Engineering Wine

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Executive Summary

A new methodology for the development of new products is applied to winemaking. A consumer preference function is developed that allows data generated by market analysis to be related to wine properties. These wine properties are easily measured throughout the winemaking process and can be manipulated by the producer at negligible cost. The manipulation of these variables affects the consumer's satisfaction obtained from the enjoyment of wine. The most influential factor is identified to be that of toasting.

Through incorporation of this consumer function, a demand model is formed that allows for the manipulation in selling price. Based on the consumer and the pricing models, a profit maximization model is formed. This function shows the characteristics of wine to target the selling price and capacity of the manufacturing plant simultaneously.

Wine is evaluated by the consumer with the following characteristics:

- Clarity
- Color
- Bouquet
- Acidity
- Sweetness
- Bitterness
- Body/Texture
- Finish/Aftertaste

Each of these characteristics is evaluated individually by the consumer's level of satisfaction attained. Once the utility of the consumer is identified, these characteristics are evaluated by their relation to physical attributes that can be manipulated throughout the process at a minimal cost. Multiplied by weights pre-determined by the consumer's ranking of priority, the summation of the products of each attribute and their corresponding weights form the consumer's overall utility function. The value of satisfaction of the consumer is then compared to that of the competition, forming the superiority function that governs the pricing model. The optimum happiness found for the engineered pinot noir proposed is 77%.

The inferiority function, alpha, is employed to allow the evaluation of the consumer's overall knowledge and familiarity with the product. It is a function of time and can be manipulated with advertisement. However, this adds operating cost and is optimized for three scenarios of alpha values: high ($2 million), medium ($1 million), and low ($0.2 million). The optimum scenario for alpha upon its incorporation into the pricing model is $2 million.

Based upon the pinot noir winery design proposed and after risk analysis, the optimum production capacity is found to be 1.15 million bottles per year with a selling price of $30. These values, when incorporated into the demand and pricing models, yield a return on investment of 102%, a net present worth of $44 million, and a pay out time of four years. These values are all found with the assumption of 20% variance in the alpha and beta values as well as a variance of $10 in the competitor's selling price of $30.

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Introduction

Wine is a very unique product. Deemed the nectar of the gods, wine predates recorded history, surviving the ages by the fables of its medicinal nature as well as being a safe alternative to water in certain regions. Today, wine plays an integral role in many different cultures around the world. Why the intrigue and enchantment with wine? Wine revolves around a sensory experience, offering its consumer a colorful array of shifting sensations that make its charm difficult to define.

Wine has long been considered an art form, where quality was held in the eyes of the producer. Those who did not agree were looked down upon and considered to be less cultured. In the new information rich market, however, the current wine industry has taken a turn, and it is now the consumer that defines quality. The consumer holds the buying power with endless amounts of information accessible at his/her fingertips. Because of this, wine producers must now cater more to the desires of their customers to not only obtain patronage, but loyalty as well.

In order to identify with the market, the producer must understand the motivations behind the consumer's choice. Currently, after the wine has been bottled, it is outsourced to labs where tests are performed to measure the qualities that the wine possesses. These tests analyze the composition of the finished product and expected flavors it will possess. Wine varietals are also sent to tasting competitions, where they are assessed by experts and awarded for overall quality. Experts form their opinions after tasting each individual wine and rank them based on a standard set of criteria, pre-determined by the host of each competition.

While these methods are both beneficial and educational to the producer, neither truly addresses the consumer's perception, and both cost the producer time and money. The producer also has no way of controlling the product at this point. It has been bottled and is simply awaiting distribution. If this knowledge was attainable before the product was complete, the process could, in theory, be modified to attain the overall quality sought by the consumer.

The following concept proposes that the quality of wine can be known before it is bottled, and that each batch of wine can be engineered to maximize the profit of the producer. This is done by the identification and quantification of the consumer's utility in any market. After quantification of the consumer's predicted overall satisfaction with the product of interest, the wine can be compared to the quality of the competitor. By comparing its quality to that of the competition, the selling price of the wine can be set, optimizing the producer's return on investment.

Market Analysis

The wine industry is comprised of several different economic segments. Wines range from economy to premium and ultra-premium to artisan. Economy wines are those costing the consumer less than $7 per 750 mL bottle. These wines dominate 70% of the wine industry[43]. 27-28% of the industry is made up of premium table wines, which range from approximately $8 to $40 per 750 mL bottle[43]. While only 2-3% of the wine market is owned by the ultra-premium and artisan wines, which are the most expensive of wines available[3]. The premium table wine market segment in the US is the only market segment with stable demand growth[17]. It is this market that will be entered due to its stability and increase in demand. This positive trend makes it the best current option.

When viewing the world market, consumption has more than doubled in the United States, Australia, and Chile. These "new world" countries have emerged as the leaders in consumption and production, while the "old world" countries, such as France, Britain, and Spain, have felt a 40-50% decline in consumption[43]. The new generation of wine consumers has established that it prefers quality to quantity, and wineries within the new world have shifted efforts to accommodate these demands[43]. The old world wineries are desperately trying to catch up.

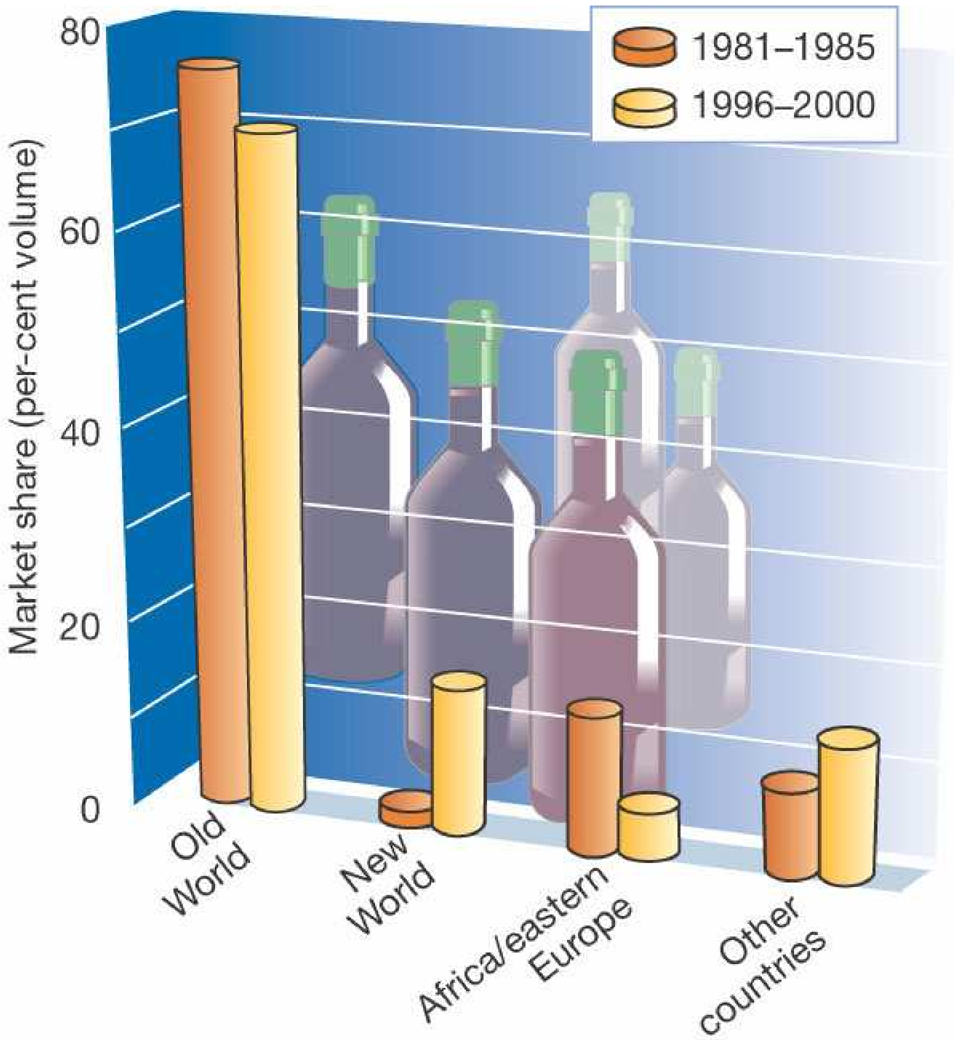

***Figure 1. Changes in market share by region of production*[43]. This figure shows the market share as a percent volume for each wine producing region throughout the world, comparing 1981-1985 to 1996-2000. "Old World" includes countries such as France, Spain, and Italy. "New world" represents the US, Australia, and Chile. "Other countries" represents Asia. It shows that although "old world" and eastern Europe and Africa have declined in market share, the new world countries have exponentially increased their overall market share.**

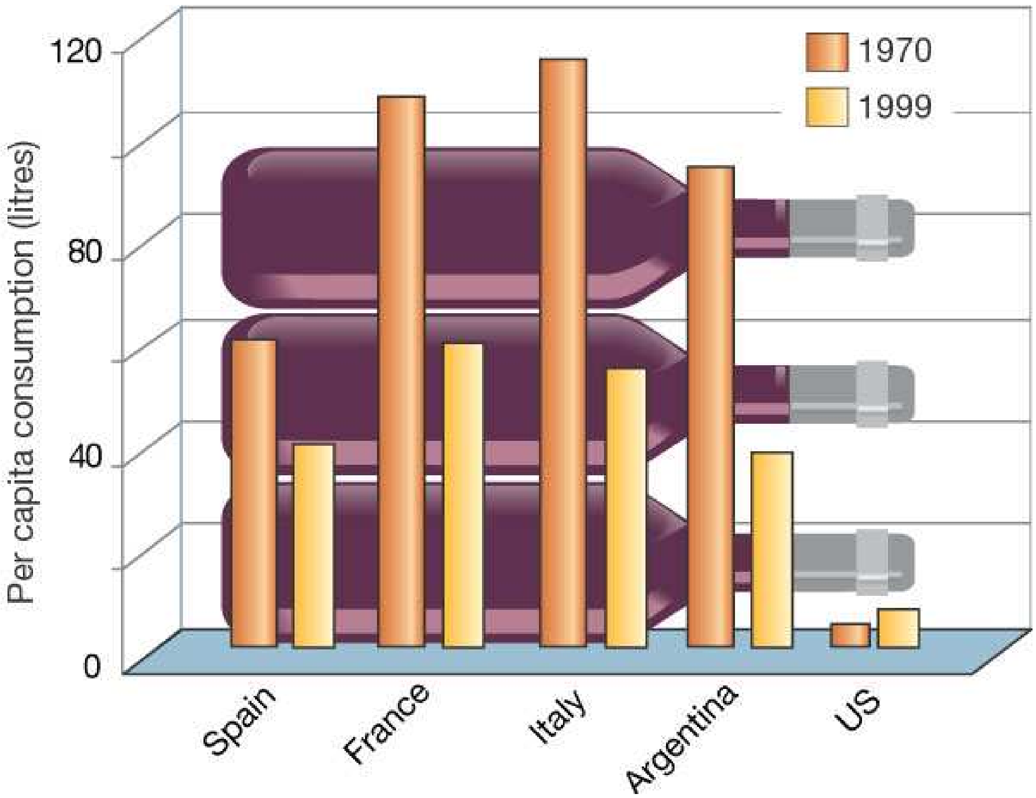

***Figure 2. Changes in total consumption of wine by country over the past three decades*[43]. This figure shows the per capita consumption in liters of Spain, France, Italy, Argentina, and the US. Every country experienced a significant decrease in per capita consumption from 1970 to 1999, with the exception of the US who actually increased its consumption.**

Specifically in the US, wine sales rose by 9.8% in 13 weeks ending June 4, 2005[43]. Over the same period, the case volume of wine sold rose 3.3%[43]. Year-on-year sales have increased 7.9% and volume has risen 3.3%[43]. Sales have increased more than volume, indicating that the per-bottle prices are rising as well.

In this particular case, Pinot noir is used to demonstrate the proposed methodology. Pinot noir is the softest of the reds and is considered to be the red wine choice of the white wine drinker. It is described as being “soft” and “supple” on the palate and is generally not high in tannins. Because of its versatile nature and softness, pinot noir is thought to have great marketing potential. Although it only claims 3.7% of the market share, it rose 78.1% in the 13 weeks ending June 4, 2005[43]. By case volume, pinot noir rose 72.7%[43].

The top market for pinot noir, in terms of dollar share of table wine category, is Portland, Oregon with 5.9%[43]. Because of this market share, it is decided that the design will be constructed in Oregon. With optimum conditions for the growing of the pinot noir grape, Oregon offers a safe market to enter for a small, venture winery.

Wine Manufacturing

The winemaking process can be divided into four basic phases: grape harvest, fermentation, clarification and stabilization, and aging. The first phase of harvesting grapes occurs when they are in optimum condition. Fermentation is the second phase and is controlled by several different parameters like temperature, contact time, and pressing technique. For clarification and stabilization, fining, racking, and filtration are used to remove excessive protein, while potassium bitartrate is used to stabilize the wine. Aging of the wine is the final phase where wines are aged in bulk and then separated into bottles for further aging. All of these phases overlap in the entire process of winemaking, excluding the harvest step. These four phases may seem simple, but are actually very involved for the producer and are described in more detail within Figure 3 as well as the sections that follow.

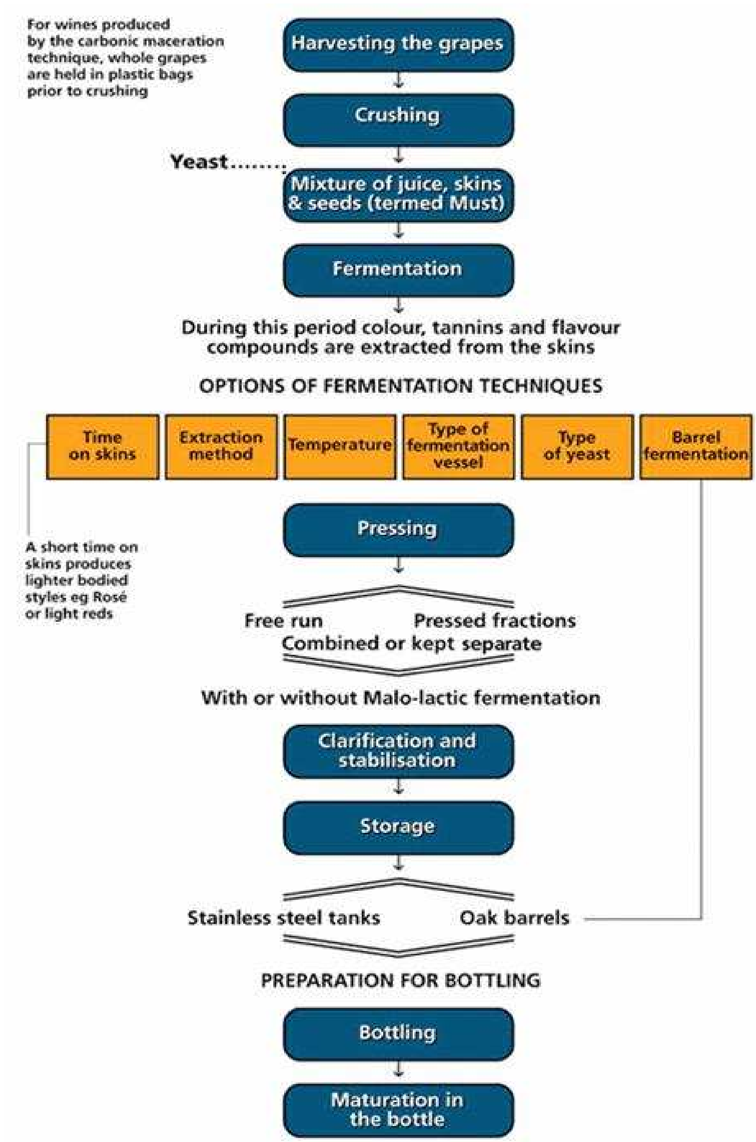

Figure 3. Process Flow Diagram of Red Wine[39]

Grape Harvest

It is often said that the quality of wine is made in the vineyard. The soil, climate and viticulture of the vineyard as well as the environment all play key roles in the quality of wine. Grapes are unique among fruits due to their levels of sugar and acidity. When allowed to ferment, enough alcohol is produced to prevent wine from spoilage. When making wine, the producer has three choices to obtain the raw materials necessary: freshly picked grapes, grape juice concentrate, or frozen must or juice. Freshly picked grapes offers the greatest quality, these grapes will therefore be used within the following model.

Grape quality is directly related to the composition of the berry when harvested. Climate is the single most important factor affecting the composition, with the pinot noir variety being obtained from cooler regions. In cooler climates, more grape acids, varietal aroma, and flavor compounds develop and, in the case of red types, tannins and color are retained at higher levels. Table 1 shows the amounts of sugar, titratable acidity, and pH that are generally considered to be of good quality wines.

Table 1. Desired sugar, acidity, and pH levels in ripe wine grapes[11].

Wine Type	Optimum Sugar	Titratable Acidity	pH
White	20.5 - 22°Brix	8 - 10 g/L	3.2 - 3.4
Red	22.5 - 24.5°Brix	6 - 8 g/L	3.3 - 3.5

The optimum sugar amount is shown in degrees Brix, which is a measurement of soluble solids and is roughly equal to the percent sugar content within wine. The tritratable acidity is measured as the amount in grams of tartaric acid per liter of wine. The pH is a measurement of the free hydrogen ions due to acid within the solution. Because climate and other influential factors are unreliable, it is sometimes impossible to find grapes with these optimum levels of sugar, titratable acidity, and pH. However, several regions have laws that greatly restrict the addition of acid and sugar to adjust levels within wine. In the US, sugar cannot be added and is strictly monitored. Tartaric acid or mixtures of acids can be used, though, to increase the acidity of the must or wine. Table 2 shows the amount of tartaric acid in grams that is required to raise acidity to desirable concentrations.

Table 2. Amounts of tartaric acid required to increase acidity[11].

Present Acid Content	Needed to obtain 6.0 g/L (g) added per gallon	Needed to obtain 8.0 g/L (g) added per gallon
3	11.3	18.9
3.5	9.4	17
4	7.5	15.2
4.5	5.6	13.2
5	3.8	11.4
5.5	1.9	9.5
6	-	7.5
6.5	-	5.6
7	-	3.8
7.5	-	1.9

A concentration of 6.0 g/L of tartaric acid is considered to be the minimal amount of acid present in wine, while 8.0 g/L is desirable, especially for white wines[11].

Harvest begins in late July or early August, and the picking of the grapes begins early in the morning to keep the fruit cool. This also helps prevent spoiling of the fruit while reducing refrigeration costs of the grapes. Grapes should be kept at roughly 68°F. If the grapes become warmer, they should proceed immediately to the refrigeration. After the grapes have been harvested completely, the crushing and destemming process can begin.

When the grapes are crushed and destemmed, the product is called the wine's must. This must is then pumped into refrigerated tanks immediately. The cold soaking stage of the pinot noir must begins at a temperature of 48°F and a blanket of carbon dioxide to prevent fermentation. It is here that the measurement of the pH, titratable acidity, and sugar content of the grape occurs. If necessary, the must is adjusted to a pH level of 3.3 and the titratable acidity to 0.8 % titratable acid, and a sugar content of 24° Brix[11]. The level of sulfur dioxide should also be kept at 50 ppm to prevent spoilage. Cold soaking of the must lasts four to five days, until it is transferred for fermentation.

Fermentation

Grape wine is the product of alcoholic fermentation of grape juice. This fermentation is caused by the conversion of the grape sugars, glucose and fructose, into ethanol and carbon dioxide. This process is accomplished by the addition of living yeast cells into the wine. The ethanol that is produced through this fermentation is wine's major flavor component, which also affects the solubility of other wine constituents. Wine types are actually divided into classes based on their alcohol content. The two classes are table wines, with an alcohol content of 9 to 14 % alcohol content, and dessert wines, which have an alcohol content of 15 to 21 % alcohol[11]. Table wines owe their alcoholic content to the fermentation of sugar naturally present in the grapes and to the sugar that may be added to them. Dessert wines, however, obtain higher alcohol contents by the addition of other wine spirits.

The cold soaked must of the pinot noir is pumped to open fermenters. Fermentation can then begin by raising the must to room temperature and adding Pasteur red yeast and diammonium phosphate. A stainless steel cap plunger is then used to work the cap of each fermenter at least twice each day. This is done to prevent microbial infection of the fermentating must. Fermentation continues until the sugar content reaches 8° Brix[11]. This point usually occurs in approximately one week. The must is then pumped into a membrane press where the skins, seeds, and must are removed from the wine. All of the wine from the membrane press is then pumped back into the refrigerated tank where the yeast fermentation continues.

This process can be simplified into three distinct stages[7]:

1. Yeast cells grow and increase to begin fermentation for twelve to 24 hours.
2. The yeast rapidly ferments one-half to two-thirds of the sugar to alcohol and carbon dioxide, causing frothing. The frothing results in skins rising to the surface to form a cap. This activity occurs for two to three days.
3. Slow fermentation continues for three to four days after the pressing of the juice from the skins.

The rate or speed with which the fermentation takes place is dependent upon the temperature and amount of yeast used within the process. Red wines typically take one to two weeks to ferment.

During or soon after the alcoholic fermentation, a phenomenon known as malolactic fermentation occurs. It is here that malolactic bacteria, known as *Viniflora oenos*, begin to convert malic acid to lactic acid and carbon dioxide. Malic acid, one of the naturally occurring acids within grapes, is a much stronger acid than lactic acid. By this conversion, the acidity of the wine is decreased, and the wine is considered to be more stable. This fermentation also increases the flavor complexity of wine due to the bacteria's metabolism. These fermentations continue until they naturally end or the sugar content reaches -1° Brix[7].

Malolactic fermentation can be affected by several factors. The growth of malolactic bacteria has many complex nutritional requirements. The nutrients needed are already naturally present in wine or have been released during alcoholic fermentation. The growth of the bacteria is thus greatly influenced by the amount of time the wine is contacted with the lees. Malolactic fermentation can be inhibited by quick separation of the wine from the lees directly after alcoholic fermentation.

Bacterial growth can also be inhibited by low pH, usually 3.3 or lower, as well as high levels of sulfur dioxide, which must be adjusted to at least 100 ppm after the yeast fermentation. Malolactic fermentation is thus encouraged by pH levels greater than 3.3 and low levels of sulfur dioxide, usually below 50 ppm[11]. Temperature can also affect the activity of the bacteria: cool temperatures of 60°F or lower inhibit fermentation, while storage tanks held from 65°F to 86°F encourage further fermentation[11]. However, it is important that the producer be cautious with warmer temperatures and low levels of sulfur dioxide. These conditions encourage the spoilage of yeast as well as the development of vinegar bacteria. Just before of directly after the completion of fermentation, wine can then begin the racking, clarification, and stabilization process before aging.

Clarification and Stabilization

Once fermentation ends or is almost complete, the wine is racked from the fermentation lees and filtered. Racking or siphoning is a simple technique for clarifying wine. This step is important and should be done carefully by the producer to ensure that the wine is at an acceptable clarity level of the producer and consumer. By siphoning or racking, sediment can be separated from clear wine, which is then transferred to clean containers.

The roughly filtered wine is then pumped back into the refrigeration tank, and bentonite is added to the wine to remove excess protein, referred to as hot stabilization, while the wine is being cooled to 27°F, for cold stabilization[11]. This process is results in the precipitation of potassium bitartrate. After malolactic fermentation has completed, the barrel or storage container should be filled to the point of overflow. The wine is now ready to begin the aging process. It is important to continue the racking of wine during the aging process to maintain clarification.

Aging

There are many benefits to aging red wine in oak barrels. Other than the many reactions that occur during the aging process, the wood in which it is aged contributes greatly to the complexity of flavor in wine. There are several aspects that affect the flavor of wine. One of these variables is the actual age of the wood used. New barrels will give more wood flavor much faster than older wood. For example, red wine that is usually aged for one to two years in 50-60 gallon barrels of old wood only need to be aged one to two months within new wood barrels, of the same size, for equal levels of flavor[11].

Wood character can also be obtained through a more quick, convenient, and satisfactory method: oak chips or granulized oak. These materials can actually provide wood odor and flavor to wine that is stored in glass or stainless steel containers. Small amounts of these oak chips can be added at almost no cost to the producer. Usually 100 to 300 grams are used per 50 gallons of wine[11]. Because these chips or granules can be made from European or American oak, different sensory effects can occur depending on which type is chosen. The level of toasting in chips, granules, and barrels also affects the complexity of the odor and flavor of wine.

After the wine has aged to its desirable degree, it is then ready for bottling. Wine is fined and filtered for the last time and is ready for distribution to the drinking public. This is the last stage the producer can affect the quality of the wine. Once the producer satisfied, the wine is sent to the bottling and corking unit which minimizes time the wine spends with oxygen. The wine is bottled, and sulfur dioxide levels are adjusted to 25 to 30 ppm to prevent oxidation after bottling. After this point, the bottle is labeled, sealed with a capsule, and packaged into cases. The cases sit in storage for about another 3 months before being shipped to the distributor.

Consumer Satisfaction and Preference

In order to determine the relationship between quality and demand through a pricing model, one needs to be able to quantify consumer satisfaction. A function describing consumer satisfaction, represented by S, can be written as:

$$S = d_1^{\beta} + d_2^{\alpha} \qquad \textit{(Equation 1)},$$

where d_1 and d_2 are the demands of the new wine produced and that of the competitor, respectively. The parameter α is defined as an inferiority function. It is related to the amount of knowledge the consumer possesses for the product of interest and ranges from zero to one. It can be expressed as a function of time and can be altered with advertisement. In turn, β is a superiority function and represents the amount of preference the consumer has for the product of interest in comparison to that of the competition.

The consumer has a budget, Y, which is represented by the following equation:

$$Y \leq p_1 d_1 + p_2 d_2 \qquad \textit{(Equation 2)},$$

where p_1 and p_2 are the respective prices of each product. The consumer looks to maximize S, subject to the budget constraint. This yields the following relationship:

$$\beta\, d_1\, p_1 = \alpha\, d_2\, p_2\, d_1^{\alpha} \;/\; d_2^{\beta} \qquad \textit{(Equation 3)}.$$

For the purposes of this derivation, it is assumed that alpha is equal to 1, showing that the consumer is equally familiar with each product. Assuming equal pricing, β is a positive coefficient that relates how much more appealing the consumer will find the product of interest in comparison to the competing product.

The superiority function β is proposed to be the ratio of the consumer preference functions:

$$\beta = H_2 / H_1 \qquad \textit{(Equation 4).}$$

In turn, the consumer satisfaction functions are related to product attribute scores (i.e. taste, bitterness, sweetness) in the following proposed linear manner:

$$\boldsymbol{H_i = \sum w_i y_i} \qquad \textit{(Equation 5).}$$

Each attribute is weighed based on the rank of importance (w_i) by the consumer.

Thus, the scores, or values of y, can be manipulated by altering the production process. This principal will be evaluated by its implementation into a winery. Operating costs will be calculated along with production modifications to ensure maximization of profitability.

Consumer Preference Function

When enjoying wine, the consumer utilizes several characteristics in his/her evaluation of its quality and his/her overall satisfaction. The following characteristics are evaluated by the consumer for different wine varieties:

- Clarity
- Color
- Bouquet
- Acidity
- Sweetness
- Bitterness
- Body/Texture
- Finish/Aftertaste

Each of these characteristics is evaluated individually by the consumer's level of preference attained. This level of preference will be normalized on a scale ranging from 0 (minimum of 0% happiness) to 1 (maximum of 100% happiness).

A curve is formed that describes the individual's preferences as a function of the characteristic identified and the consumer's words used to evaluate each characteristic. These words can then be related to physical, measurable qualities. By identifying the correlation of the consumer's words to these qualities, the qualities can then be related to the consumer's preferences.

A correlation will be found for each individual characteristic that will mathematically describe the relationship between the quality and happiness. Each characteristic must also be weighted in order to address the consumer's rank of importance of each quality on evaluation. The weighted correlation of each characteristic is then summed in order to obtain the consumer's overall happiness or utility.

The following sections detail each characteristic separately and show examples of consumer preferences. Adjustments to the process that affect each characteristic are also described with associated process costs.

Weights

The weight of each characteristic must be established in order to show priority and preference of the consumer. Individual characteristics influence the consumer more so than others in his/her evaluation of any product or experience. In order to account for these differences in perception and effect on the consumer's judgment, the individual function of each characteristic will be allotted a percentage or weight. These weights sum to equal 1 or 100%, and are multiplied by the each characteristics score. The summation of these scores will lead to an overall happiness score, representing the consumer's total evaluation of the product.

A point system can be used to assign weights to the characteristics that consumers use to evaluate wine. For example, clarity and color are awarded two points because they are the first sense utilized when evaluating wine. Their interpretation begins the process and thus affects the response of the other senses. Color is evaluated using hue and brightness, therefore, its weight is divided evenly between these characteristics. Acidity, sweetness, and bitterness are sensations occurring within the mouth. These characteristics are awarded one point, because the palate is not as sensitive as other areas of evaluation. Because the palate is the last place to evaluate the product, it has already been influenced by the nose and the eyes. Body/texture is awarded two points, due it being an overall evaluation of the wine.

This system yields a point total of 13. Each characteristic's allotted points are then divided by the total, resulting in the weight assigned. Table 1 provides the weights of each characteristic obtained. It is important to note that the point system for this particular evaluation can vary for each consumer or market. The system as a whole is completely dependent upon the consumer's personal preference of the importance of each characteristic. The weights illustrated in Table 3 are to serve as an example.

Table 3. **Wine characteristic weights used in evaluation.**

Characteristic	w_i
Clarity	0.15
Color	
Hue	0.08
Brightness	0.08
Bouquet	0.30
Acidity	0.08
Sweetness	0.08
Bitterness	0.08
Body/Texture	0.15

Clarity

When judging wine, the consumer has two areas of visual evaluation: clarity and color. The clarity of the wine is expected to be crystal clear. Any type of cloudiness or sediment that can be seen in the wine disappoints the individual and hints to possible contamination as well as poor processing. It is an indication of possible bacteria, excess yeast, and unwanted compounds. The following words are used to describe clarity of wine:

- Crystal Clear
- Clear
- Slightly Blurred
- Blurred
- Milky, Cloudy
- Sediment Present

These descriptions of clarity from the consumer are shown in Figure 4, which demonstrates the expected consumer response when evaluating clarity. This particular curve assumes that the slightest change in clarity of the wine results in the consumer's happiness level to drop significantly. The maximum occurs when the wine is described as being "crystal clear" whereas the minimum is shown to be at the presence of sediment.

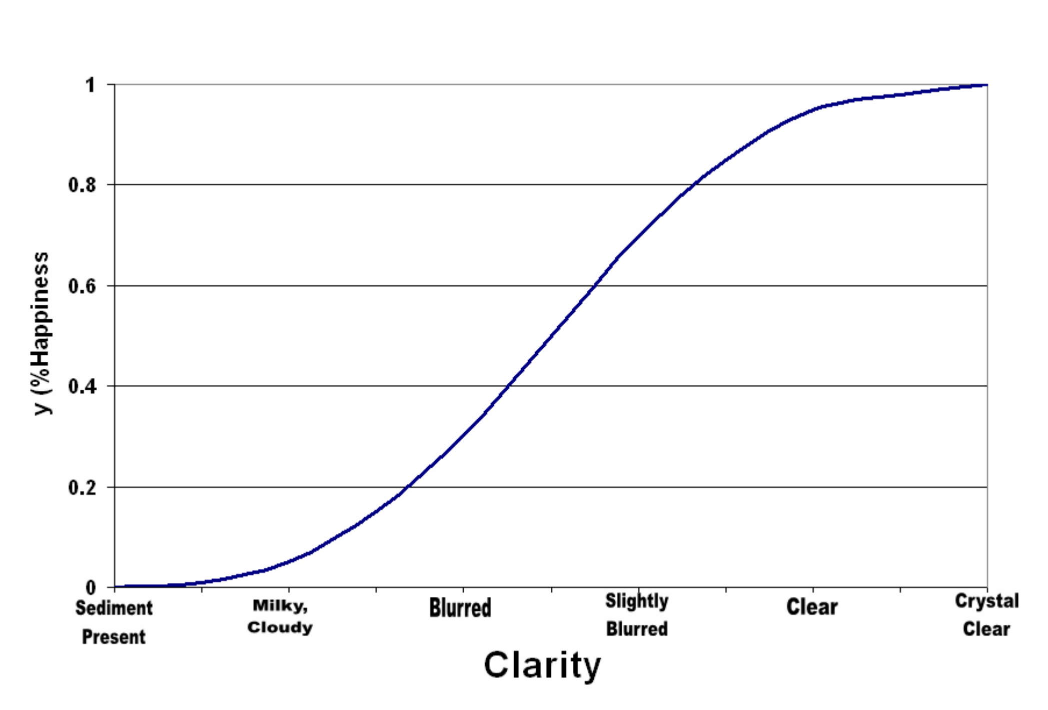

Figure 4. Example curve for clarity versus happiness of consumer. **The happiness curve for clarity shows the terms consumers use to evaluate clarity along the x-axis. These terms indicate a certain level of happiness of the consumer, quantified on the y-axis, with 1=100%happiness and 0=0%happiness*.**

**These terms are arbitrary and not necessarily accurate. The values on the y-axis will change with data generated from the sampling of different market segments. This curve is generated assuming the reaction of a normal human being. No socio-economic characteristics are taken into account nor any previous experiences or perceptions. This is an example.*

It is important to note that the curve generated for clarity is an estimation and is to serve only as an example as to how a correlation can be found. This curve will vary upon the actual consumer's response to these descriptions when evaluating wine. This curve does not take into consideration any socio-economic characteristics or previous experiences of the consumer. This curve is generated on assumption only.

Now that the feelings of the consumer have been quantified it is necessary to find a system of measure for clarity. Turbidity is a measurement used to evaluate sample clarity. Turbidity is defined as an "expression of the optical property that causes light to be scattered and absorbed rather than transmitted in straight lines through the sample[26]." In order to measure the clarity of a liquid, a beam of light is passed through the medium. The suspended solids within the sample cause a scattering of light in all directions. This causes the beam of light to lose intensity, resulting in a measure of turbidity by the change in light intensity.

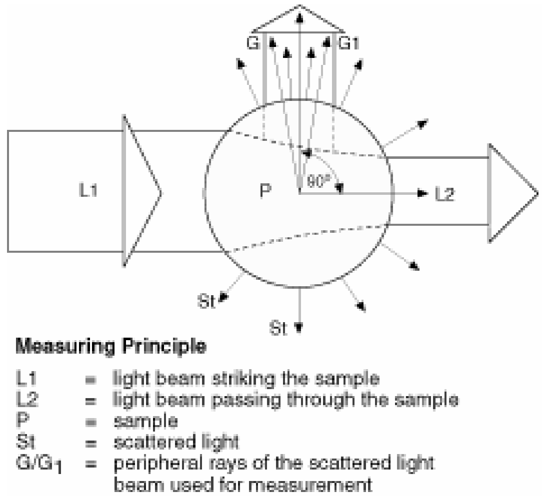

Figure 5. Schematic of method used to measure turbidity[26]. **As the light beam (L1) strikes the sample (P), it is scattered in all different directions (indicated by the vectors labeled: St). The light beam then exits the sample (L2) at a lower intensity due to the scattering effect. G/G_1 are used for the measurement of turbidity. Absorbance can also decrease the intensity of L1 and should be subtracted from the difference in intensities when evaluating turbidity.**

In order to assure quality throughout the wine-making process, there are three places turbidity readings are taken that have the following expected values[31]:

1. Alcoholic Fermentation <600 NTU
2. Malolactic Fermentation <100 NTU
3. Filtration <1.0 NTU.

A correlation must now be formed that relates the consumer’s description to the measurement of turbidity. The limpidity value for a bottled wine should not be greater than 4 NTU, so it is this region below 4 NTU that is the region to be evaluated by the consumer. Figure 6 shows the correlation between consumer description and the turbidity measurement.

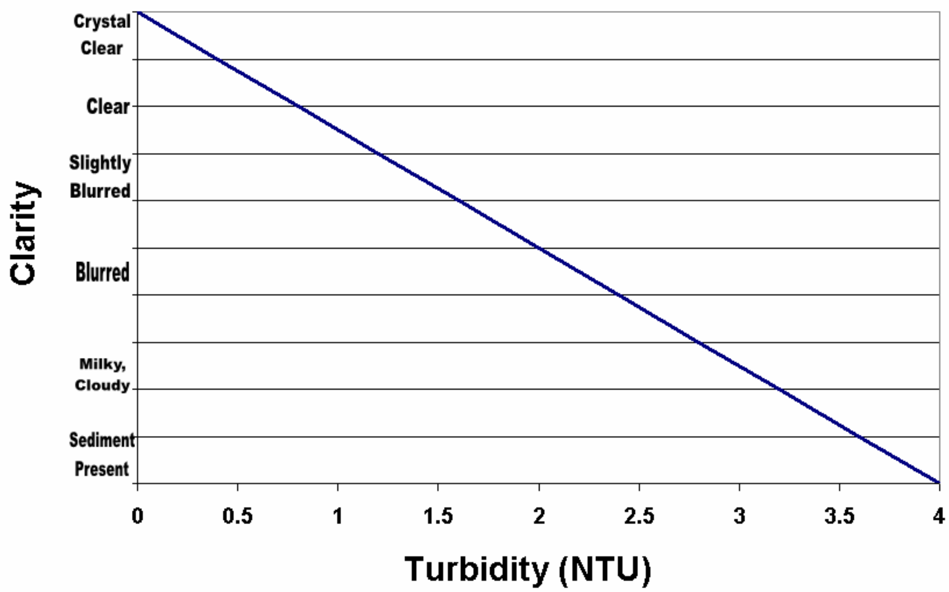

Figure 6. Correlation of clarity as a function of turbidity[31]. **Turbidity ranges from 0.1 NTU to 4.00 NTU for a glass of wine. The higher the turbidity, the more sediment is present. 0.1-0 NTU is the optimum range for lack of turbidity.**

The correlation formed in Figure 6 makes it possible to link the turbidity to the happiness of the consumer. This is a very important step, because it allows the evaluation of the wine before reaching the consumer. The function shown in Figure 6 allows the quantification of happiness by the simple input of the physical, scientifically-tested value of the wine's turbidity. This presents the producer the opportunity to change the process to try to shift the product more toward the happier region of clarity. Modifications can be made during the process to adjust to the happiness of the consumer.

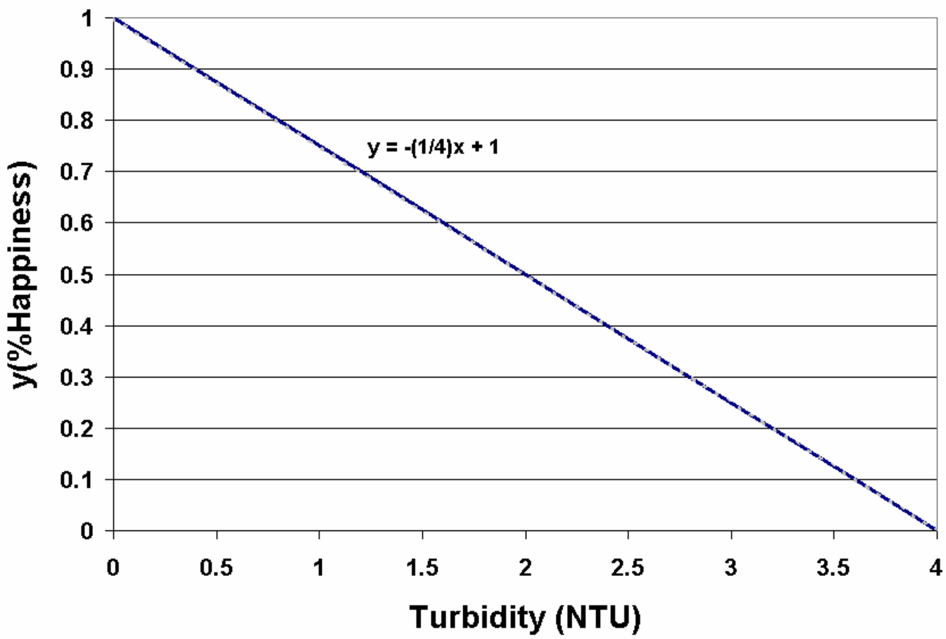

Figure 7. Happiness model as a function of turbidity. **As turbidity increases from a range of 0.1-4.0 NTU shows a decrease in happiness for the consumer. A linear model is fit to the correlation. This linear model will serve as the happiness function for turbidity.**

The most common causes of wine turbidity are salts, enzymes, colloids, or biological factors. By monitoring the turbidity levels of the wine throughout the process, winemakers can make adjustments to alter the happiness of the consumer. Fining is the clarification phase of winemaking. Fining can be as simple as allowing gravity to settle sediments to the bottom of the bottle or can be controlled by adding fining or clarifying agents.

The particles that cause haze in a wine are charged. The fining agent used will have an opposite charge and will bind to the turbidity causing particles, and by gravity, will settle to the bottom of the wine. These particles can then be filtered. Fining agents are added sequentially with opposite polarities to assure the removal of each unwanted particle.

The fining agent to be used within the red winemaking process is Bentonite. Bentonite is naturally occurring clay, composed of hydrated aluminosilicate of sodium, calcium, magnesium, and iron[37]. Bentonite absorbs large quantities of water, which leads to an increase in its surface area and aids to deproteinizing. Bentonite also aids in flavour retention and protein stability[37]. Bentonite can be used during or after fermentation to aid in clarifying wine.

Bentonite is negatively charged, binding to the positively charged proteins. After this neutralization, the bonded particles gradually settle to the bottom of the wine due to gravity. These sediments will be removed by the racking of the wine. When added during fermentation, 0.8-1.3 g/L can be added, while after fermentation, only 0.25-0.375 g/L of a 5% aqueous solution can be added. The cost of Bentonite is about $6.99 per 8 ounces[37].

Color

The color or hue of the wine is another visual property that is used to evaluate wine. White wines can range from light straw to a dark amber color. Blush wines range from light pink to light red. Red wines range from light red to dark, almost an opaque red. When the consumer looks at an object, color is evaluated on two different scales: hue and brightness.

Hue

Hue is the actual shade of color that is reflected. The expected hue of each different type of wine is different, i.e. white, blush, and red. For purposes of simplicity, red wine is used for this particular evaluation of color. The hue of red wine reflects a clear judgment of not only the age of the wine but the particular level of quality it has reached within the aging process. Red wine has three different, easily identifiable hues that the consumer uses to describe it: red, crimson, and brown.

The red hue is associated with a young wine that has not had ample time to age. It has not reached its peak of quality. When the hue is described as being crimson, more of a deeper red, it is here that the consumer views the wine to have aged enough and indicates a high quality. This color shows a maximum of happiness for the consumer. Once the wine proceeds through this stage, it begins to turn brown, and is interpreted as being of less quality. The wine has either aged too long or oxygen has been allowed to enter the bottle. Figure 8 shows the expected relationship between the happiness of the consumer and the hue of a red wine.

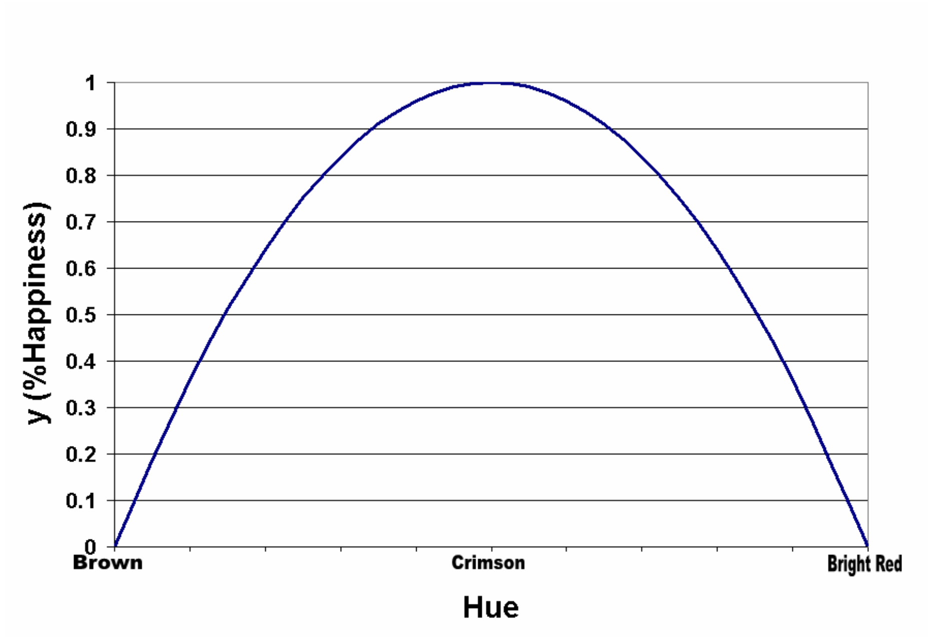

Figure 8. Example consumer happiness curve as a function of hue*. **As the hue goes from brown to crimson to bright red, the happiness increases, then peaks right at crimson and then decreases to 0% happiness at red. This shows the need for a balance between red and brown shades in the evaluation of color.**
**These terms are arbitrary and not necessarily accurate. The values on the y-axis will change with data generated from the sampling of different market segments. This curve is generated assuming the reaction of a normal human being. No socio-economic characteristics are taken into account nor any previous experiences or perceptions. This is an example.*

After identifying the consumer's perception of the hue of a red wine, a method must be developed that enables the scientific measurement of hue. When evaluating the hue of a red wine, the absorbance of the wine can be calculated by measuring the percent transmittance of the wine. Red wine has absorbs light at two different wavelengths: 420 nm (yellow) and 520 nm (red). The absorbance (D) at these wavelengths can be calculated using Equation 6[42] and measuring the percent transmittance (%T) at each individual wavelength (λ):

$$D_\lambda = -\log(\%T_\lambda) \qquad \textit{(Equation 6).}$$

The actual hue of a red wine is given by the ratio of the absorbances at the 420 nm and 520 nm wavelengths (D_{420}/D_{520})[42]. This ratio has the following ranges that correspond to red wines[18]:

- Red: <.44
- Crimson: 0.44-1.0
- Brown: >1.0

These values of the ratio associated with the descriptions of the hues, allow the measurement and the formation of the correlation as a function of the absorbance ratio. This correlation can be seen in Figure 9.

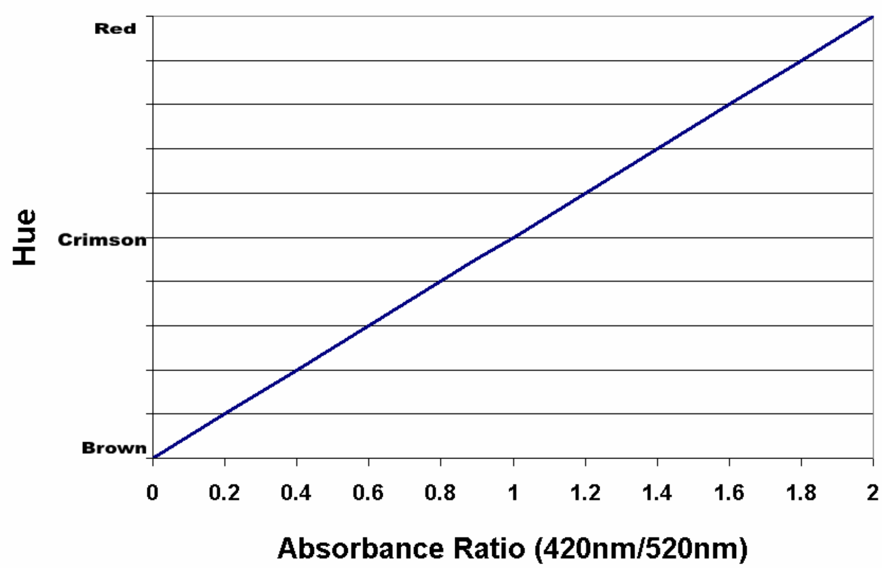

Figure 9. Correlation of happiness as a function of the absorbance ratio. **The linear correlation developed shows an increase in red tones with increased absorbance ratio values. This correlation has been normalized and made linear for simplicity.**

Figure 9 shows a linear relationship between the hue of a red wine and the absorbance ratio at wavelengths of 420 nm and 520 num. The brown hue has a low absorbance ratio due to the wine absorbing more light at the 520 nm wavelength, leading to the light being reflected having shades of yellow. This results in the brown shade that consumers describe.

The same trend occurs at the red hue range, which results in high values for the absorbance ratio. More light is absorbed at 420 nm (yellow) and reflects the 520 nm (red) resulting in the characteristic red hue. Crimson, the consumer's maximum level of happiness with a red wine, indicates a balance required by the absorbance of both 420 nm and 520 nm wavelengths. These absorbance ratio values allow the formation of the relationship between the consumer's happiness as a function of the absorbance ratio. Figure 10 shows this correlation.

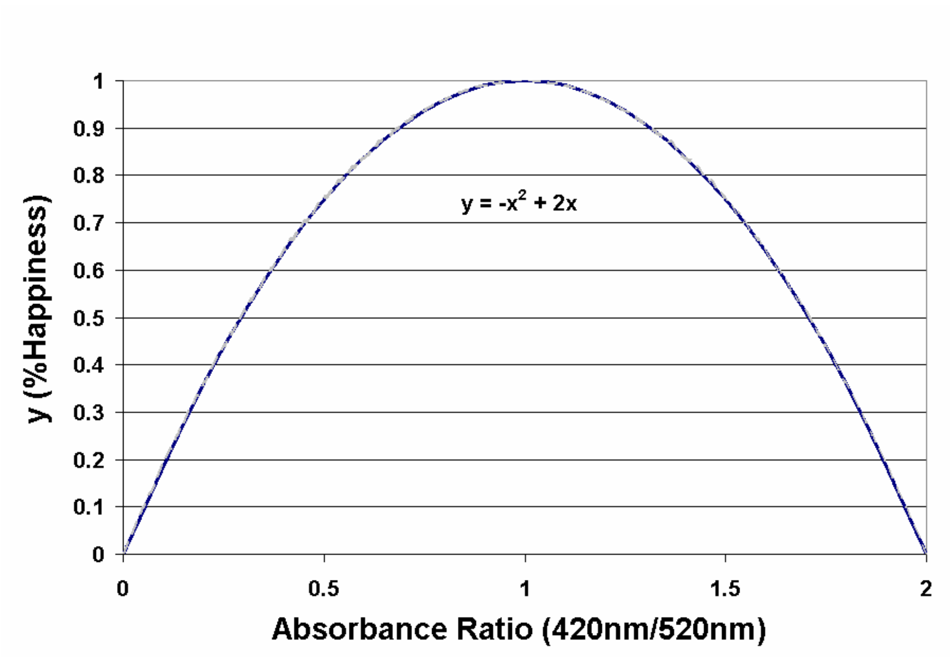

Figure 10. Consumer happiness curve as a function of Absorbance Ratio. **The function generated by the fitting of a binomial. This function yields a y score for the consumer evaluation of hue and, when multiplied by its weight, will be used in conjunction with the other models generated to yield the consumer's overall utility.**

The hue of the wine can be manipulated by the adjustment to the melanoidins, or colouring particles of wine. In order to adjust the process to accommodate necessary absorbance ratios for the needed consumer preference score, cold soaking can be used. This method does not allow the juices to extract as many phenolic compounds as in regular soaking, because it does not facilitate further fermentation to take place.

Another method that can be used after fermentation is a fining agent known as gelatin. Gelatin is composed of amino acids. It is colloidal and positively charged. The most powerful organic fining agent, it removes excess melanoidins from wine. A solution of 1 g gelatin per 20 mL of water is used in quantities of only 18 mL per 19 mL of wine. The cost of gelatin is estimated at $9.59 per pound[37].

Brightness

Brightness is the second property used to evaluate color. Brightness ranges from dull to bright. The duller the color, the less appealing it is to the consumer, because it indicates too much aging of the wine. A bright color adds intrigue and indicates freshness, making the wine more appetizing. The response of the consumer can be seen in Figure 11. As the color goes from dull to bright, the happiness increases, showing the maximum happiness to be described as bright.

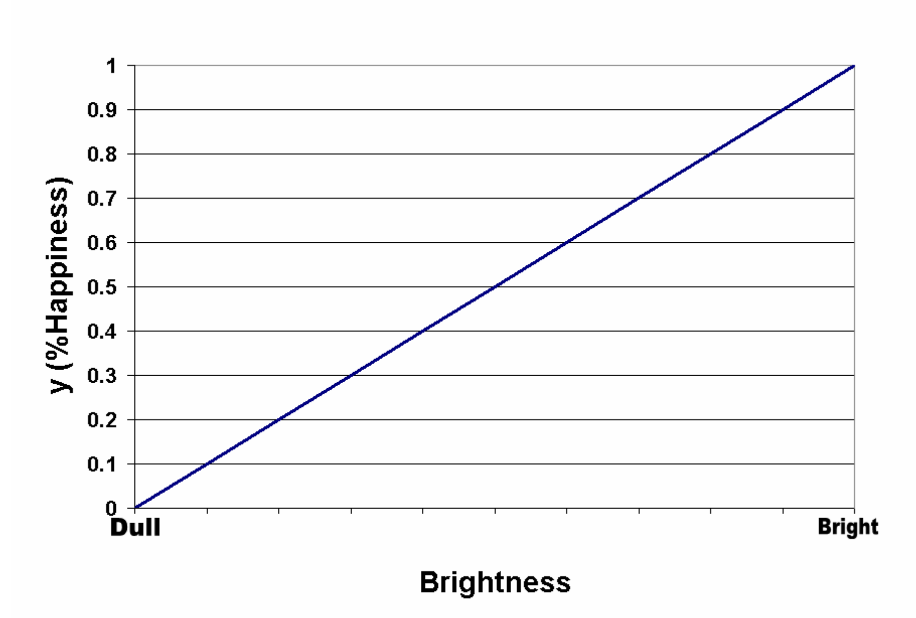

Figure 11. Example of consumer happiness as a function of brightness. **As the brightness increases from dull to bright, so does the consumer's utility. The optimum description for the consumer is bright.**

**These terms are arbitrary and not necessarily accurate. The values on the y-axis will change with data generated from the sampling of different market segments. This curve is generated assuming the reaction of a normal human being. No socio-economic characteristics are taken into account nor any previous experiences or perceptions. This is an example.*

It is now important to find a method of quantifying the brightness of color. This can be done by again incorporating the absorbance of light. To stay consistent with the previous model, red wine will again be used to form the correlation for brightness. For red wines, absorbance occurs at wavelengths of 420 nm and 520 nm. After measuring the percent transmittance (%T) and using it to calculate the absorbance (D) at each wavelength (λ) by using Equation 7, the sum of the absorbance of each is equal to the percent brightness (%Brightness):

$$\%Brightness = D_{420} + D_{520} \qquad \text{(Equation 7)}^{42}.$$

By using Equation 7, it is possible to form the correlation shown in Figure 12, which relates the brightness of color to the % Brightness, a function of absorbance. The descriptions are normalized by distributing even percentages to %Brightness, creating a linear correlation.

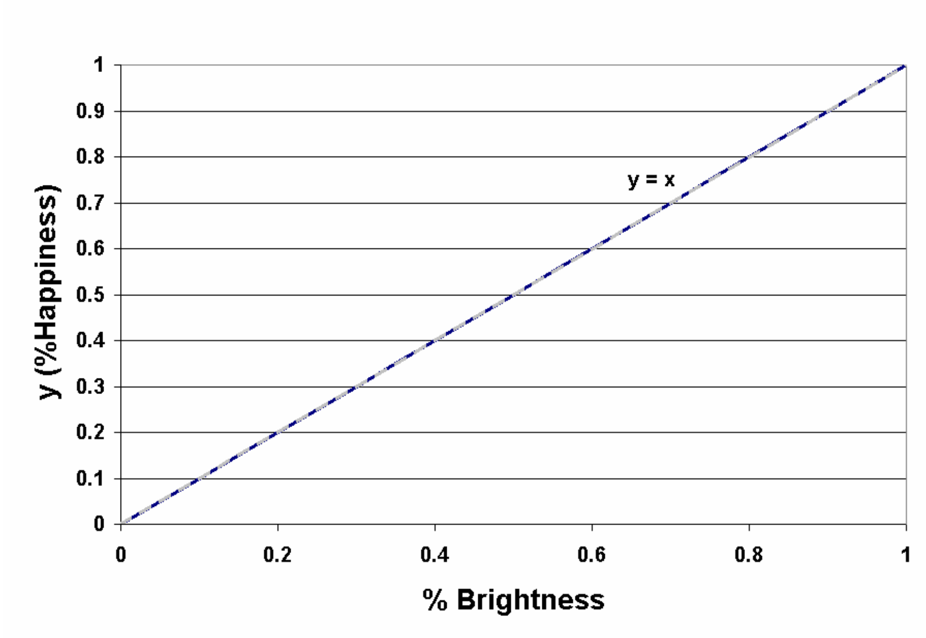

Figure 12. Consumer* h*appiness curve as a function of percent brightness. **The function generated by the fitting of a linear model. This function yields a y score for the consumer evaluation of brightness and, when multiplied by its weight, will be used in conjunction with the other models generated to yield the consumer's overall utility.**

Figure 12 shows that with the increase in brightness, there is an increase in the consumer's happiness. The maximum happiness of the consumer occurs at the 100% brightness while the minimum is at no brightness. Because brightness is also dependent upon the absorbance of light at different wavelengths, the same soaking and fining methods can be used that are explained for the manipulation of the hue.

Bouquet

The strongest sense used in evaluating the wine experience is the nose. The nose houses over 200 identifiable scents. Therefore, when evaluating food, drinks, or any type of sensory decision, the scent is most often the sense that most controls the consumer's decision and evaluation.

There are two different types of odors that are used in evaluating wine: aroma and bouquet. Aroma is the scent associated with grape variety and type. These scents can be found in the fresh juice before fermentation. Bouquet is the odor used to describe the characteristics of wine due to processing. The bouquet of a wine is generated by the byproducts of fermentation and the oak barrels the wine is aged and stored within for example. Bouquet will thus be evaluated because it is more easily identifiable and it is the process that can be controlled rather than the grape type.

Bouquet is described the following ways by consumers:

- Complex, Flowery
- Developed, Fruity
- Delicate, Clean
- Elusive

Figure 13 shows the consumer's happiness upon evaluation of bouquet using the descriptions listed above.

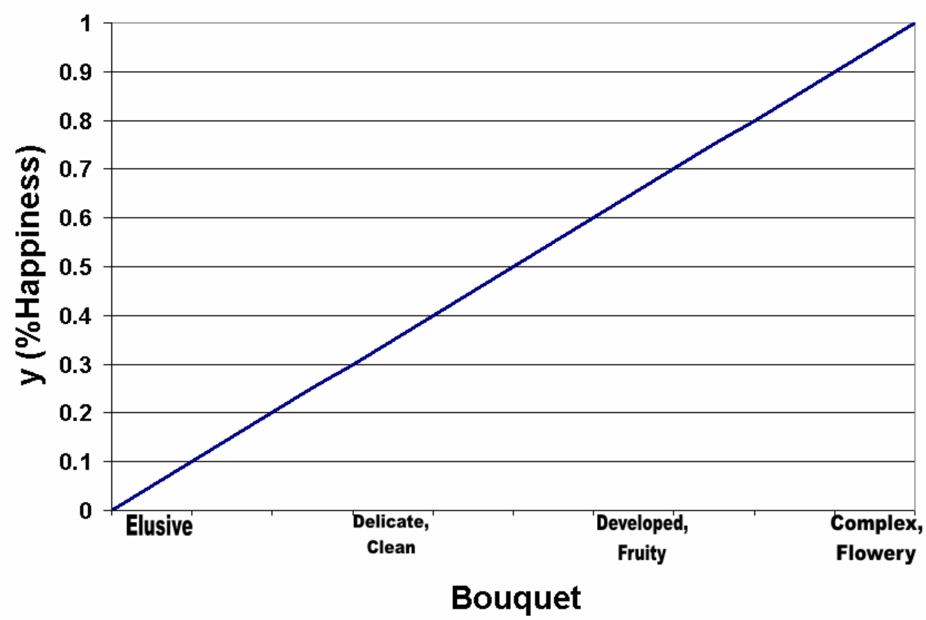

***Figure 13. Example consumer happiness model as a function of bouquet*.* As the bouquet becomes more and more complex and structured, the happier the consumer appears, reaching his/her peak at complex and flowery. This indicates a full bouquet.**

**These terms are arbitrary and not necessarily accurate. The values on the y-axis will change with data generated from the sampling of different market segments. This curve is generated assuming the reaction of a normal human being. No socio-economic characteristics are taken into account nor any previous experiences or perceptions. This is an example.*

Each wine houses many different aromatic compounds, some at greater quantities than others, especially if the wine has not aged to its full potential. It is the presence of these aromatic compounds that cause pleasant smells in the nose. The more compounds that saturate the air on top of the wine in the wine glass, the more complex the bouquet is. Therefore, Figure 14 shows a correlation between #Aromatic Compounds and the consumer descriptions found in Figure 13.

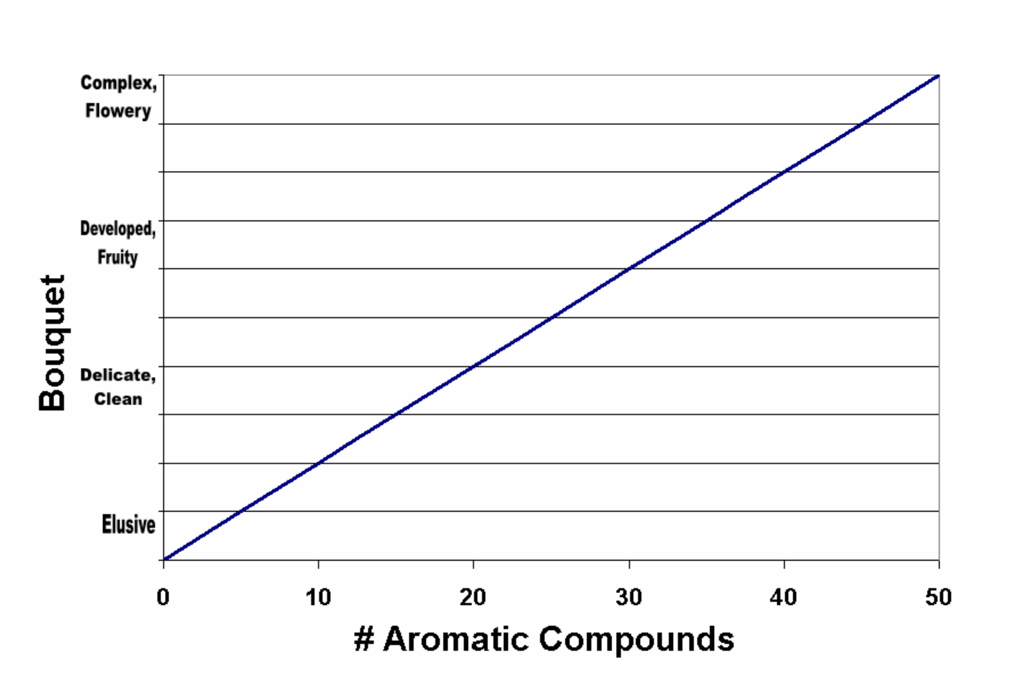

***Figure 14. Correlation of the consumer's description of bouquet as a function of the physically measurable number of aromatic compounds.* As the number of compounds increases, so does the happiness of the consumer.**

With the correlation formed in Figure 14, Figure 15 is easily formed to allow the calculation of the consumer's happiness when evaluating the bouquet of the wine in terms of # Aromatic Compounds.

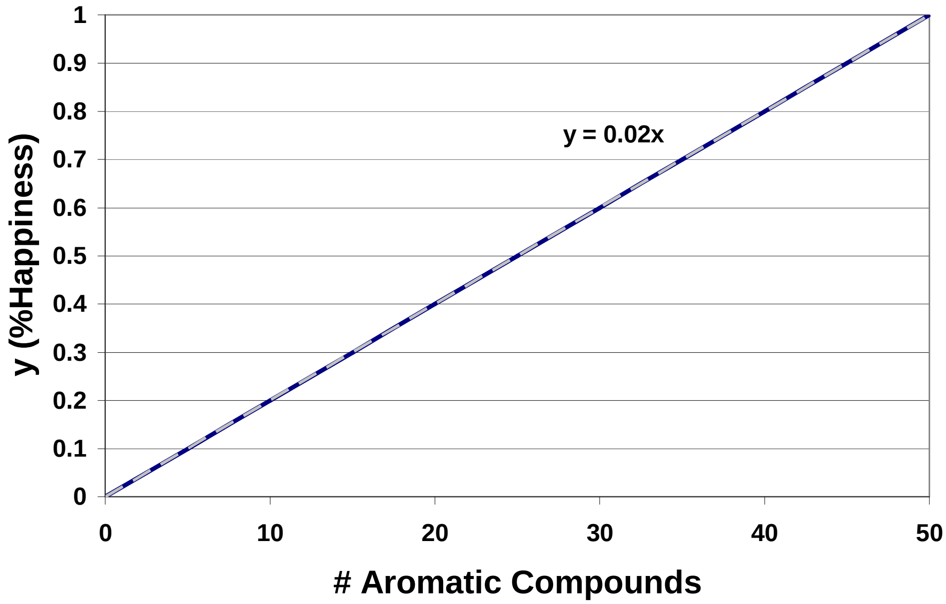

Figure 15. Consumer happiness curve as a function of the number of aromatic compunds. **The function generated by the fitting of a linear model. This function yields a y score for the consumer evaluation of bouquet and, when multiplied by its weight, will be used in conjunction with the other models generated to yield the consumer's overall utility.**

These functions are evaluated with the assumptions that there are no bad smelling aromatic compounds present. There are also several off-odors that can result in a negative view of the wine's bouquet. These off-odors can be described or identified as sulfur dioxide, hydrogen sulfide, raisin, green or mossy, bacterial, rubber, or moldy for example. For purposes of simplicity, these odors are not considered, but should be addressed in future analysis.

Body

The body or texture of the wine is a major component to the evaluation of wine. Body or texture is what is used to describe the feeling of wine in the mouth, and is an overall evaluation of the effects of the wine on the palate. A full-bodied wine feels heavy and viscous within the mouth. The body is ranked as being appropriate for the type and age of the wine. For example, a cabernet sauvignon has a much fuller body than that of a white zinfandel.

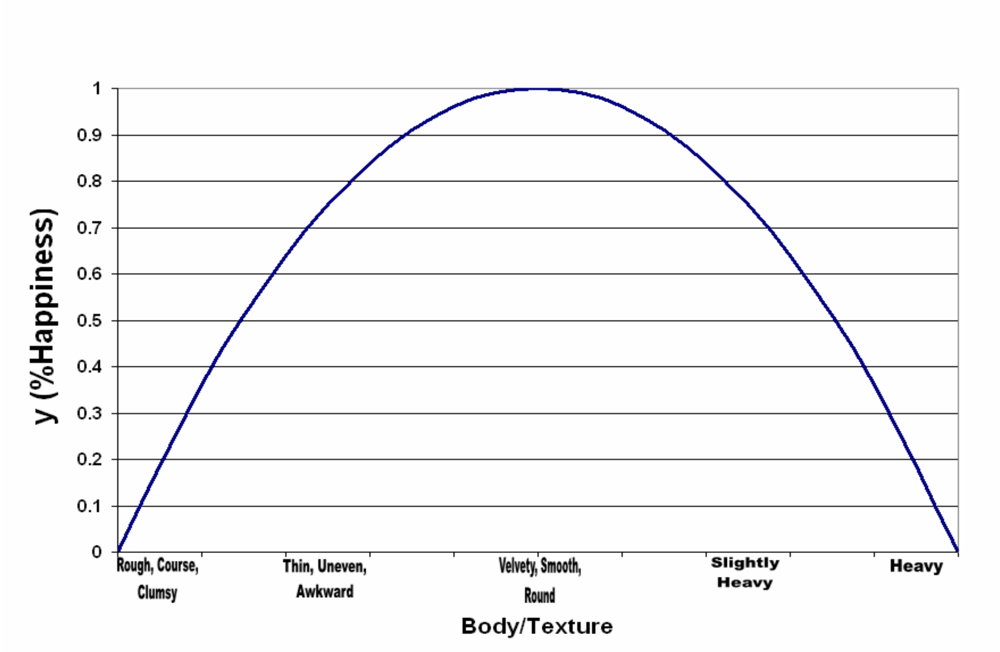

Figure 16. Example of consumer happiness as a function of consumer described attributes of body or texture*. **As the body or texture increases in complexity, the happiness of the consumer increases. This is shown linearly.**
**These terms are arbitrary and not necessarily accurate. The values on the y-axis will change with data generated from the sampling of different market segments. This curve is generated assuming the reaction of a normal human being. No socio-economic characteristics are taken into account nor any previous experiences or perceptions. This is an example.*

A way of measuring these descriptions must now be found. The body/texture can be related to the percent alcohol of the wine. Percent alcohol is in reference to the mass fraction of ethanol found within wine. It is responsible for giving wine its depth and thickness. After normalizing the consumer's descriptions with the alcohol mass fraction, Figure 17 shows the correlation that describes the consumer's utility.

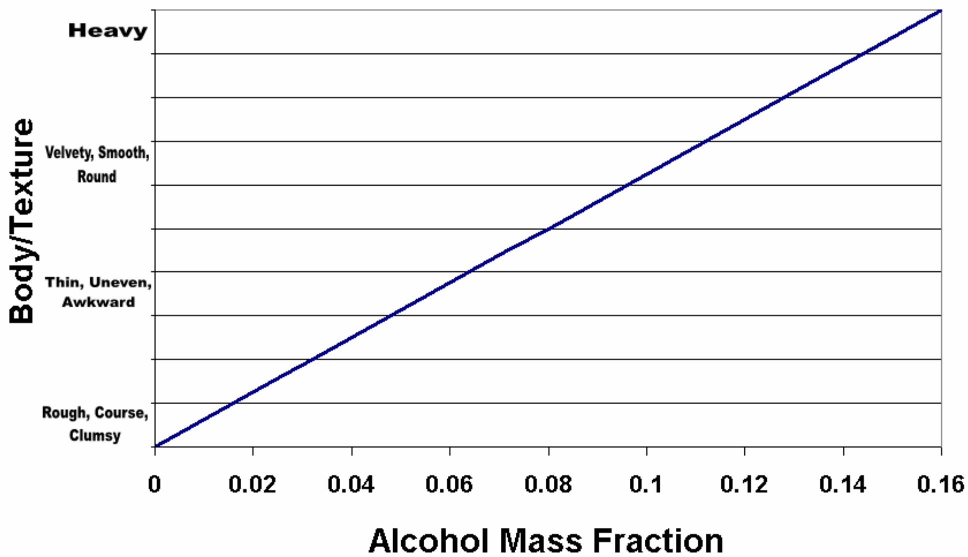

Figure 17. Body or Texture of a wine described as a function of Alcohol Mass Fraction. **As the mass fraction of alcohol increases, the body or texture of the wine does as well.**

Figure 17 shows the relation of the consumer's described attributes of body and texture to the alcohol mass fraction in wine. Table wines have a maximum alcohol concentration of 16 % by mass. With decreasing fraction of alcohol, the wine is described as being less balanced and complete. By the formation of this correlation, it is now possible to relate the consumer's happiness to the physical property of alcohol mass fraction.

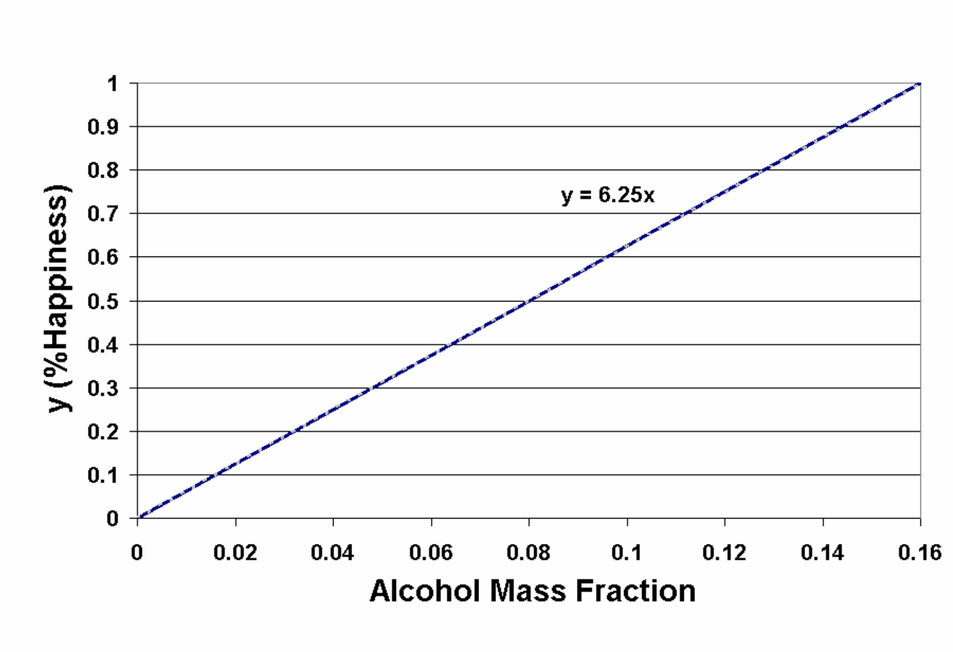

***Figure 18**. Consumer happiness curve as a function of alcohol mass fraction.* **The function generated by the fitting of a linear model. This function yields a y score for the consumer evaluation of body or texture. When multiplied by its weight, it will be used in conjunction with the other models generated to yield the consumer's overall utility.**

Alcohol is formed in wine by the fermentation of the natural sugars of the grapes. Sugar is converted into alcohol and carbon dioxide by yeast. Once the yeast is exhausted, no more alcohol can be formed. In order to manipulate the alcohol content, the amount of time allowed for fermentation can be varied in order to find the necessary balance of alcohol and sugar content. The longer fermentation is allowed, the more alcohol is produced. Fermentation usually ends after when 12-15% by mass of alcohol is reached due to the yeast being exhausted.

Acidity

Acidity is a common word used to describe the flavor of wine. This characteristic is the result of the balance or lack of balance between the acidity level, alcohol content, and body. Wines that are low in acidity tend to taste flat, while those with too much acidity taste sharp or harsh and unbalanced. Figure 19 shows the consumer's view of acidity and how it affects his/her happiness.

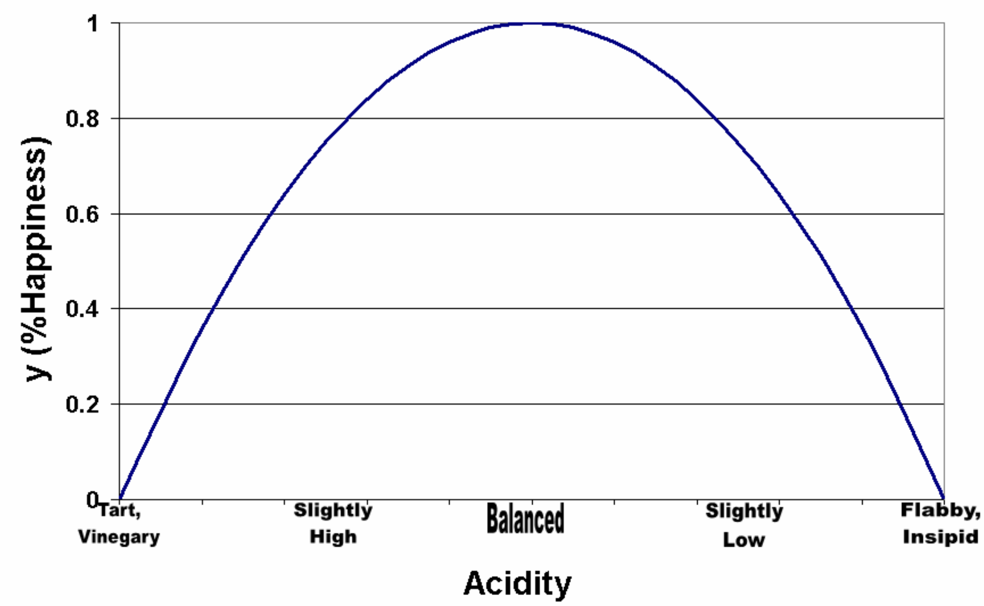

Figure 19. Example of consumer happiness shown as a function of the consumer's description of acidity*. **The following curve shows the need for the balance of acidity, where the peak occurs for consumer happiness. If the acidity is too high, it begins to taste tart or vinegary, whereas if it is too low, the wine begins to taste flabby and insipid.**

**These terms are arbitrary and not necessarily accurate. The values on the y-axis will change with data generated from the sampling of different market segments. This curve is generated assuming the reaction of a normal human being. No socio-economic characteristics are taken into account nor any previous experiences or perceptions. This is an example.*

The easiest and most cost effective way to test acidity levels is pH. The lower the pH, the more acidic the wine is, and the higher the pH, the less acidic it is. It is necessary to normalize the pH of the wine with the scale presented by Figure 20.

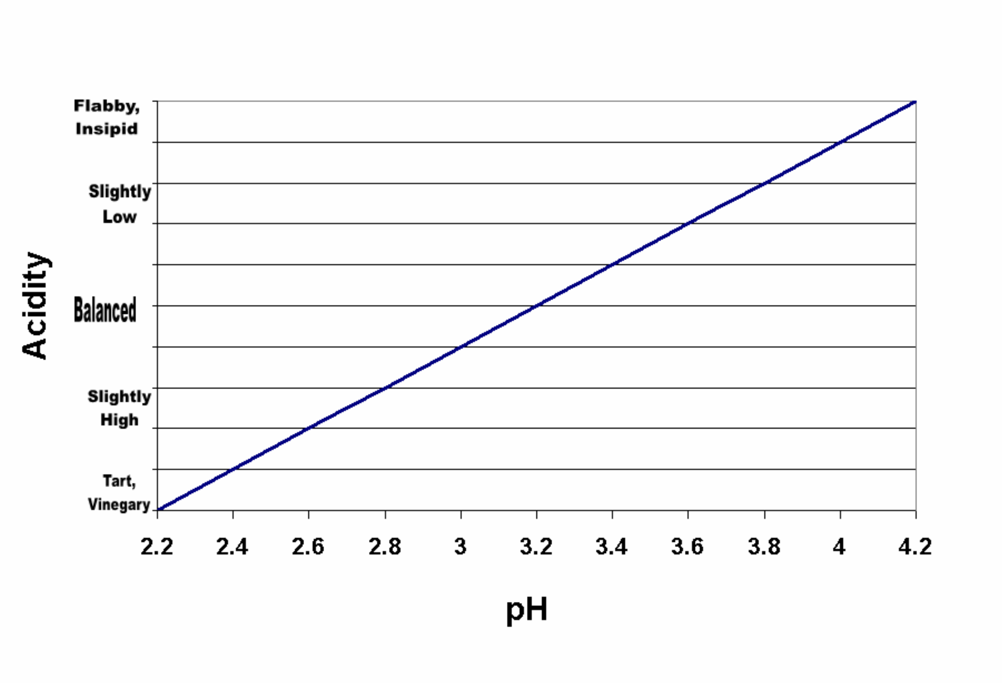

Figure 20. Correlation of consumer described acidity as a function of physically measurable pH. **This shows the correlation between the acidity of what the consumer describes and the pH level. The pH for table wine begins at 2.2 and be as high as 4.2.**

Once this correlation is formed, the happiness of the consumer can be plotted against the pH to find the optimum values and the function that describes its happiness.

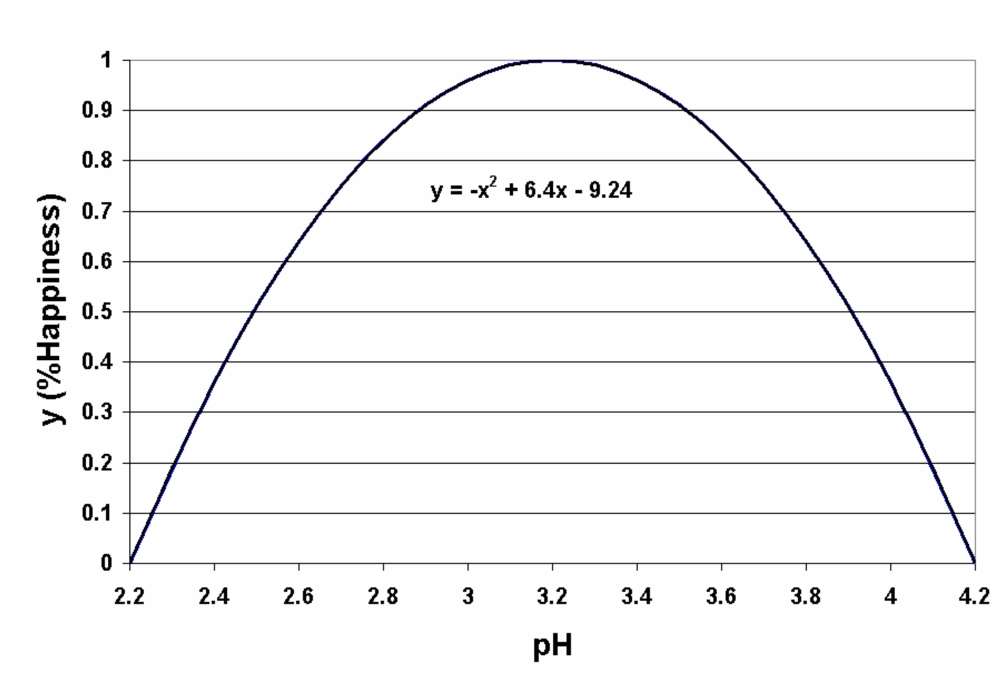

Figure 21. ***Consumer happiness curve as a function of pH.*** **The function generated by the fitting of a binomial. This function yields a y score for the consumer evaluation of acidity. When multiplied by its weight, will be used in conjunction with the other models generated to yield the consumer's overall utility.**

The principle acids in wine are tartaric and malic acids. The relative amounts of these acids vary depending on the grape variety and the climate in which the grapes are grown. The acidity of wine can be tested by the composition of these wines or by simply checking the pH. The pH level of the wine is the measurement of the active acidity, and the optimal range for any table wine is between 3.3 and 3.7[30].

The pH level of wine can be altered by malolactic fermentation. Malolactic fermentation is a naturally occurring process that lowers the acidity by converting malic acid to lactic acid and carbon dioxide. Almost all red wines automatically undergo this process, and although it is difficult to stop, winemakers work hard to control the timing of this secondary fermentation.

If a higher acidity is needed, acid can simply be added to the batch of wine. More malic acid can be added after the completion of the second fermentation, as well as adding tartaric acid. A blend of tartaric, malic, and citric acid, known as Acid Blend, can be purchased for $5.10 per 6 ounces and will result in the acidity increase of 0.15% tartaric acid with the addition of one teaspoon per gallon of wine[37].

Sweetness

The sweetness of wine is another important characteristic of wine that provides balance. Sugar is a very important component in wine production. During alcoholic fermentation, yeast converts the sugar found within the grape juice into ethyl alcohol and carbon dioxide. The amount of sugar that is fermented determines the wine's alcohol level and, ultimately, the amount of residual sugar left in the wine. These leftover sugars are what contribute to wine's sweet taste. The estimation of the consumer's perception of sweetness in wine can be seen in Figure 22.

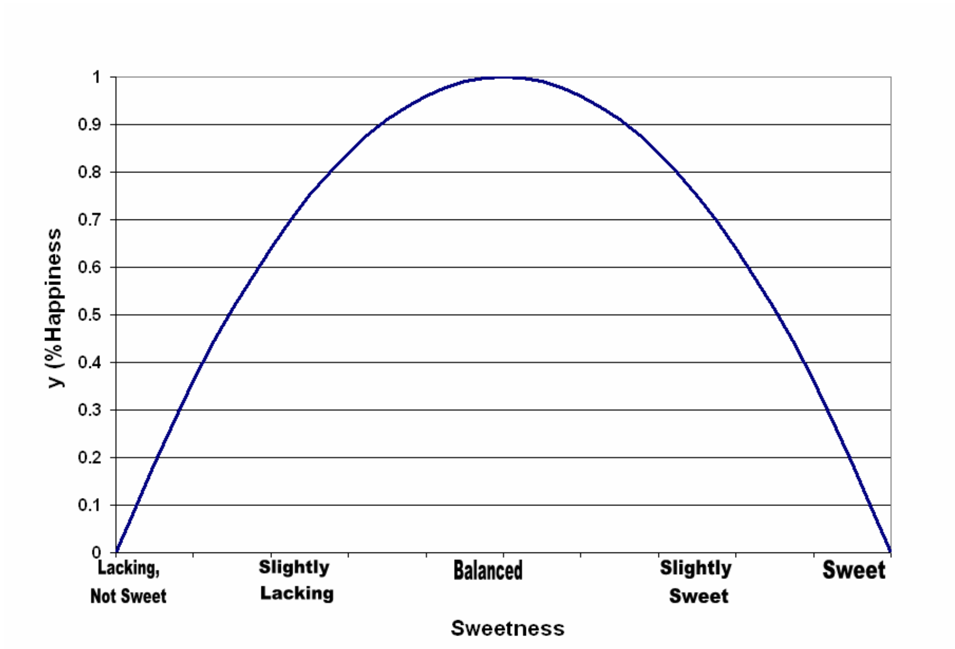

Figure 22. Example of consumer happiness as a function of consumer described sweetness*. **As the sweetness in wine increases, so does the happiness of the consumer.**
**These terms are arbitrary and not necessarily accurate. The values on the y-axis will change with data generated from the sampling of different market segments. This curve is generated assuming the reaction of a normal human being. No socio-economic characteristics are taken into account nor any previous experiences or perceptions. This is an example.*

Once the consumer's utility of sweetness in wine has been identified, it is important to find a method to quantify sweetness. The sweetness of a wine can be measured by calculating the percent of residual sugar in the wine after fermentation. Figure 23 shows the relationship between sweetness in wine and the percent residual sugar.

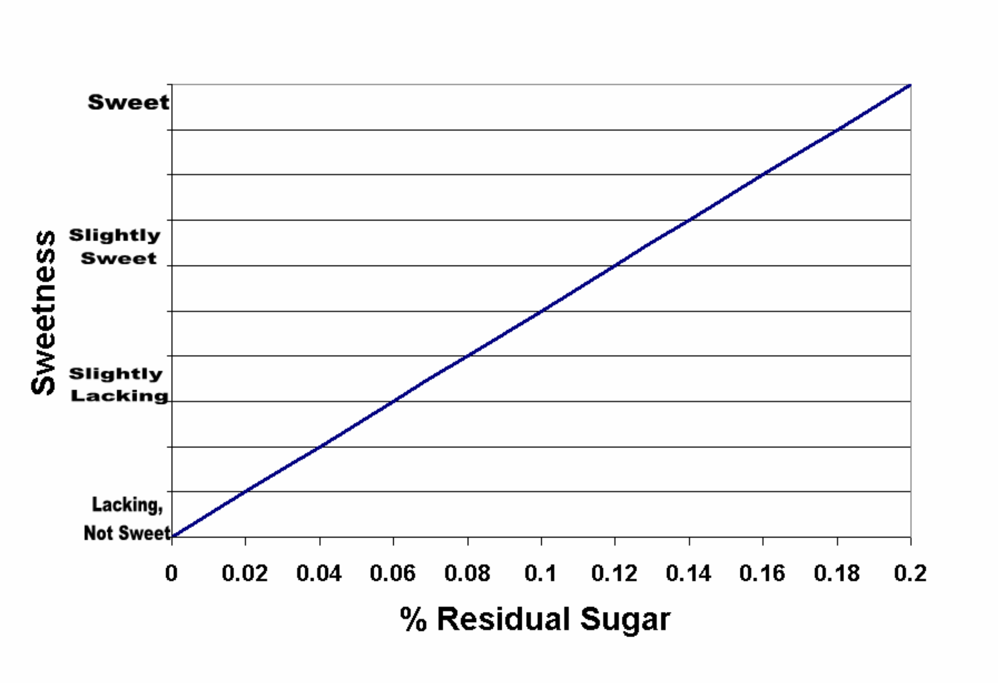

Figure 23. Correlation of consumer described sweetness as a function of percent residual sugar. **As the sweetness of the wine increases, so does the percent of the residual sugar found within the wine.**

Now that the scientific measurement has been related to the consumer's descriptions, it is possible to form the correlation between percent residual sugar and the consumer's utility. Figure 24 identifies this correlation and function based upon the estimation of the consumer's utility, which will vary with marketing data. A model is then fit to the curve that mathematically describes the relation of the consumer's happiness as a function of percent residual sugar.

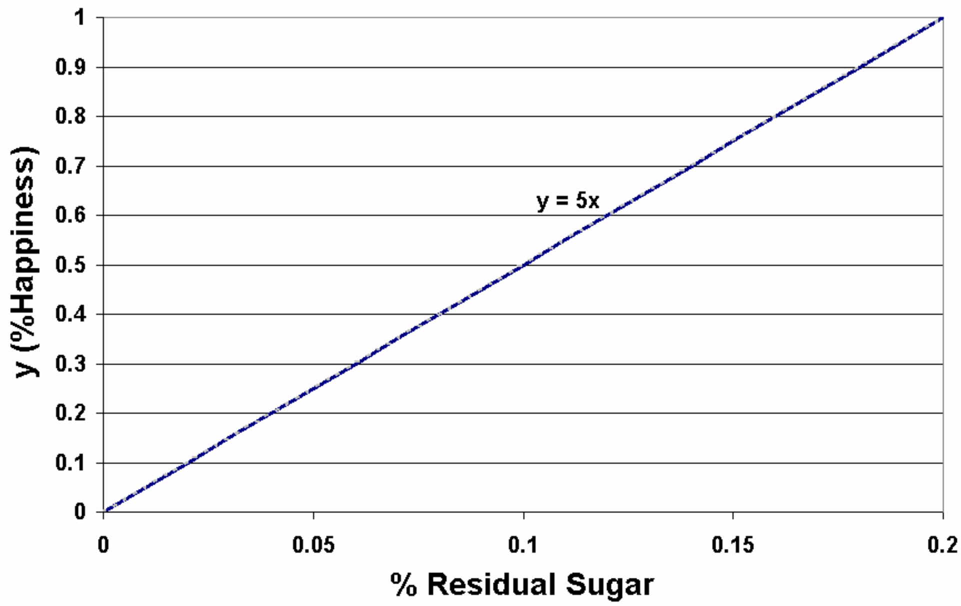

Figure 24. Consumer happiness curve as a function of % residual sugar. **The function generated by the fitting of a linear model. This function yields a y score for the consumer evaluation of sweetness. When multiplied by its weight, it will be used in conjunction with the other models generated to yield the consumer's overall utility.**

The function used to describe the model in Figure 24 is linear. It is simplified for purposes of integration into the overall function. Again, this function will change with the accumulation of marketing data, and the trend seen will be altered. This is an approximation based upon the authors' personal experience and generalizations with consumer response to sweetness.

When measuring the level of residual sugar, there are several methods the producer can employ. The most common and simple method to measure residual sugar concentration is by using Clinitest® reagent tablets[28]. This particular method is a compliment to the use of the hydrometer. The two methods are coupled because the hydrometer cannot be used to for quantitative residual sugar measurement alone. The hydrometer only indicates if too much sugar is present.

Clinitest® tablets are most commonly used within industry by diabetics to monitor blood sugar levels my measuring glucose in urine[28]. Because of this tablet's simplicity and quickness, it is great for employment within the wine industry. The cost of thirty-six tablets is approximately $30[28]. Only one tablet and 10 drops of wine are used to measure the residual sugar concentration up to five percent. This method is based on the chemical reaction of the reduction of copper. The tablets contain copper sulfate that is reactive to the sugars present in wine. The result of the boiling reaction is a color change that varies with the amount of sugar present[28].

The hydrometer method is employed when measuring Brix or specific gravity. This method is used to monitor the rate of fermentation. Fermentation is near completion when the reading is less than or equal to negative one degree Brix, equivalent to a specific gravity of 0.995[28]. However, this method cannot be used alone, because it does not specifically measure the concentration of residual sugar. Rather, it is a measurement of the possibility of sugar being present. It must be used in conjunction with the Clinitest® tablets.

Fermentation is the process in wine where yeast converts sugar into alcohol and carbon dioxide. When this process is complete, the wine is usually dry, having converted most of the sugar. However, yeast can be exhausted before all of the sugar has been converted. This happens when the alcohol content ranges from about 12-15%. The leftover sugar, deemed residual sugar, remains within the wine. This residual sugar gives wine its sweetness. The sweetness in wine can be altered by manipulating the amount of time allowed for fermentation. The shorter the time allowed for fermentation, the sweeter the wine will be. However, if the sugar content is greater than .2% by mass, further fermentation will be enabled as well as the promotion of bacteria growth.

Bitterness

Bitterness is an undesirable characteristic that makes the wine harsh. It, along with the acidity and sweetness, needs to be in balance within the wine. Any kind of bitter taste to a wine is unpleasant to the consumer, but the happiness levels actually achieved vary.

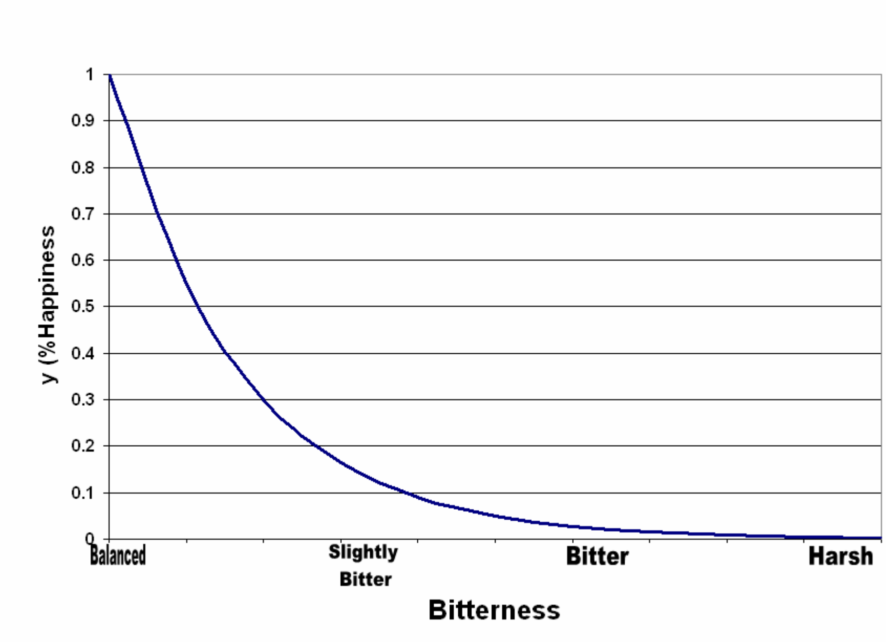

Figure 25. Example of consumer happiness as a function of consumer described bitterness. **This shows that with no bitterness, the wine is described as balanced and with 100% happiness. With the increase in bitterness, the happiness of the consumer dramatically drops.**
**These terms are arbitrary and not necessarily accurate. The values on the y-axis will change with data generated from the sampling of different market segments. This curve is generated assuming the reaction of a normal human being. No socio-economic characteristics are taken into account nor any previous experiences or perceptions. This is an example.*

It is now important to identify a physical property that can be related to the bitterness of wine. Tannins are the astringent and bitter group of compounds found in the seeds and skins of grapes. Tannins slow oxidation in wine, which gives red wine great aging potential. Tannin extraction is a very important part of red winemaking. Red wine is fermented with the grape skins, sometimes even with whole grapes still in tact. Bitterness can thus be measured by the mass fraction of tannins within the wine. This correlation is shown with the consumer's description in Figure 26.

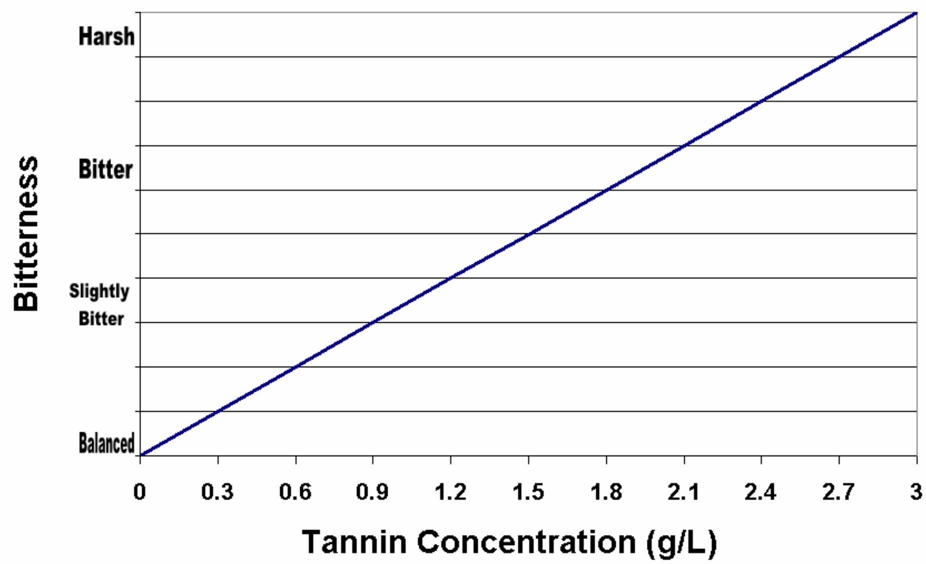

Figure 26. Relation of consumer described bitterness to physically measurable tannin concentration, measured in grams per liter. **As bitterness increases, so does the tannin concentration. The optimum amount of tannin concentration is in the low range of 0-.25g/L. The maximum tannin concentration that can be reached after filtration is 3 g/L.**

The tannin concentration ranges from 0 to 3 gallons per liter. At 3 g/L, the wine is described as being harsh. This tannin level is the highest level attainable after filtration of a red wine. Now that this relationship is developed, it is now possible to form a correlation that describes the consumer's utility as a function of tannin concentration. This correlation is shown in Figure 27.

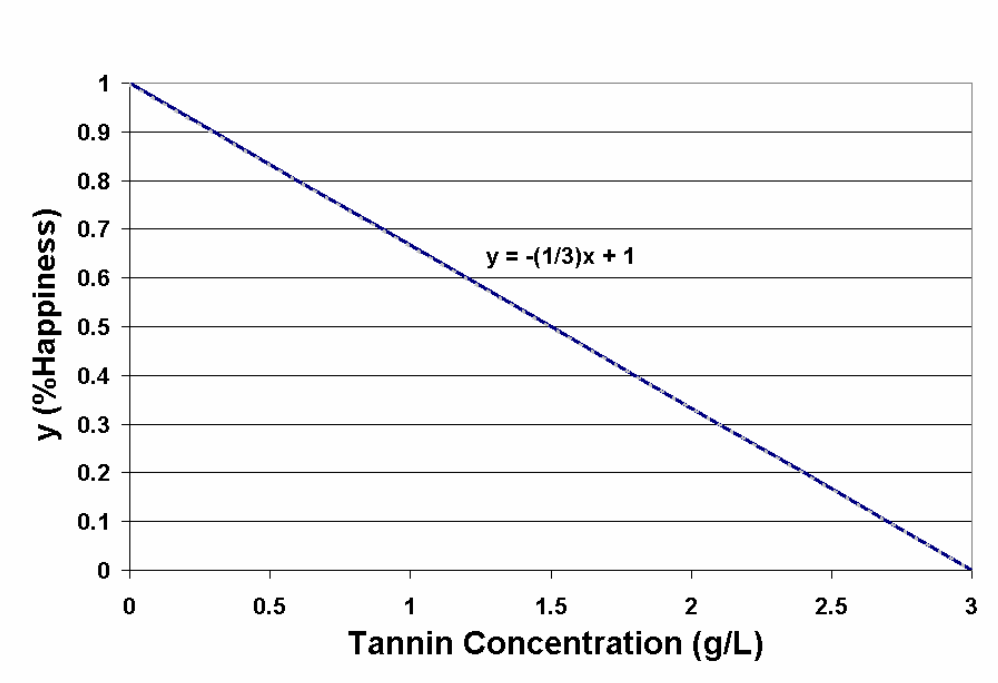

Figure 27. Happiness curve as a function of tannin concentration. **The function generated by the fitting of a linear model. This function yields a y score for the consumer evaluation of bitterness. When multiplied by its weight, it will be used in conjunction with the other models generated to yield the consumer's overall utility.**

The extraction of tannins is monitored by the manipulation of the skins, which rise to the top of the batch of wine, forming a cap. These skins are removed at the surface. Wine also gathers tannins by maceration or prolonged skin contact. This can occur before and after fermentation to ensure the optimum amount of tannins. Both of these points in the process can be adjusted. The longer the juices are in contact with the skins, the more tannins are allowed into the wine.

When a red wine is young, its tannins are new and bitter. Over time, however, tannin compounds join together and with pigment molecules, long polymers are formed. These polymers settle to the bottom of the bottle of wine, making the wine softer and more pleasantly astringent rather than bitter. This process begins during maceration and continues after bottling. However, after bottling, wine is not exposed to oxygen. The process is anaerobic and occurs much slower than before bottling.

In order to decrease tannin concentration before bottling, leading to a decrease in necessary aging of the wine, fining agents can be employed. Although gelatin does bond to tannins within the wine, the tannins that are specific to its charge are those with higher molecular weights. These polyphenols are responsible for the astringent characteristic of wine.

Polyclar is a fining agent that focuses on the lower molecular weight polyphenols that lend the bitter attribute of wine. Polyclar uses the formation of hydrogen bonds between the carbonyl groups of itself and the phenolic hydrogens of the polyphenols. The tannins that bond to the Polyclar settle to the bottom of the wine and can be gathered by filtration. In order for the Polyclar to be effective, 0.5 grams per liter of wine should be used, at a cost of about $29.95 per pound[37].

Balance

It is very important that the acidity, sweetness, and bitterness achieve a balance. Without the perfect balance, wine begins to become less appealing to the consumer. The following equation is used that results in an overall y score that describes the utility of the consumer with the harmony of these three attributes. The distance formula is used to account for any values that result in an imbalance. The y score that is found for the balance will be multiplied by the summation of each individual characteristic's weight:

$$y_{balance} = [y_{pH} + y_{bitterness} + y_{sweetness}] - [(y_{pH} - y_{sweetness})^2 + (y_{pH} - y_{bitterness})^2 + (y_{sweetness} - y_{bitterness})^2]^{1/2} \quad \textit{(Equation 8).}$$

Aroma and Flavor Profiles

Bouquet and flavor can also be evaluated further by the formation of sensory profiles. These profiles are made by evaluating the intensity of distinct aromatic and flavor compounds. Some of these compounds are the result of the grape type and the tannins present. The oak with which the wine is processed is also a very large contributing factor as well. The type, age, seasoning and toasting of the oak used to age the wine greatly influences the bouquet and flavor. Now that seasoning and aging of oak methods have all become uniform throughout Europe and the US, the different types of wood used only show small differences in the overall aroma and flavor profiles formed. The single most determining factor in flavor and aroma complexity is the level of toasting of the wood.

Toasting is described traditionally by the terms light, medium, and heavy, which are based on the actual appearance of the inside face of the staves. A light toast refers to a mild visual darkening, while a heavy toast is very dark and "chocolate-like" in appearance. However, in a heavy toast, unlike whiskey barrels, a wine stave does not have any formation of char. A medium toast is an intermediate level of toasting, appearing similar to the color of toasted bread. Additional levels of toasting from cooperages are described as being "light char" and "medium plus" among the most common.

A temperature profile can also be used to describe each level of toasting. The data provided in Table 4 shows the surface temperature readings for an 18-month seasoned American oak found in the study presented by Hale et al.[18] about the effects of seasoning and toasting on the quality and characteristics of wine. The temperatures collected are averaged at each time interval, and plotted as a function of time. The resulting profiles can be seen in Figure 28.

Table 4. Surface temperature readings for 18-month seasoned American Oak (°C)[18].

Toast Level	TIME (min)			
	0	10	25	50
Light	24	129	144	153
	24	127	145	148
	22	125	141	147
Medium	22	151	172	178
	23	147	172	181
	22	141	160	171
Heavy	23	168	197	205
	22	176	200	208
	21	162	185	194

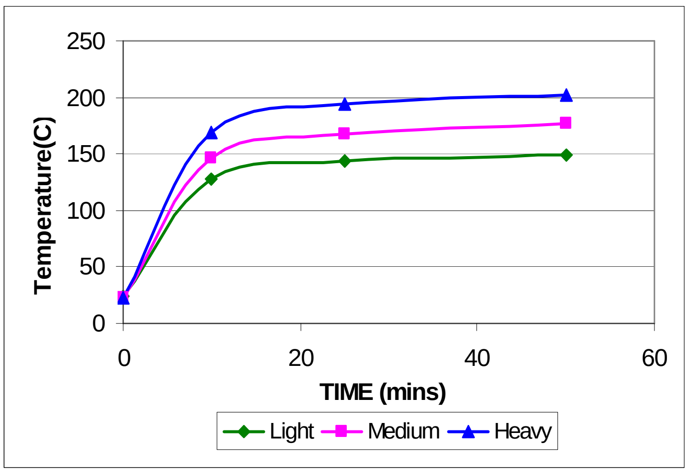

Figure 28. Surface temperature profiles for light, medium, and heavy toast samples[18].

As time increases, so does the surface temperature of the oak stave, being greatest for the heavy roast and the least for the light roast. The roasting of the wood begins to degrade the hemicellulose and lignin of the wood, triggering the creation and release of an abundance of aromatic and flavor compounds[18]. The amount of compound released will depend upon the length of time and level of toasting.

In order to understand the full effects of pyrolysis as the oak is being toasted, it is important to look below the surface of the oak stave. As the surface of the oak increases in temperature, energy is transferred in the form of conduction throughout the entire stave. The result of this temperature gradient is the further breakdown of the hemicellulose and lignin of the wood. This temperature increase can be seen on a two-dimensional level by the formation of a temperature profile, formed by the gathering of various temperature readings throughout the depth of the stave. These effects can be seen below in Figure 29, which shows a temperature profile for a medium toast of American Oak.

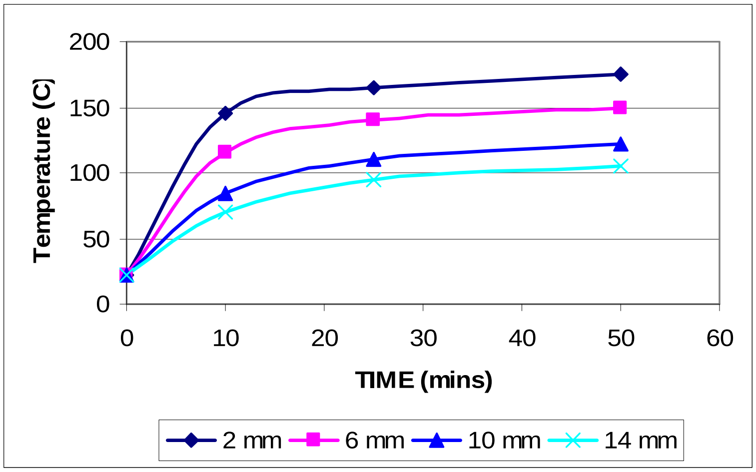

Figure 29. Temperature profile for a medium toast stave of American oak at varying depths[18].

As the oak medium begins to increase in temperature, not only on its surface, but throughout its entire medium, the composition of the wood is broken down further and further. This allows more aromatic and flavor components to be released to the aging wine. The temperature and depth of the stave both play significant roles in the amount of compounds that are released. Hale et al. gathered a panel comprised of six trained professionals to evaluate the sensory characteristics of wine that was aged with each of the four depths of oak[18]. After the American oak had been seasoned and toasted, it was sliced into chips of 9 cm X 1 cm X 4 mm in dimension. These chips were then placed in 375 mL of wine and aged for two months. The following profile was developed by the trained panel.

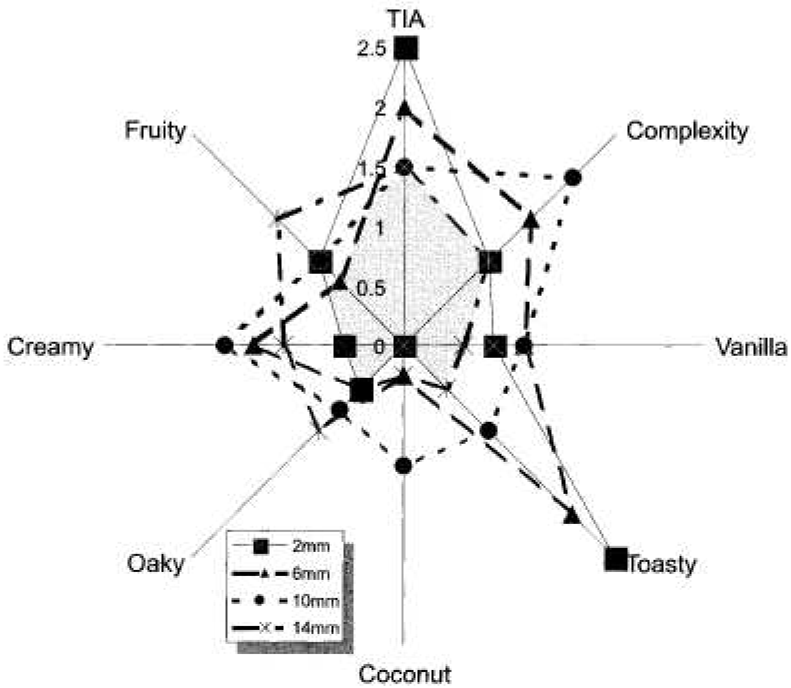

Figure 30. Sensory spider diagram of cabernet sauvignon from each layer of toasted oak[18].

The term "toasty" is used to describe wine with a strong sweet, caramel, vanilla, and oak character[18]. "Oaky" represents a green, astringent, raw, and woody character, and "TIA" refers to the total intensity of aroma[18]. Although this particular profile describes the sensory analysis of a cabernet sauvignon, and not that of a pinot noir, it is an important step to understanding the relationship between these aromatic and flavor characteristics. This particular profile, however, is representative of a medium toast of an oak stave. It is necessary for the producer to be familiar with the temperature and sensory profiles for the light and heavy toasts of oak as well. With this knowledge, the producer can engineer any wine with a desirable sensory profile by simply manipulating the toasting level.

In order to characterize the new scents and flavors of the wine as a whole, a sensory profile can be constructed. Figure 31 shows an example of an aroma profile for two pinot noirs: one is aged in oak that is not toasted, while the other has been aged with "heavy toasted" oak barrels. Each profile is formed by the summation of the compounds resulting from the degradation of the wood throughout the depth of the stave. Each profile will vary depending upon the specific varietal of interest.

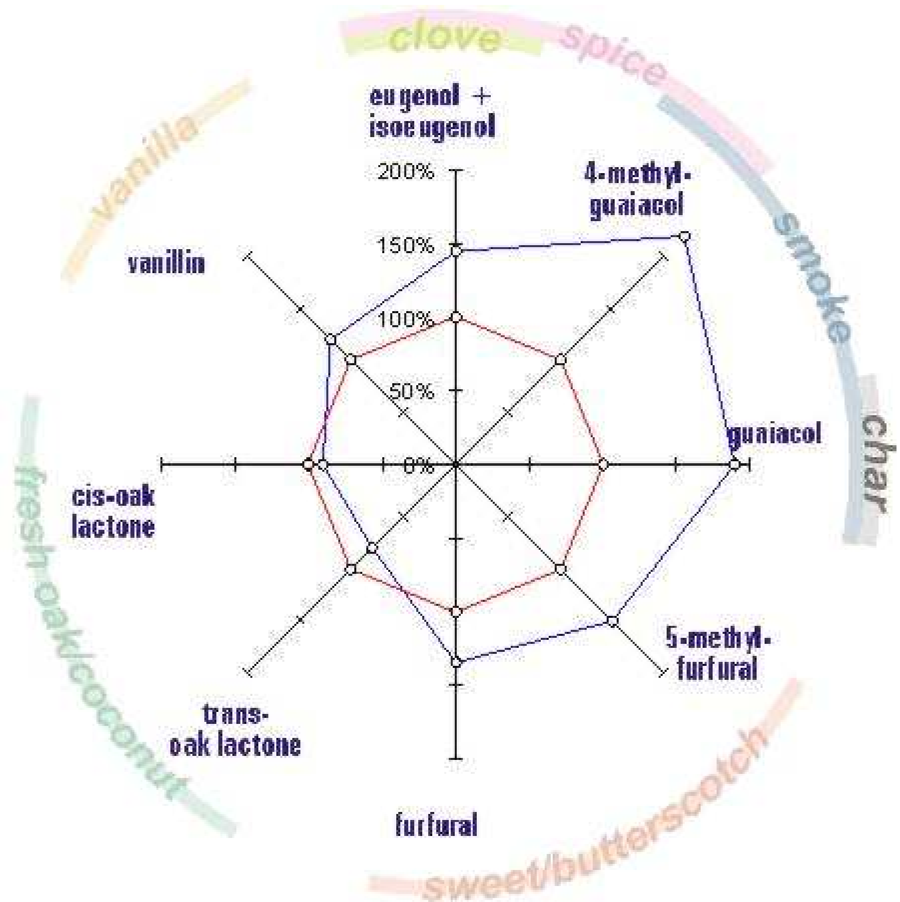

Figure 31. Aroma profile of two sample pinot noir wines[12]. **The aroma profile is a comparison of a traditionally oak aged wine (indicated in red) to the same wine soaked in a "heavy toast" of oak (shown in blue). The profile shows a high level of intensity for the 4-methyl-guaiacol and guaiacol, which are both associated with heavy smells of smoke. The levels of compounds reached are found by the comparison of the control: the untoasted oak.**

Figure 31 shows that the "heavy roast" pinot noir has much higher levels of aromatic compounds associated with char and smoke smells. These flavor profiles can be constructed for each different wine that is to be measured in order to evaluate the wine more specifically. This flavor profile is the next step in evaluation of the happiness associated with the bouquet of the wine. Flavor profiles can be used to help target specific markets searching for scents that are more specific to the wine varietal or to accommodate pairing with different foods.

Although current research has identified up to 64 aromatic compounds within the pinot noir varietal, the aroma profile shown in Figure 31 contains nine compounds that represent a broad range of chemical classes and sensory effects. All of these attributes vary depending upon the type and roast of the oak as well as the time spent aging. These compounds are described in more detail below along with the adjustments necessary to alter their individual levels of concentration.

Vanillan is the main aroma compound in natural vanilla and can also be found in raw oak. The amount of this compound present in wine varies with the species and seasoning of oak used. Its concentration increases with medium toast levels and decreases with high toasts[12]. The level of vanillan is also affected by the fermentation process that occurs within the barrel. It is partially transformed to non-aromatic vanillyl by the yeast, leading to the reduction of the characteristic vanilla scent[12].

Eugenol and isoeugenol are the main aroma compounds found in cloves, hence their attribution of such a scent to the pinot noir. These compounds can also be found in raw oak and are reported to increase in concentration during open-air wood seasoning[12]. Increasing the concentrations of these compounds is done by the increase in toasting of the oak barrel.

Guaiacol and 4-methylguaiacol are results of pyrolysis of wood lignin, which is a compound found in the cell wall of wood. These compounds contribute a smoky scent and increase with increasing toasts. These particular characteristics are seen at their peak in heavy toasts[12]. Guaiacol only contributes a char scent while the 4-methylguaiacol possesses scents characteristic of char and spice.

Furfural and 5-methylfurfural are the result from degradation of carbohydrates due to heat. Cellulose and hemicellulose are degraded during barrel toasting. The furfural compounds possess sweet, butterscotch, light caramel and almond-like aromas[12]. The heavier the toast on the oak barrels, the more apparent these scents will be within the wine[12].

Both cis and trans oak lactones comprise most of the aroma constituents of raw oak. These two compounds are responsible for the fresh oak and coconut scents that consumers describe. Because the cis isomer is more aromatic than the trans, American White Oak can be used to sharpen these particular scents to tailor to consumers[12]. If the scents are too strong, an increase in the barrel toast will soften the oak lactones in the wine[12].

The sensory impact of an aromatic compound within wine is evaluated by comparing its concentration found within wine to that of the threshold determined by adding the pure compound to a neutral wine. The concentrations of these compounds are presented as percentages in reference to the sample concentration. The radial plot, shown in Figure 31, is used to demonstrate the relationship of each compound with the other, and to indicate possible cross influence of each compound. Masking effects between unrelated volatile compounds are a definite concern that can cause some error in the radial profile shown in Figure 31. These effects are currently being researched[12].

The next step in understanding the toasting effects on the wine characteristics is the modeling of the activity associated with the diffusion of the compounds throughout the depth of the stave as well as into the wine being aged. In order to form the necessary models of the bouquet and flavor profiles, more data must be gathered and combined with chemistry knowledge to predict the effects of temperature and toasting. This will lead to the ability to control the flavor and aroma profiles by manipulation of the temperature and length of time the barrel is toasted. This particular subject exceeds the scope of this particular project, however, it is necessary to address for continuance in the understanding and manipulation of wine.

Finish/Aftertaste

The finish or aftertaste of the wine is one of the final characteristics evaluated when deciding the quality of the wine. Finish is attributed to tannins as well as the alcohol content of the wine. Excess tannin in wine produces dry, puckering, and tart flavors and tends to give a coating on the teeth of the taster. The younger the wine, the more tannins are present. With age, the tannins dissolve, and the wines begin to ripen and smooth, leaving the astringency or harshness behind. Red wines typically have many more tannins than those of white wines due to their processing being with the vines and stems.

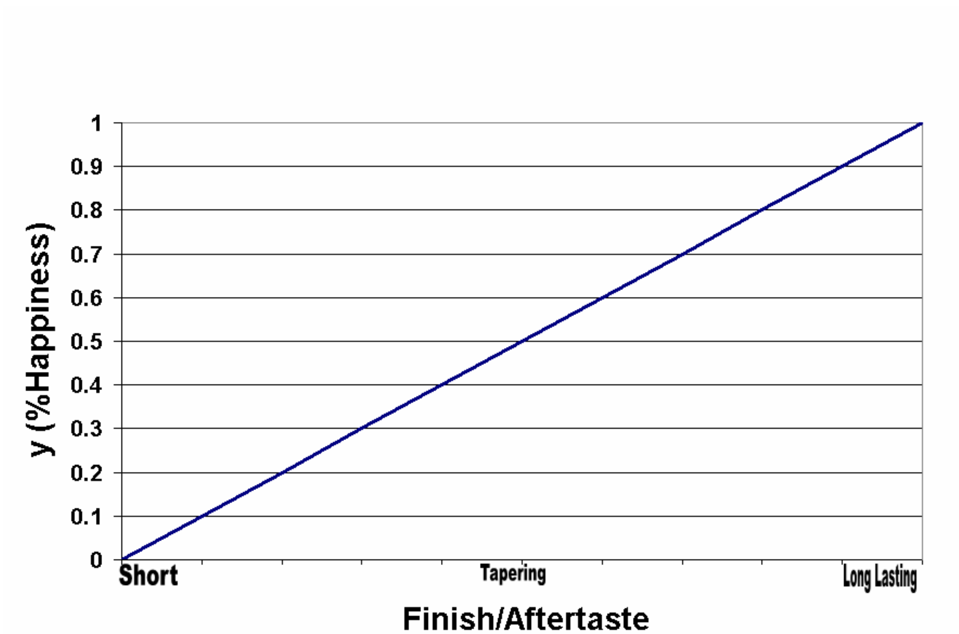

***Figure 32.* This curve describes the consumer's view of the finish/aftertaste. The longer the aftertaste lasts, the happier the consumer.**

**These terms are arbitrary and not necessarily accurate. The values on the y-axis will change with data generated from the sampling of different market segments. This curve is generated assuming the reaction of a normal human being. No socio-economic characteristics are taken into account nor any previous experiences or perceptions. This is an example.*

Because the finish or aftertaste is evaluated by the consumer with descriptions of longevity, it is only logical to relate these characteristics to that of time. Residence time on the palate can be used to correlate the consumer's description of finish and aftertaste. This can be done on a scale of zero to 120 seconds and is normalized to the consumer's descriptions.

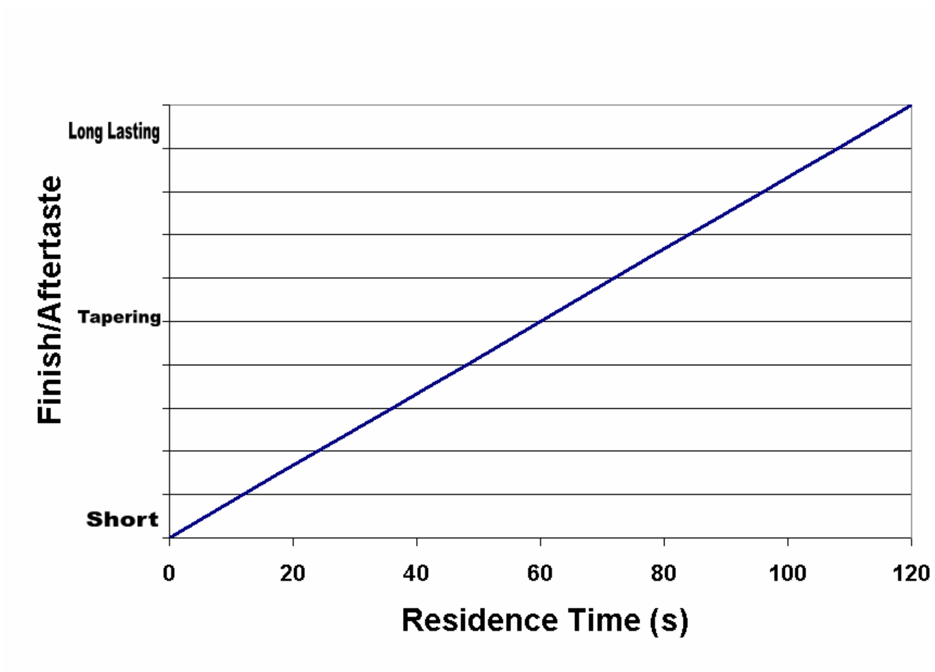

Figure 33. Finish or aftertaste described as a function of residence time on the tongue. As the residence time on the tongue increases, so does the finish or aftertaste of the wine on the palate.

After developing the relationship between the consumer's description of the finish and aftertaste to that of the residence time on the palate, it is now possible to evaluate the consumer's utility as a function of time on the tongue. When plotting residence time versus happiness, Figure 34 is formed and displays the function used to describe the linear function developed.

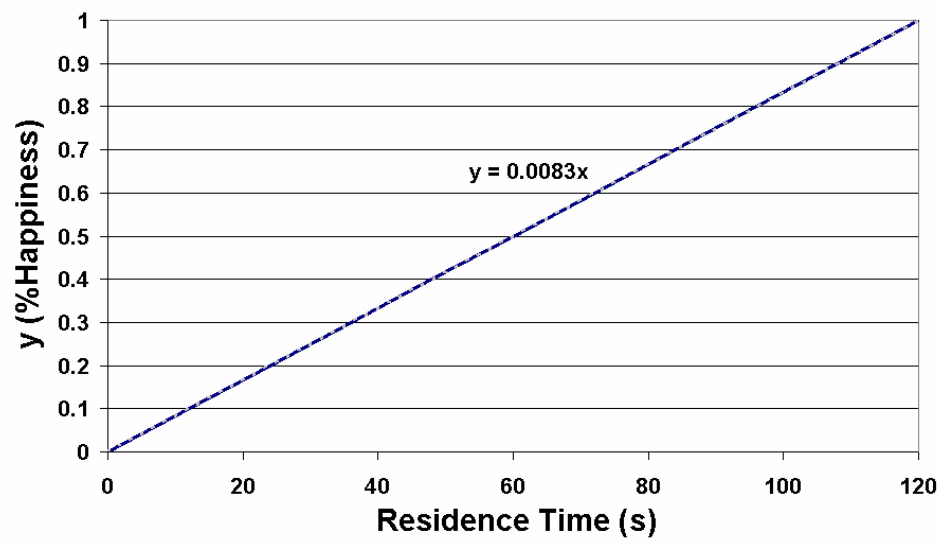

Figure 34. Consumer happiness expressed as a function of the physical property, residence time. **The function generated by the fitting of a linear model. This function yields a y score for the consumer evaluation of finish or aftertaste. When multiplied by its weight, it will be used in conjunction with the other models generated to yield the consumer's overall utility.**

The residence time on the tongue involves several different properties that are needed to be studied in detail to allow the manipulation of the winemaking process. As wine enters the mouth and is swallowed, a residue is left on the palate. This residue absorbs onto the tongue, giving an initial taste of the wine. However, it also absorbs into the saliva that is also present within the mouth. With every swallow hereafter, the aftertaste of the wine becomes less and less dominant. The dynamics of the absorbance of the wine within the oral cavity of the consumer must be understood, due to its influence on the consumer's evaluation.

While in the mouth absorbing onto the tongue and saliva, wine also has aromatic compounds that are traveling up throughout the oral cavity into that of the nose. Bouquet is once again assessed, and the aftertaste is affected by the consumer's reaction to the volatile compounds that desorb from the tongue. This effect must also be taken into account when assessing the aftertaste or finish of the wine. Because neither of these occurrences has been addressed in current research, future efforts will be needed to focus on such issues, as such, it will not be included in the happiness function formed. However, it is essential to the development of more accurate utility functions of the wine consumer. Therefore, this attribute will be held constant in the integration of the happiness model into the design and business model proposed.

Business Model

The ultimate goal of any business is to maximize profit. Profit is defined as the difference between the revenue that is generated by a product or service provided to the consumer and its operating costs that result from its production. Profit, also known as a positive net cash flow, is also decreased by taxes and the depreciation of equipment and other assets. This relationship is described in Equation 12:

Net Cash Flow = Gross Revenues – Operating Costs – Taxes *(Equation 9).*

This equation can also be represented as a function of the discounted net cash flow and the fixed capital investment (FCI) that is required by the business for operation:

Profit = Discounted Net Cash Flow- FCI *(Equation 10).*

In order to achieve the maximization of profit, operating costs must be minimized while revenues are maximized. The revenue from a particular product or service is calculated as the product of the selling price per unit (P) and the number of units sold. In this particular model, the product of interest is wine. The selling price of the wine inversely affects the demand of the consumer: as the selling price of the wine increases, the demand decreases.

If two existing wine companies are competing for the same market share, the budget (Y) that the consumer has allocated toward that particular wine varietal is divided between both wine companies' products. The point of division is dependent upon the demand for each product. This relationship is illustrated by Equation 14:

$$d_1 = \frac{Y}{P_1(1+\frac{\beta}{\alpha})} \qquad \textit{(Equation 11).}$$

Equation 14 demonstrates that the demand, also known as the consumers' want, for the first bottle of wine is dependent upon the consumers' budget, the wine's selling price, the happiness fraction, β, and the wine's popularity, α. This demand model is bound by the constraints of the consumer's overall demand, illustrated in Equation 15, as well as the consumer's overall budget, formed previously in Equation 2:

$$D \leq d_1 + d_2 \qquad \textit{(Equation 12)}$$

$$Y \leq p_1 d_1 + p_2 d_2 \qquad \textit{(Equation 2).}$$

When these boundary conditions are integrated into the demand model, the demand of the engineered wine can be described in Equation 16:

$$d_1 = \frac{\alpha}{\beta} * \frac{p_2}{p_1} * \left(\frac{Y - p_1 d_1}{p_2} \right)^{1-\beta} * d_1{}^{\alpha} \qquad \textit{(Equation 13).}$$

In order to maximize the profit of the first wine company, it is possible to alter the value of α by increasing advertisement. This of course corresponds to a cost of advertisement and may result in less profit due to its increase in operating cost. This leaves the possible manipulation of β, proposed to be calculated by the comparison of the happiness, or maximum utility, each product brings the consumer. Equation 4, developed previously, presents this relationship:

$$\beta = \frac{H_2}{H_1} \qquad \textit{(Equation 4),}$$

where H_2 is the happiness of the consumer associated with the competitor's product and H_1 is that associated with the wine being engineered. For a wine to approach maximum happiness, the following values of characteristics must be met according to the model that was formed within the previous section.

Table 5. Values of physical properties necessary to obtain maximum happiness.

Perfect Bottle of Wine	
Characteristic	$\boldsymbol{x_i}$
Clarity (NTU)	0
Color	
Hue (D_{420}/D_{520})	1
Brightness (%Brightness)	1
Bouquet (#Aromatic Compounds)	60.00
Acidity (pH)	3.2
Sweetness (wt% Residual Sugar)	0.2
Bitterness (g/L Tannins)	0
Body/Texture (%Alcohol)	0.12

These characteristics also possess associated costs. As costs increase, the demand decreases. Therefore, by using the demand and pricing models previously formed, it is possible to find the most profitable product for the producer. This product may not be the "perfect" bottle of wine the consumer envisions or desires, however, it will maximize the return on investment for the producer. The following sections will evaluate this concept while illustrating the integration of the consumer satisfaction model within the proposed pinot noir winery design.

Integration of Consumer Satisfaction Model

After identifying the wine consumer's utility as a function of physical and measurable characteristics, it is necessary to understand how the producer can manipulate the variables through adjustments to the process. The process that is evaluated through this integration is that of a pinot noir winery. A detailed description and process flow diagram of the design proposed can be found within Appendix A. In order to demonstrate this integration of the consumer satisfaction model, each step of the process is evaluated, showing the levels or values of each characteristic as well as how they can be affected by the process.

After the harvest of the grapes, they are sent to the destemming and crushing stage of the process. This is where the grapes are crushed and mixed with the skins, juices, stems, and seeds, forming what is called the must. The level of turbidity is greater than 600 NTU at this point due to the numerous solids present throughout. The acidity level of the must is calculated to be 3.6 with a sugar content of 22%. The acidity and sugar levels are high due to the natural sugars and acids found within the grapes as well as fermentation not being initiated yet.

This must is then transferred to a refrigeration tank to begin cold soaking. This step in the process is where phenolic compounds begin to desorb from the skins into the juice. The longer the juice is allowed to have contact with the skins of the grapes, the more color is extracted. This is where the hue and brightness can be altered for the happiness function. For this particular process that is designed, the hue's absorbance ratio has a value of 0.3 while the percent brightness is 0.5. Tannins are also extracted from the stems and seeds of the grapes. It is also very important to note that cold-soaking also affects the flavor and bouquet profiles. Table 6 summarizes these changes due to the crushing/destemming process as well as cold soaking.

Table 6. Characteristic summary of changes due to crushing/destemming and cold soaking.

Process - Crushing / Destemming & Cold Soaking		
Physical Properties of Must	Initial	Final
Clarity (NTU)	600	600
Color (absorbance fraction)	0	0.3
Color (brightness fraction)	0	0.5
Bouquet (# of aromatic compounds)	0	15
Acidity (pH)	3.6	3.2
Sweetness (wt% sugar)	22	22
Bitterness (g Tannin/L wine)	0	0.2
Body (wt% alcohol)	0	0
Calculated Happiness (H_1)	0.20	0.39

After the must has been cold soaked for the desired amount of time, it is then sent to a refrigerated fermentation tank. Pasteur red yeast is added to the must to begin alcoholic fermentation. It is here that the fermentation time can be altered to accommodate desired levels of residual sugar and alcohol. Once this level is reached, the fermented must is sent to be pressed. Table 8 offers a summary of the changes in the wine as it passes through this particular part of the process in the model presented in Appendix A.

Table 7. Characteristic summary of changes due to alcoholic fermentation and pressing.

Process - Primary Fermentation & Pressing		
Physical Properties of Must	Initial	Final
Clarity (NTU)	600	600
Color (absorbance fraction)	0.3	1
Color (brightness fraction)	0.5	1
Bouquet (# of aromatic compounds)	15	18
Acidity (pH)	3.2	3.2
Sweetness (wt% sugar)	22	10
Bitterness (g Tannin/L wine)	0.2	2.6
Body (wt% alcohol)	0	0.07
Calculated Happiness (H_1)	0.39	0.40

After pressing, the must that is extracted from the juice is purged and saved for later addition into the wine when needed during the aging process. The juice that has been through the first fermentation is sent to begin the second fermentation known as malolactic fermentation. This fermentation involves the conversion of malic acid through the use of *Viniflores oenus* bacteria into lactic acid. Malolactic fermentation actually increases the pH of the system, reducing acidity. This is due to lactic acid being less strong of an acid than malic, leading to a softer feel to the wine. Increasing the fermentation time during this process will lead to less acidity, while decreasing it will increase the acidity. Table 8 summarizes the affects of this fermentation on the process designed in Appendix A.

Table 8. Characteristic summary of changes due to malolactic fermentation.

Process - Secondary Fermentation (Malolactic)		
Physical Properties of Must	Initial	Final
Clarity (NTU)	600	600
Color (absorbance fraction)	1	1
Color (brightness fraction)	1	1
Bouquet (# of aromatic compounds)	18	18
Acidity (pH)	3.2	3.8
Sweetness (wt% sugar)	10	0.2
Bitterness (g Tannin/L wine)	2.6	2.6
Body (wt% alcohol)	0.07	0.12
Calculated Happiness (H_1)	0.40	0.43

After the completion of malolactic fermentation, the wine is decanted, or separated from the sediment deposits, and sent to begin the stabilization process. The sediment that results from the fermentation is sent to waste. There are two stabilizations that occur: hot and cold. The hot stabilization is the addition of heated Bentonite, a fining agent, as well as potassium bisulfite. The wine is then cooled to ensure the inhabitability of bacteria and to decrease the possibility of spoilage. Table 9 offers a summary of the changes of characteristics due to the hot and cold stabilization.

Table 9. Characteristic summary of changes due to hot and cold stabilization.

Process - Rough Filtering & Hot / Cold Stabilization		
Physical Properties of Must	Initial	Final
Clarity (NTU)	600	50
Color (absorbance fraction)	1	0.9
Color (brightness fraction)	1	0.97
Bouquet (# of aromatic compounds)	18	18
Acidity (pH)	3.8	3.2
Sweetness (wt% sugar)	0.2	0.2
Bitterness (g Tannin/L wine)	2.6	2.6
Body (wt% alcohol)	0.12	0.12
Calculated Happiness (H_1)	0.43	0.45

Once the wine has concluded its stabilization stage, it is ready for clarification and further stabilization. After the wine is decanted and passed through a rough filtration, it is sent to be aged in a polyethylene tank with oak planks to help in flavor and bouquet development. The clarification and stabilization process continues to take place. After proper aging has completed, the wine is passed through a medium filter frame that reduces the turbidity to being less than one micron. It is then sent through further filtration in the form of a membrane filter that reduces the turbidity less than 0.4 microns. The following table shows this impact on the happiness of the wine produced due to aging in the tanks with oak planks as well as the filtration, pre-bottling.

Table 10. Characteristic summary of changes due to sterile filtration and bottling.

Process - Fine / Sterile Filtering & Bottling		
Physical Properties of Must	Initial	Final
Clarity (NTU)	30	0.02
Color (absorbance fraction)	0.7	0.6
Color (brightness fraction)	0.95	0.93
Bouquet (# of aromatic compounds)	30	30
Acidity (pH)	3.2	3.2
Sweetness (wt% sugar)	0.15	0.15
Bitterness (g Tannin/L wine)	0.2	0.1
Body (wt% alcohol)	0.12	0.12
Calculated Happiness (H_1)	0.63	0.77

The total happiness shown in Table 10 is equal to 77%. This happiness is therefore employed within the demand model derived previously. A value of 0.5 will be used for the competition and varied accordingly. These values can both be altered by the small changes to the process mentioned within the brief overview provided. Also, these values can be further manipulated by the aging process, i.e. the type of oak used, the way it is seasoned, and the toast applied to the oak staves. Again, however, these affects need to be further evaluated in the future to accurately manipulate them.

The inferiority function, alpha, can also be varied, rather than having a constant value of one. Alpha is varied by increasing or decreasing advertisement costs. For the evaluation of the demand function, three scenarios for alpha are evaluated: high, medium, and low. Figure 35 displays these scenarios with alpha being a function of time.

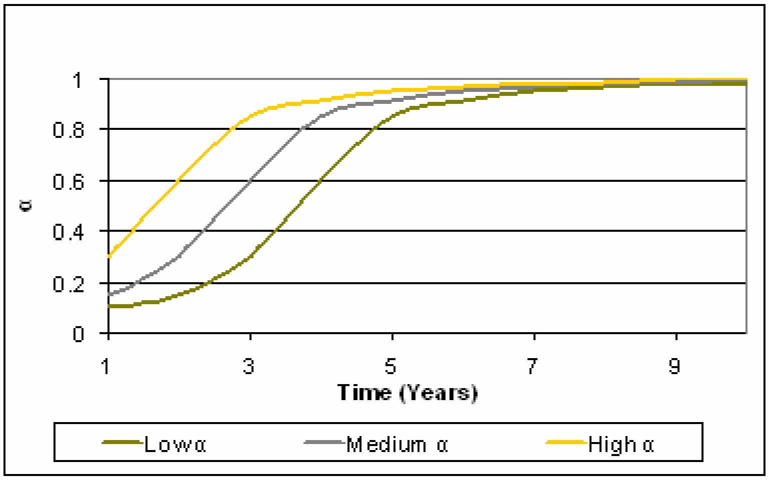

Figure 35. The superiority function represented as a function of time for three scenarios: high, medium, and low. **The high alpha value shows the market saturation occurring at a much earlier period in time than that of the medium and low. This is also associated with advertising costs of high:$2 million, medium: $1 million, and low: $0.2 million.**

The high, medium, and low alpha values have costs of $2 million, $1 million, and $0.2 million dollars, respectively. Figure 35 shows that with an increase in advertising, there is a decrease in time needed for market saturation. With increased cost, however, there is a decrease in consumer demand. This must be modeled to understand the affects of alpha on the demand of the product.

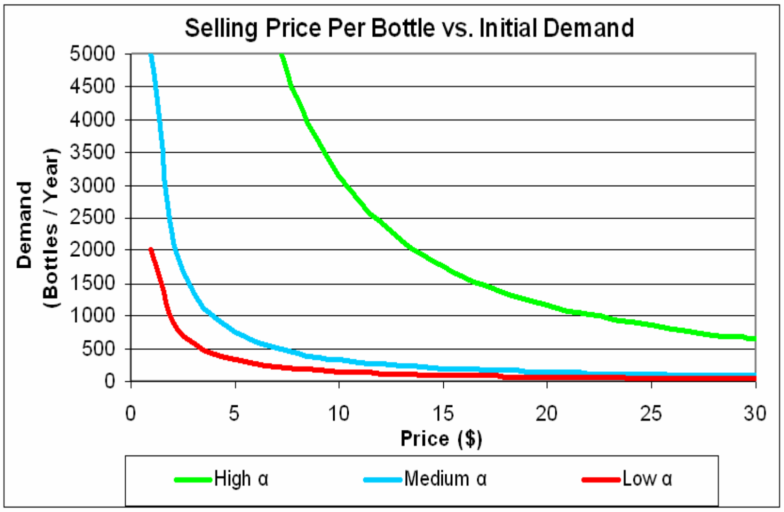

Figure 36. Demand shown as a function of selling price for each scenario of alpha.

Figure 36 shows the concept of the demand function: as the selling price increases, the demand decreases. There is an inverse relationship. Alpha, however, shifts the curves to the right, increasing the potential for possible profit. Because the functions vary so greatly, it is possible, that even at a larger selling price and lower demand, profit can be greater. Now that the alpha and beta functions have been integrated into the demand model, it is now possible to begin varying the parameters for optimization and the performance of risk analysis.

Financial & Risk Analysis

When estimating the total capital investment of the winery that is necessary to begin operations, several costs must be evaluated. The beginning costs associated with the pinot noir winery proposed are summarized in Table 11. The total direct and indirect costs are $12.6 million and $9.4 million, with a working capital of $17.3 million. This leads to a total capital investment of $39.3 million.

Table 11. Total capital investment summary of proposed pinot noir winery.

Component	Basis for Estimate	Cost ($)
DIRECT COSTS		
Purchased equipment:		
9000L Indoor Open Ferementer	www.Flextank.com.au	482,417
20000L FermentationTank	www.Flextank.com.au	862,297
2000L Maturation Tank	www.Flextank.com.au	3,243,169
Access Platform	www.Flextank.com.au	6,461
Crusher / Destemmer		101,145
Filter Frames		44,055
Variable Speed Control Unit		16,445
Pumps		42,900
Transfer Tubing		61,500
Forklift		69,180
Membrane Press		36,000
Refrigeration		441,490
Bottling Machine	www.stpats.com	98,000
Labeling Machine		21,570
Conveyor Belt		42,543
Total Purchased Equipment		5,569,171
Installation	39% of Equipment	2,171,977
Instrumentation and controls	5% of Equipment	278,459
Piping	16% of Equipment	891,067
Electrical	10% of Equipment	556,917
Building	18% of Equipment	1,002,451
Yard Improvement	12 % of Equipment	668,301
Service Facilities	26% of Equipment	1,447,984
Planting Costs	$4700 per Acre	1,106,798
Total Direct Cost		12,586,327
INDIRECT COST		
Engineering	32% of Equipment	1,782,135
Land Purchase	$8600 per Acre in Oregon	2,107,000
Construction	34% of Equipment	1,893,518
Legal expenses	4% of Equipment	222,767
Contractor's fee	17% of Equipment	946,759
Contingency	44% of Equipment	2,450,435
Total Indirect Plant Cost		9,402,614
Fixed Capital Investment	Direct + Indirect Cost	21,988,941
Working Capital	% (From Input) of Total Capial Investment	17,277,025
Total Capital Investment		39,265,966

Now that the capital investment of the design has been calculated, it is possible to begin estimations of the total product cost and return on investment over a ten year period. Table 12 offers a summary of these estimations for year two.

Table 12. Total product cost for year two of pinot noir winery.

Component	Basis for Estimate	Cost ($/yr)
I. MANUFACTURING COST		
A. Direct production costs		
1. Raw Materials		
Grapes	$2000 / ton + 20% shipping	3359477
Yeast	240 g / ton of Grapes + Nutrients	6643
Malolactic Bacteria	Includes Nutrients	808
Potassium Metabisulfite		1599
Citric Acid		10341
French Oak Quick Plank	1 / 3x2000L Maturation Tank	64535
Sodium Carbonate		1622
Tartaric Acid		15488
Filter Pads	40 Gallons per pad x 3 levels of filtration	22965
Packaging	$6.83 per Case for Bottles, Corks, Capsules, Labeling & Casing	667524
2. Operating Labor		
Hourly Labor	15$/hr @ 2000 hr / 40000 gallons of wine	367200
Salaried Labor	Enologist - $50000 / year	51000
Harvest Labor	$184 / ton of grapes harvested	44539
Subtotal		462739
3. Direct supervisory and clerical	15% of Operating Labor + Vineyard Management Costs	960181
4. Utilities		
Process electricity	$.045 / kWh, 150000 kWh	6885
Refrigeration	8760 hr @ Electrical Rates	457035
Water	5 x Total Tank Volume @ $1.81/1000gallons	42800
5. Maintenance and Repair	3% of FCI	659668
6. Operating Supplies	15% of Maintenance and Repair	98950
7. Laboratory charges	15% of Operating Labor	69411
8. Patents and Royalties	assumed to be zero	0
Subtotal		6908672
B. Fixed charges		
1. Capital costs	Annualized Fixed Cost - Based on Input	5851787
2. Insurance	1% of FCI	219889
3. Depreciation	MACRS - 2nd Year 32%	6362221
Subtotal		12433897
C. Overhead Costs	1$ per Bottle Made	1
Manufacturing Cost Subtotal		**20492570**
II. GENERAL EXPENSES		
A. Administration Costs	20% of Operating Labor	92548
B. Distribution and Marketing costs	5% Total Manufacturing Cost + α Based Cost	3024628
C. Research and development	3% Direct Production Costs	207260
Subtotal		3324436
TOTAL ANNUAL PRODUCT COST	Manufacturing Cost + General Expenses	23817006
TOTAL PROCESSING COST	Total Annual Cost / (BottleMade)	21
III. SALES		
Bottles Made		1150000
Bottles Sold		625041
TOTAL REVENUE	Selling Price x Bottles Sold	18751236
GROSS PROFIT	Total Revenue - Total Annual Product Cost	-5065770
VI. TAXES		
Liquor Tax	Oregon - $.67/gal over 40,000	152675
Property Tax	Assume 10% of Property Value	210700
Income Tax	Assume 35% Tax Rate	0
NET PROFIT	Total Revenue - Total Annual Product Cost	-5429145
TOTAL PROCESSING PROFIT	Profit / Bottle	-4.7
RETURN ON INVESTMENT	Profit / Total Capital Investment	-0.13

It is shown that there is a possibility of a negative return on investment and a loss rather than a profit. This is due to the alpha function. Because the market has not yet been saturated, or is not fully aware of the wine being engineered, the demand of 1.15 million bottles is not completely met. Rather, the extra wine produced goes into storage for later sale. This process does not yield a positive ROI until the third year. The following table summarizes the ROI associated with the year of operation.

Table 13. ROI summary of design life.

Year	ROI
1	-0.52
2	-0.13
3	0.75
4	0.42
5	0.46
6	0.49
7	0.51
8	0.51
9	0.51
10	0.51

With capital investment and production costs estimated for the life of the design, it is now possible to begin risk analysis to optimize the scenario and values of variables available. In order to evaluate the risk of each pricing model, it is important to define the boundaries. The selling price of the engineered wine will be constant at $30. If the price falls below this value, no profit is achieved throughout the ten year life of the project. It is important not to exceed this price, or the wine produced begins to move into the premium wine classification, which is not the market intended. The high value of alpha is also chosen for operation due to the shortening of time needed to reach market saturation for profit needed circumstances. The following regret analysis has been generated at varying prices of the competitor in a range from $20 to $40.

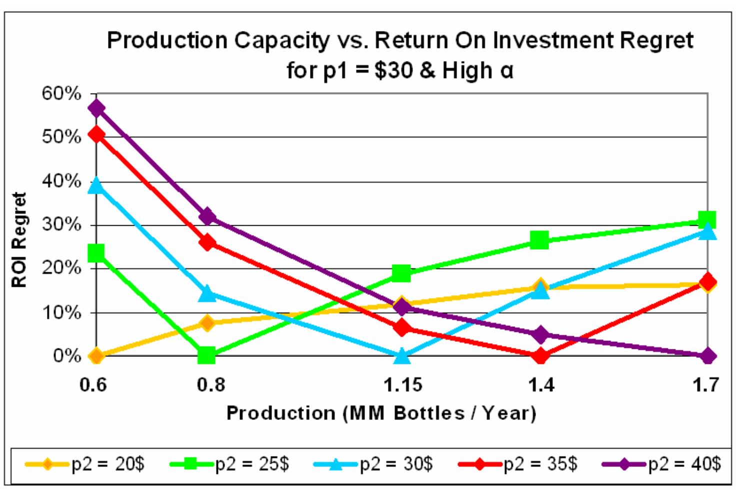

***Figure 37. Regret analysis as a function of production in millions of bottles per year.* The scenarios are identified by a range of varying prices for the competitor's product**.

Figure 37 compares the regret for each production in terms of ROI over the various competition pricing scenarios. This regret is shown as a function of production of millions of bottles per year. Each production has zero regret for one of the pricing scenarios. The lowest maximum regret represents the optimum production size given a varying competition price. Table 14 summarizes these results to show the numerical values generated.

Table 14. Scenario comparison for regret analysis of ROI as a function of production.

Optimum Scenario Comparison					
Production = 1.15 MM bottles / year & p_1 = $30					
p_2 ($)	ROI	NPW ($)	TCI ($)	POT (years)	WC %
20	33%	21000000	64000000	6	67%
25	46%	27000000	59000000	5	64%
30	67%	35000000	51000000	5	59%
35	93%	42000000	45000000	4	53%
40	107%	45000000	42000000	4	50%

Risk analysis is now employed to identify the optimum scenarios for production of the life of the design. Production costs are assumed to have a 20% variance. The inferior and superior functions, alpha and beta, are assumed to vary 20% as well. The selling price of the competition is assumed to be $30 and is allowed to vary only by $10. Based on these assumptions, the following risk curves can be generated.

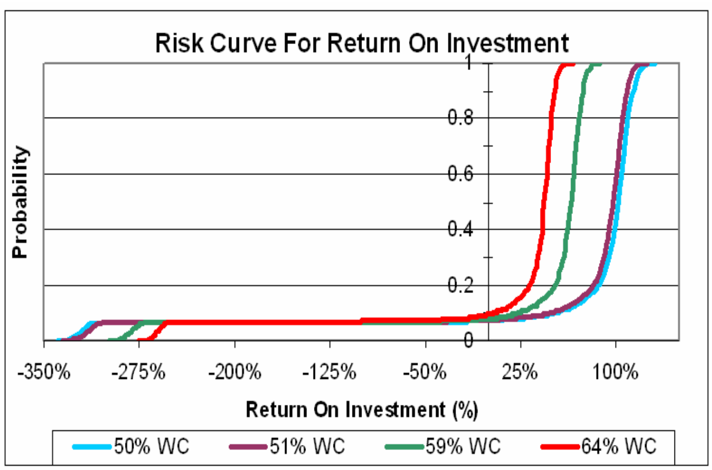

Figure 38. Risk curve generated for probability as a function of return on investment. **Each scenario is a variance in working capital.**

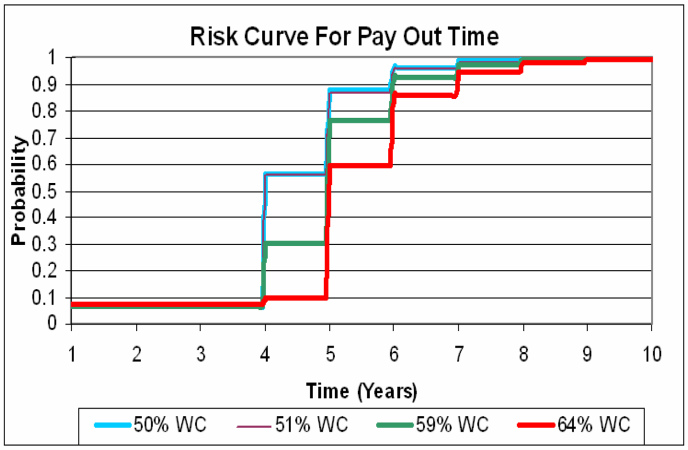

Figure 39. Risk curve of probability of pay out time in years. **Each scenario is a variance in working capital.**

Figure 38 shows the risk curves generated with respect to the return on investment. Each scenario is based upon varying percentages of working capital. Although all of the scenarios have large probabilities of losing money, there is still a potential for profitable ventures. The greater the working capital used, the less risky the venture is. After analysis, the optimum return on investment is found to be 102%. Figure 39 shows the risk curves generated when evaluating the designs pay out time necessary. As the working capital increases, the probability of increasing the amount of time required to break even increases. Therefore, a payout time of four years is found to be optimum for the pinot noir winery design proposed.

Conclusions

- The quality of wine can be evaluated and manipulated at negligible cost before bottling, and each bottle of wine can be engineered to maximize the profit of the producer. This evaluation is allowed by the identification and quantification of the consumer's utility and its relation to physical and easily manipulated characteristics.
- By the use of the demand model formed and the incorporation of the consumer's utility and preference function, a pricing model can be evaluated to maximize the producer's return on investment and profit by comparing the engineered product to that of the competition.
- Based upon the pinot noir winery design proposed, the optimum production capacity is found to be 1.15 million bottles per year with a selling price of $30. These values, when incorporated into the demand and pricing models, yield a return on investment of 102%, a net present worth of $44 million, and a pay out time of four years.

Future Work

The engineering of wine is a concept that involves a very broad scope as well as a depth that continues beneath what is apparent at any first glance. This particular design and concept presented is the beginning of a very complex and difficult problem. There are several questions that have been left unanswered, and require much further attention, consideration, and analysis. In order to better evaluate and build upon the concept of engineering wine and the demand model proposed, it is important that the characteristics in wine be predictable and able to manipulate.

An example of such a characteristic is the toasting effects of wine. Although there are several studies being currently conducted within the wine industry, with a chemical engineering background and the technology available to students, it would be very beneficial to develop models that describe the convection of heat through the wood, the effects this has on the breakdown of the lignin and hemicellulose, and the rate at which the compounds are released to the wine. Similar models have been produced by chemical engineering capstone groups when evaluating the process of aging scotch and whiskey. Wine, although more difficult and complex, could definitely be evaluated with the help of programs such as FLUENT.

Continued evaluation and study should be employed in the evaluation of the aftertaste and finish of the wine. Although this step in the consumer's evaluation of wine is last and an overall opinion, it is very influential in the lasting impression the wine gives. Diffusions, absorption, and the effects of the bouquet on the oral evaluation should all be accounted for within this particular model as well as the individual taste evaluation.

Further optimization should be addressed as well within this model. Resources, equipment, and location were all chosen based on current market conditions and the availability of supplies from large companies. It would be very beneficial to this model to model an optimization program that could optimize the place from which resources are gathered, the exact location of the potential winery and/or vineyard when considering markets, climate, and logistics, as well as the optimum consumer of which to sell the product.

Although this particular project is submitted as a final product, it is hoped that it is the beginning of what might be a very profitable venture, not only in terms of money and technology, but a great learning experience. Wine truly presents a difficult task to all who try to identify and manipulate the very characteristics that set it aside as the unique sensory experience into which it has evolved.

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