve

Refrigeration Coils

Sediments to Waste

Decanted Wine to Aging / Storage
Application of Model

- Harvesting the grapes
  - Crushing
  - Mixture of juice, skins & seeds (termed Must)
  - Fermentation
  - Pressing

- Fermentation
  - Clarification and stabilisation
  - Storage
  - Bottling
  - Maturation in the bottle
# Application of Model

<table>
<thead>
<tr>
<th>Physical Properties of Must</th>
<th>Initial</th>
<th>Final</th>
</tr>
</thead>
<tbody>
<tr>
<td>Clarity (NTU)</td>
<td>50</td>
<td>30</td>
</tr>
<tr>
<td>Color (absorbance fraction)</td>
<td>0.9</td>
<td>0.7</td>
</tr>
<tr>
<td>Color (brightness fraction)</td>
<td>0.97</td>
<td>0.95</td>
</tr>
<tr>
<td>Bouquet (# of aromatic compounds)</td>
<td>18</td>
<td>30</td>
</tr>
<tr>
<td>Acidity (pH)</td>
<td>3.2</td>
<td>3.2</td>
</tr>
<tr>
<td>Sweetness (wt% sugar)</td>
<td>0.2</td>
<td>0.15</td>
</tr>
<tr>
<td>Bitterness (g Tannin/L wine)</td>
<td>2.6</td>
<td>0.2</td>
</tr>
<tr>
<td>Body (wt% alcohol)</td>
<td>0.12</td>
<td>0.12</td>
</tr>
<tr>
<td><strong>Calculated Happiness (H₁)</strong></td>
<td>0.45</td>
<td>0.63</td>
</tr>
</tbody>
</table>
Application of Model

Diagram of wine production process involving tanks, pumps, and valves.
Application of Model
Decanted Wine from Hot and Cold Stabilization
Application of Model

Maturation Vessels

- **Closed Tank Maturation Vessel 2000L**
  - **Oak Plank**
  - **Racking Elbow**
  - **2" Butterfly Racking Valve**
  - **Flexible Impeller Pump** 120 gal/min
  - **Lees**

- **Potassium Metabisulfite (K₂S₂O₅)**

- **Wine**
  - **2" Butterfly Drain Valve**

- **Wine**
  - **Racking Elbow**
  - **Oak Plank**

- **Lees**
  - **2" Butterfly Racking Valve**

- **Lees**
  - **2" Butterfly Drain Valve**

- **Lees**
  - **2" Butterfly Drain Valve**

- **Wine**
  - **Flexible Impeller Pump** 120 gal/min

- **Lees**

- **Wine**
  - **Flexible Impeller Pump** 120 gal/min
Application of Model

1. Harvesting the grapes
2. Crushing
3. Mixture of juice, skins & seeds (termed Must)
4. Fermentation
5. Pressing

6. Fermentation
7. Clarification and stabilisation
8. Storage
9. Bottling
10. Maturation in the bottle
## Application of Model

<table>
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<th>Physical Properties of Must</th>
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</thead>
<tbody>
<tr>
<td>Clarity (NTU)</td>
<td>30</td>
<td>0.02</td>
</tr>
<tr>
<td>Color (absorbance fraction)</td>
<td>0.7</td>
<td>0.6</td>
</tr>
<tr>
<td>Color (brightness fraction)</td>
<td>0.95</td>
<td>0.93</td>
</tr>
<tr>
<td>Bouquet (# of aromatic compounds)</td>
<td>30</td>
<td>30</td>
</tr>
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<td>3.2</td>
<td>3.2</td>
</tr>
<tr>
<td>Sweetness (wt% sugar)</td>
<td>0.15</td>
<td>0.15</td>
</tr>
<tr>
<td>Bitterness (g Tannin/L wine)</td>
<td>0.2</td>
<td>0.1</td>
</tr>
<tr>
<td>Body (wt% alcohol)</td>
<td>0.12</td>
<td>0.12</td>
</tr>
<tr>
<td>Calculated Happiness ($H_1$)</td>
<td>0.63</td>
<td>0.77</td>
</tr>
</tbody>
</table>
Application of Model

Wine → Flexible Impeller Pump 15 gal / min → Filter Frame Medium Polish (1 Micron) → Flexible Impeller Pump 15 gal / min → Filter Frame Sterile (0.4 Micron) → Bottling

Distribution → Warehouse Storage → Packaging
Application of Model

Decanted Wine from Aging / Storage

Distribution

Flexible Impeller Pump 15 gal / min

Filter Frame Medium Polish (1 Micron)

Flexible Impeller Pump 15 gal / min

Filter Frame Sterile (0.4 Micron)

Warehouse Storage

Packaging

Bottling

Application of Model

Engineering Wine

Decanted Wine from Aging / Storage

Flexible Impeller Pump 15 gal / min

Filter Frame Medium Polish (1 Micron)

Flexible Impeller Pump 15 gal / min

Filter Frame Sterile (0.4 Micron)

Warehouse Storage

Packaging

Bottling
**Application of Model**

**Fine Filtration**

- Wine
  - Flexible Impeller Pump 15 gal/min
  - Filter Frame Medium Polish (1 Micron)
  - Flexible Impeller Pump 15 gal/min
  - Filter Frame Sterile (0.4 Micron)
  - Bottling

**Sterile Filtration**

- Warehouse Storage
- Packaging
- Distribution
Application of Model

Wine -> Flexible Impeller Pump 15 gal/min -> Filter Frame Medium Polish (1 Micron) -> Flexible Impeller Pump 15 gal/min -> Filter Frame Sterile (0.4 Micron) -> Bottling

Shipping

Distribution

Warehouse Storage

Packaging
Business Model
Business Model

Goals

- Maximize return on investment (ROI)
  - Maximize net present worth (NPW)
  - Minimize total capital investment (TCI)

\[
ROI = \frac{NPW}{TCI}
\]

- Do not run out of working capital (WC)
- Minimize pay out time (POT)
Assumptions

- Location – Oregon
- Grape Variety – Pinot Noir
  - Purchase grapes initially
  - Replace with vineyard production
**Business Model**

**Assumptions**

- Rate of Return (ROR) – 10%
- Product Selling Price ($p_1$) – $30
- Competitor Selling ($p_2$) – $30
- Superiority function ($\beta$) – 0.64
  - Happiness of Product ($H_1$) – 0.78
  - Happiness of Competitor Product ($H_2$) – 0.5
- Total pinot noir market ($Y$) - $148$ MM / year
Business Model

\[ \beta = \frac{H_2}{H_1} \]

\[ \beta d_1 p_1 = \alpha d_2 p_2 d_1^\alpha / d_2^\beta \]

\[ Y = d_1 P_1 + d_2 P_2 \]
\[ d_1 = \frac{\alpha}{\beta} \cdot \frac{p_2}{p_1} \cdot \left[ \frac{Y - p_1 \cdot d_1}{p_2} \right]^{1-\beta} \cdot d_1^\alpha \]
Business Model

Variables

- Production – 0.1 to 2.0 MM Bottles / Year
- Advertising – 2.0, 1.0, or 0.2 MM $ / Year
- 99% > WC > 50% of TCI
Assumptions

- $\alpha$ is a function of time
- $\alpha$ values based on advertising costs
  - High - $2.0$ MM / year
  - Medium - $1.0$ MM / year
  - Low - $0.2$ MM / year
Time vs. Superiority Function

- Low $\alpha$
- Medium $\alpha$
- High $\alpha$

Time (Years)

$\sigma$

0 0.2 0.4 0.6 0.8 1
Business Model

Assumptions

- Demand \((d_1)\) varies with selling price \((p_1)\)
  - Constant \(\alpha\) values
  - Constant competition selling price \((p_2)\)
Selling Price Per Bottle vs. Initial Demand

- High $\alpha$
- Medium $\alpha$
- Low $\alpha$
Time vs. Demand

- $20 - High \alpha$
- $20 - Medium \alpha$
- $20 - Low \alpha$
- $25 - High \alpha$
- $25 - Medium \alpha$
- $25 - Low \alpha$
- $30 - High \alpha$
- $30 - Medium \alpha$
- $30 - Low \alpha$
Business Model

Assumptions

▪ Constant production
  • Increase $\alpha$
    ➢ Decreases WC
    ➢ Increases ROI

▪ Constant $\alpha$
  • Increase production
    ➢ Decreases WC
    ➢ Increases ROI
Business Model

Production Capacity vs.
Return On Investment or Working Capital

ROI or WC (%)

Production (100k Bottles / Year)

-100% -80% -60% -40% -20% 0% 20% 40% 60% 80% 100%

ROI for Low α
ROI for Medium α
ROI for High α
WC for Low α
WC for Medium α
WC for High α
Assumptions

- **Constant \( \alpha, p_1, \) and production
  - Increase \( p_2 \)
    - Increase ROI

- **Constant \( \alpha, p_1, \) and \( p_2 \)
  - Increase production
    - ROI finds a maximum
Business Model – Regret Analysis

Production Capacity vs. Return On Investment
for $p_1 = 30$ & High $\alpha$

- $p_2 = 20$
- $p_2 = 25$
- $p_2 = 30$
- $p_2 = 35$
- $p_2 = 40$
Business Model – Regret Analysis

Production Capacity vs. Return On Investment Regret
for $p_1 = $30 & High $\alpha$

- $p_2 = 20$ $\bullet$
- $p_2 = 25$ $\Delta$
- $p_2 = 30$ $\Box$
- $p_2 = 35$ $\cdot$
- $p_2 = 40$ $\diamond$

Production (MM Bottles / Year):
- 0.6
- 0.8
- 1.15
- 1.4
- 1.7

ROI Regret:
- 60%
- 50%
- 40%
- 30%
- 20%
- 10%
- 0%
### Optimum Scenario Comparison

Production = 1.15 MM bottles / year & \( p_1 = $30 \)

<table>
<thead>
<tr>
<th>( p_2 ($) )</th>
<th>ROI</th>
<th>NPW ($)</th>
<th>TCI ($)</th>
<th>POT (years)</th>
<th>WC %</th>
</tr>
</thead>
<tbody>
<tr>
<td>20</td>
<td>33%</td>
<td>21000000</td>
<td>64000000</td>
<td>6</td>
<td>67%</td>
</tr>
<tr>
<td>25</td>
<td>46%</td>
<td>27000000</td>
<td>59000000</td>
<td>5</td>
<td>64%</td>
</tr>
<tr>
<td>30</td>
<td>67%</td>
<td>35000000</td>
<td>51000000</td>
<td>5</td>
<td>59%</td>
</tr>
<tr>
<td>35</td>
<td>93%</td>
<td>42000000</td>
<td>45000000</td>
<td>4</td>
<td>53%</td>
</tr>
<tr>
<td>40</td>
<td>107%</td>
<td>45000000</td>
<td>42000000</td>
<td>4</td>
<td>50%</td>
</tr>
</tbody>
</table>
Business Model – Risk Analysis

Assumptions

- Production costs – 20% standard deviation
  - Raw materials, labor, utilities
- Superiority function - $\beta$
  - $H_1$ & $H_2$ – 20% standard deviation in each
- Inferiority function – $\alpha$
  - 20% standard deviation for each year
- Selling price – $p_2$
  - $30 with a standard deviation of $10$
Risk Curve For Return On Investment

<table>
<thead>
<tr>
<th>Return On Investment (%)</th>
<th>Probability</th>
</tr>
</thead>
<tbody>
<tr>
<td>50% WC</td>
<td></td>
</tr>
<tr>
<td>51% WC</td>
<td></td>
</tr>
<tr>
<td>59% WC</td>
<td></td>
</tr>
<tr>
<td>64% WC</td>
<td></td>
</tr>
</tbody>
</table>
Risk Curve For Pay Out Time

- 50% WC
- 51% WC
- 59% WC
- 64% WC
Risk Curve For Running Out of Working Capital

- 50% Working Capital (50% WC)
- 51% Working Capital (51% WC)
- 59% Working Capital (59% WC)
- 64% Working Capital (64% WC)
Conclusions

- Quality of wine can be evaluated before bottling.
- Process can be adjusted at negligible cost.
- A business model can be formed to maximize ROI.
Conclusions

• For higher values of $\alpha$ and lower values of $\beta$, the less a competitor’s price effects the producer’s ROI.

• Based on the current business model, the optimum production capacity is 1.15 million bottles / year at a selling price of $30:
  - ROI – 102%
  - NPW – $44,000,000
  - Pay Out Time – 4 years
Future Work

• Incorporate more detailed economies of scale
• More detailed analysis of the physical properties and effects of process adjustments: modeling
• Study effect of bottle aging on happiness of wine
Acknowledgements

• Dr. Susan E. Ebeler, UC Davis
• Trung Hoang, T.A.
• Dr. Miguel Bagajewicz, Instructor
• OU CBME Department
• “Sideways”
Questions?