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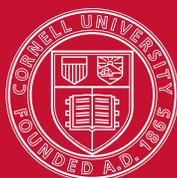
Cornell Hospitality Report

Optimizing a Personal Wine Cellar

by Gary M. Thompson, Ph.D., and Stephen A. Mutkoski, Ph.D.

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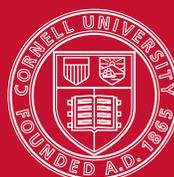
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Cornell University
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Optimizing a Personal Wine Cellar

by Gary M. Thompson and Stephen A. Mutkoski

EXECUTIVE SUMMARY

This report takes what we believe to be the first scientific approach to optimizing a personal wine cellar. We identify the key factors related to optimizing a personal cellar: performance metrics, such as drinking the best possible wine; constraints, such as budget and cellar capacity; and decisions, specifically what to buy and when to consume the purchased wines. We describe the Personal Wine Cellar Optimizer, which is a tool designed to identify the optimum cellar management plan. Using scenarios differing in cellar capacity, cellar life, and wine budget, we examine how the constraints affect the optimal cellar management plan. Using an example of a real cellar, we also illustrate how the recommendations can be used to improve the cellar management. This report is cosponsored by The Vance A. Christian Beverage Management Center, Cornell University School of Hotel Administration.

ABOUT THE AUTHORS



Gary M. Thompson, Ph.D., is professor of operations management at the Cornell University School of Hotel Administration (gmt1@cornell.edu), where he teaches undergraduate and graduate courses in service operations management. His research, which focuses on wine cellars, restaurant operations, scheduling conferences, and on workforce staffing and scheduling, has appeared in a number of outlets. He has consulted for several prominent hospitality companies and is the founder and president of Thoughtimus, Inc., a small software development firm focusing on scheduling products. In his free time, he enjoys music and fine red wine.

Stephen A. Mutkoski, Ph.D., is Banfi Vintners Professor of Wine Education and Management, Beverage Management Center, Cornell University School of Hotel Administration (sam29@cornell.edu). A former food and beverage manager and restaurant owner, Mutkoski teaches several food and beverage management courses at Cornell. Additionally, he conducts food and beverage management executive education seminars and lectures on wine throughout the world. With Patricia Mutkoski, he has developed and published a series of interactive multimedia training and educational programs on the wine producing regions of the world called *The Wine Professor*®. The author of two distance learning courses: "Foodservice Management Systems: Issues and Concepts," and "Foodservice Management Systems: Operations," he also serves as a food and beverage management consultant to several hotel, restaurant, airline and cruise line companies. In 2006 the European Wine Council honored Mutkoski with its Wine Educator of the Year award.



Optimizing a Personal Wine Cellar

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Wine, a simple pleasure but a complex substance, has been called the “elixir of life.”¹ Consumption of wine in the United States has been growing for at least 13 years, passing the 250 million case mark in 2006,² perhaps in part as a result of the purported health benefits of moderate consumption.³ While most of the wine that is purchased in United States is consumed within two days of its purchase,⁴ many wine drinkers “graduate” to having their own wine cellars. Indeed, by one estimate nine of ten homes in high-end areas of major U.S. cities have wine cellars.⁵

¹“Could Red Wine Be The Elixir Of Life,” *Time*, Nov. 05, 2006 (www.time.com/time/magazine/article/0,9171,1555109,00.html)

²“Wine Market Council’s 2006 Consumer Tracking Study,” as reported on www.winemarketcouncil.com/research_summary.asp

³ See, for example, www.winepros.org/wine101/wine-health.htm.

⁴ Though we have been unable to find an original citation for the amount, figures reported range from 80 percent in: Frank J. Prial, “WINE TALK; Starting a Cellar: A Closet Will Be Fine,” *New York Times*, December. 1, 1999) to 98 percent (www.theworldwidewine.com/Wine_trivia/How_many_wine.php).

⁵ Annika Mengisen, “What’s Hot Now: A Wine Cellar in Your Home,” *TheStreet.com*, July 19, 2007.

People develop wine cellars for a variety of reasons, but the chief reason is that many wines improve greatly with age. This motivates some people to cellar wine because it enables them to drink better (more fully developed) wine than is available from local wine merchants. Some purchasers are motivated by the prospect of using wine as an investment. Others want a variety of wine on hand so they can pick the right wine for any occasion. Others cellar wines because they are collectors, and a collection of wine can be visually pleasing. Others cellar wine so that they can impress people with the extent and quality of their wines.

Wine cellars can range from a few bottles under the stairs to elaborate rooms and extensive collections. Stand-alone cellars that hold from dozens to hundreds of bottles can be purchased from a variety of manufacturers, and custom cellars are available from a large number of vendors. It is not unusual for home cellars to run in the thousands of bottles.⁶

This report focuses on optimizing a personal wine cellar. By optimizing, we mean making choices about what to buy, hold, and drink, so as to best accomplish one's objective of drinking both the best possible wine and a variety of wine. Complicating the decisions are factors such as one's budget, one's tastes, and the life, storage capacity, and storage conditions (temperature and humidity levels) of one's cellar. To date, little has been written that is directly relevant to cellar optimization, and the advice that is available tends to be generic. In contrast, we take what we believe is the first scientific approach to optimizing a personal wine cellar.

In the remainder of this report, we first examine the factors related to optimizing a personal wine cellar, including the guidelines currently available. We then give a brief description of the Personal Wine Cellar Optimizer developed by author Gary Thompson. Following that, we present sample scenarios, based on budget and cellar capacity, which show how the ideal cellar composition varies, based on

⁶ Bill Slocum, "House Wine Gets Its Own Room; And What a Room! From Big-Screen TV's to Tuscan Hardware, Cellars Are Getting Grander," *New York Times*, December 5, 2007; Angelo Ragaza, "Serious Wine Buyers Need Serious Wine Cellars," *Forbes*, January 26, 2001.

certain characteristics. Finally, we conclude with a short discussion of the factors that affect wines but are nevertheless outside the scope of this report.

Factors in Optimizing a Personal Wine Cellar

We have seen little specific guidance regarding optimizing a wine cellar. The advice that is available focuses more on cellar size⁷ and general suggestions about composition such as balancing everyday (short-hold) and age-worthy (long-hold) wines,⁸ or having the majority of the cellar being everyday wines.⁹ Software packages are available for assisting the management of a cellar (an excellent list is maintained by Bay Country Liquors¹⁰), but these are largely just tools for tracking the inventory of wine in the cellar. In the words of one expert "there are no hard and fast rules about the composition of a wine cellar."¹¹

We take a more scientific approach to the issue of optimizing the management of a personal wine cellar. From our perspective, there are three main components related to cellaring wine—performance criteria, constraints, and decisions. We describe each below.

Performance criteria. The performance criteria are the metrics one might use to judge whether one is managing the cellar effectively. Obviously, the relative importance of the criteria will vary from person to person, and some criteria may not be relevant for some wine drinkers. The criteria include the following:

- *Drinking the best possible wine.* This criterion incorporates drinking every bottle of wine at or close to its peak quality. However, not all wines reach the same level of

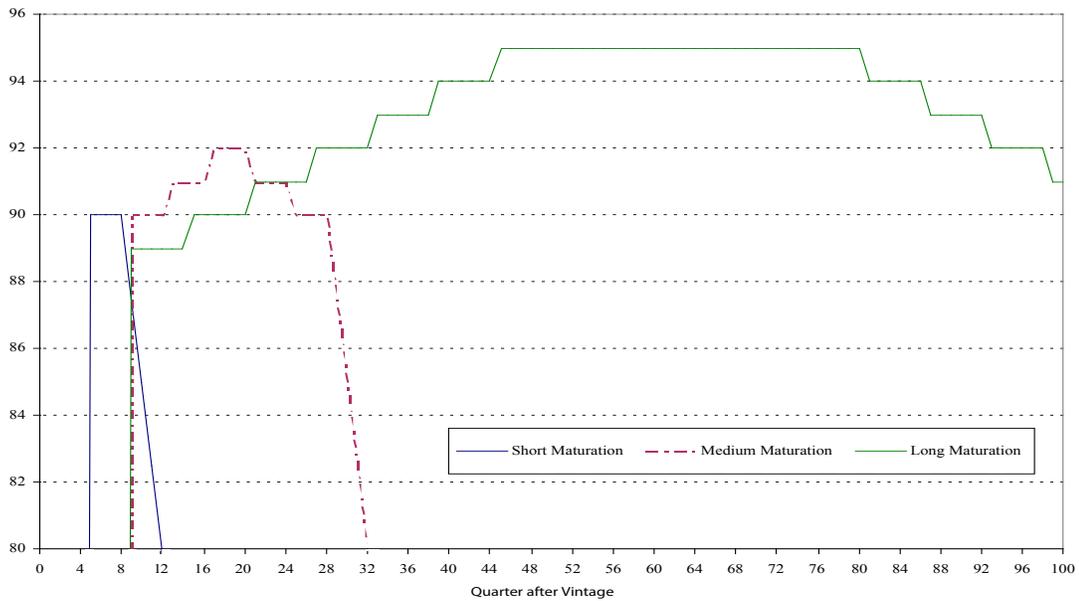
⁷ Jeff Cox, *Cellaring Wine: A Complete Guide to Selecting, Building, and Managing Your Wine Collection* (North Adams, MA: Storey Publishing, 2003).

⁸ Ed McCarthy and Mary Ewing-Mulligan, *Wine for Dummies*, 4th Edition, (Hoboken, NJ: John Wiley & Sons, 2006), pp. 317-219.

⁹ Robert Joseph & Margaret Rand, *KISS: Guide to Wine* (New York: DK Publishing, 2000), p. 144.

¹⁰ www.baycountryliquors.com/softlink.htm

¹¹ Peter D. Meltzer, *Keys to the Cellar: Strategies and Secrets of Wine Collecting* (Hoboken, NJ: John Wiley & Sons, 2006), p. 10.

EXHIBIT 1**Sample drinkability curves for short-, medium, and long-lived wines**

quality at maturity, and this criterion incorporates that factor.

- *Drinking wines of different types.* Few wine drinkers only want to drink the same type of wine—heavy red or sweet white, for example. Most wine drinkers have preferences for certain types but, within their preference range, wish to have a mix of types in what they drink.
- *Drinking wines from different regions.* Some wine drinkers prefer to drink wines only from specific geographic regions, such as Bordeaux, Barossa Valley, or Sonoma Valley. Others prefer to drink wines from a variety of regions—to compare and contrast Syrah or Shiraz from different wine growing regions, for example.
- *Drinking a variety of wine.* This criterion is designed to capture the idea that, even if a person wanted to drink, for example, only Australian Shiraz or Californian Cabernet Sauvignon, she would still like a mix of vintages and vineyards. Rare is the wine drinker who wishes to drink the same wine day after day, even if the wine is exceptional.
- *Meeting targets on the composition of the wine consumed by time of year.* Some wine drinkers prefer to drink the same type of wine year around. Others prefer to vary their wine consumption, based on such things as weather. They might, for example, drink a higher percentage

of white wine in the summer than at other times of the year.

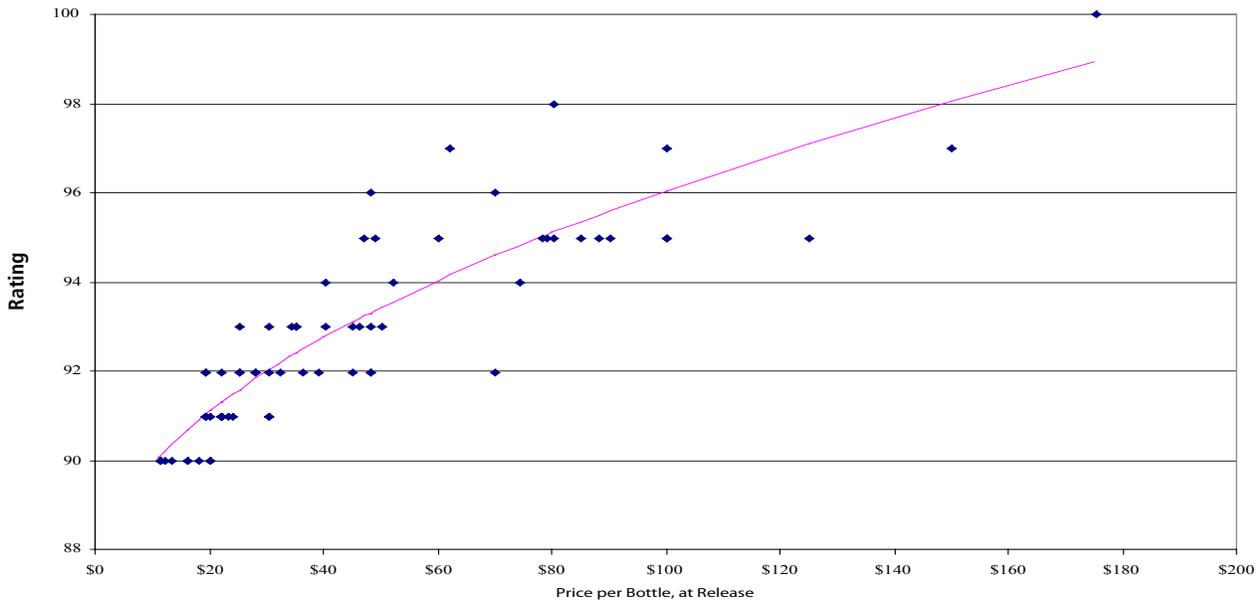
- *Profiting on the sale of wine.* This criterion would apply only for people who treat their cellar as an investment. In attending a wine tasting of Bordeaux wines, the authors were treated to the following advice by a wine grower from the area: “Always buy three cases—one to drink over time to identify when the wine has reached its peak; the second to enjoy at its peak in a party with one’s friends; and the third to sell on the auction market to generate funds to repeat the process.” While this may be sound advice, it may be impractical for many people for reasons of space and budget. This leads to our discussion of constraints.

Constraints. Constraints are the factors that potentially limit how well the criteria can be achieved. The constraints include:

- *Available storage space and storage conditions.* One’s cellar may have space for both short-term and long-term holds, or all the wine may be held together and not separated based on the length of time it will be cellared. Another storage option is off-site storage rented on a per-case basis. If wine is stored in a non-climate-controlled space it will mature at a different rate than that of wines stored in a temperature and humidity controlled cellar.

EXHIBIT 2

Wine Spectator rating of red wines in its top list of 100 wines of 2007, by function of price



Monthly wine budget. We distinguish the budget for the initial “fill” period and the later “maintenance” period. For many people, these may be the same amount. The level of flexibility in the budget is also important—for example, if the monthly limit must be adhered to every month, or if the monthly expenses could exceed the budget as long as the budget was observed on a quarterly basis.

Wine preferences. These constraints include limits on the types of wines consumed, by time of year if appropriate. Preference constraints also include limits on the wines from different regions consumed, also by time of year if desired.

Each wine’s drinkability curve. A drinkability curve depicts a wine’s anticipated performance. The curve represents a profile of how the wine improves and declines in quality as it ages. Some wines, such as Beaujolais, reach their peak of quality early, within one or two years of the vintage, and then decline in quality rapidly. Other wines, such as Bordeaux, take a long time—ten or more years from the vintage—to reach their peak, and then decline slowly. Yet others, such as Zinfandels, peak within about five years of the vintage. Exhibit 1 shows examples of drinkability curves for short-, medium-, and long-maturation wines.

Wine prices. In general, spending more money per bottle will allow one to purchase better wine. Consider, for example, the top 100 wines of 2007 published by *Wine Spectator*.¹² Exhibit 2 shows the relationship between suggested retail price at release and the score assigned by *Wine Spectator* in blind tastings, for red wines in the top 100 of 2007. In testing various relationships between price and rating score, we found the following to best predict the rating score of red wines in the top 100 list of 2007:

$$\text{Wine Spectator Rating} = 87.103 + [0.89535 * \sqrt{\text{Price per Bottle, at Release}}]$$

This relationship, which is represented as the line in Exhibit 2, explains 79 percent of the variation in the rating score.¹³ In practical terms, for the top 100 wines at least, paying more does improve the quality of the wine, though at a less-than-linear rate. (As expressed in the above equation, paying more increases the rating score with the square root of the price). As an example, the predicted score of a \$20 wine is 91.1 (think of this as an average score of \$20 red wines in the top 100 list), while the predicted score of a \$40 wine increases to 92.8.

¹² www.winespectator.com

¹³ The adjusted R² of this relationship is 0.7904. The relationship is significant at the p < 0.001 level.

- 🍷 *Wine types.* Constraints on wine types can include such things as limits on the percentage of wine of certain types—heavy red or sweet white, for example. There may be both upper and lower limits, and the limits may change over the course of the year. For example, one may desire to have between 35 percent and 50 percent of the wines one drinks in the summer be dry whites, but limit such wines to between 5 percent and 10 percent of the wine consumed in the winter.
 - 🍷 *Wine origins.* As with wine types, one may wish to limit the amount of wine consumed by region. There may also be upper and lower limits on the consumption. For example, one may wish to limit red Burgundies to between 20 percent and 40 percent of one's consumption.
 - 🍷 *Purchase quantities.* Once a person has a wine cellar, it becomes common to purchase multiple bottles of a wine, rather than only single bottles. Having multiple bottles of the same wine allows one to taste the wine over time, seeing how it develops and ensuring that at least some bottles are consumed at their peak. Another reason to buy more than a single bottle of each wine, particularly for good wines, is that a person may wait too long for an occasion that's "special enough" to merit opening that one outstanding bottle. Then when it is opened, it may be past its peak. Despite the advantage of purchasing multiple bottles of the same wine, a small cellar or a small budget means that purchasing a case (12 bottles) of the same wine can limit the variety of wine one can hold. In such situations, it may be preferable to purchase quantities of less than a case—three or six bottles at a time, for example.
 - 🍷 *Wine availability.* Wine quality varies from year to year, largely depending on growing conditions. This variation in quality means that prices can likewise vary from year to year. If one's budget is fixed, then one may have to tolerate purchasing wines of different quality every year or shift to purchasing from different wine regions. In addition, the more tightly constrained a person's budget, the fewer the wines of a particular rating will fall within that budget. Thus, one might have to accept drinking the same wines more frequently in tight budget situations.

Wine is generally available for only a limited time after its release. Typically, higher-rated wines disappear faster than lower-rated wines. Besides purchasing after release, wine buyers can purchase some wines before they are released. These programs, known as "pre-release" or "futures," typically are available only for higher-end wines. Back-vintage wine can also be purchased on the auction market, well after its initial release. Using the auction market can enable a person to jump start a cellar, but some cellar owners prefer to perform all the cellar-ing themselves, to ensure the wine is always stored in appropriate conditions.
 - 🍷 *Existing cellar stock.* Certainly the existing inventory of wine in one's cellar is a constraint to be considered when deciding what to purchase. Certain vintages, types, or regions may be over- or underrepresented, and one's cellar may be close to, or a long way from its capacity.
 - 🍷 *Time horizon.* The time horizon is the length of time one plans to keep a cellar. There are three phases in cellar management—building, maintenance, and decline. In the building phase, more wine is being put into the cellar than is being removed. In the maintenance phase, the cellar is in balance, with the volume of wine being removed equaling the amount being stored. Finally, in the decline phase, more wine is being consumed than saved. The length of these phases will vary with the amount of time one plans to keep a cellar, and the decline phase may not actually occur at all, if the cellar is being managed in perpetuity. Moreover, a person starting a cellar at age 30 will have different strategies than a person starting one at age 60.
 - 🍷 *Bottle sizes.* Many wine drinkers purchase wine in regular-sized bottles holding 0.75 liters. However, one may wish to purchase wine in half-bottles (0.375 litres), magnums (1.5 litres), jeroboams (3 litres), or methuselahs (6 litres). All of the constraints described above may be imposed, as appropriate, for each size of bottle. In general, larger bottle sizes slow the maturation rate of the wine.
- Decisions.** The decisions related to optimizing a personal wine cellar involve identifying the optimal purchase, holding, and consumption policies given the constraints and criteria. Decisions include the following:
- 🍷 *Recommended amount of wine purchased, by month, by type.* This decision commonly has two primary components. First, there are the initial stocking decisions for the cellar. Second, there are the ongoing decisions of what to purchase to replace what has been consumed.
 - 🍷 *Recommended wine consumption, by month.* While one can and should deviate from a plan, a recommended consumption plan is useful, because it is designed to allow the cellar owner to drink each wine at or near its peak. Allowing a special wine to go well past its peak is one of the niggling missed opportunities of life.
 - 🍷 *Recommended cellar composition, by month.* The cellar composition is, in fact, determined by the wine

EXHIBIT 3**Wine options in the sample scenarios**

Maturation	Maximum Score	Price per Bottle	Purchase Quantity (bottles)
Short	90	\$10.47	12
Short	91	\$18.94	12
Medium	92	\$29.91	6
Medium	94	\$59.33	3
Long	95	\$77.80	3
Long	97	\$122.19	3

purchases and consumption. Nonetheless, it is useful to examine the cellar composition in the optimal cellar management plan, since it will offer insight as to the amount of wine on short-, medium- and long-term holds.

Identifying the decisions that yield an optimal wine cellar management plan is worth doing, because of the complexity of the constraints and criteria. The next section describes how it was accomplished.

Personal Wine Cellar Optimizer

Professor Thompson constructed an optimization engine for managing personal wine cellars. This engine, which we call the Personal Wine Cellar Optimizer, currently resides in an Excel spreadsheet, and is implemented using Visual Basic for Applications. The Excel spreadsheet allows the data to be organized, with typically one sheet used for each constraint.¹⁴ At its core, optimizing the wine cellar is essentially a scheduling problem, with the key schedule components being the purchase and consumption of wine. The sidebar at the end of this report gives an overview of how the optimizer works.

The task involved in optimizing a wine cellar is deceptively complex. As a comparison of this complexity, consider the game of chess. Chess is a game of considerable strategic complexity, but it has just sixteen pieces, and each of those pieces has a relatively small number of possible moves. Moreover, every move in chess has but a single criterion—that being to achieve checkmate. By contrast, in a wine cellar, if each bottle of wine is analogous to a piece, there are easily hundreds of options. Although the “moves” in this instance are nothing more than wine purchase and wine consump-

¹⁴ Professor Thompson has extensive experience building optimizing engines, including optimizers for restaurant table mixes (www.hotelschool.cornell.edu/research/chr/pubs/tools/tooldetails-14044.html), workforce staffing (www.hotelschool.cornell.edu/research/chr/pubs/tools/tooldetails-14603.html), workforce scheduling, conference scheduling, university course scheduling, and course scheduling in corporate and government training environments (the last three at www.thoughtimus.com).

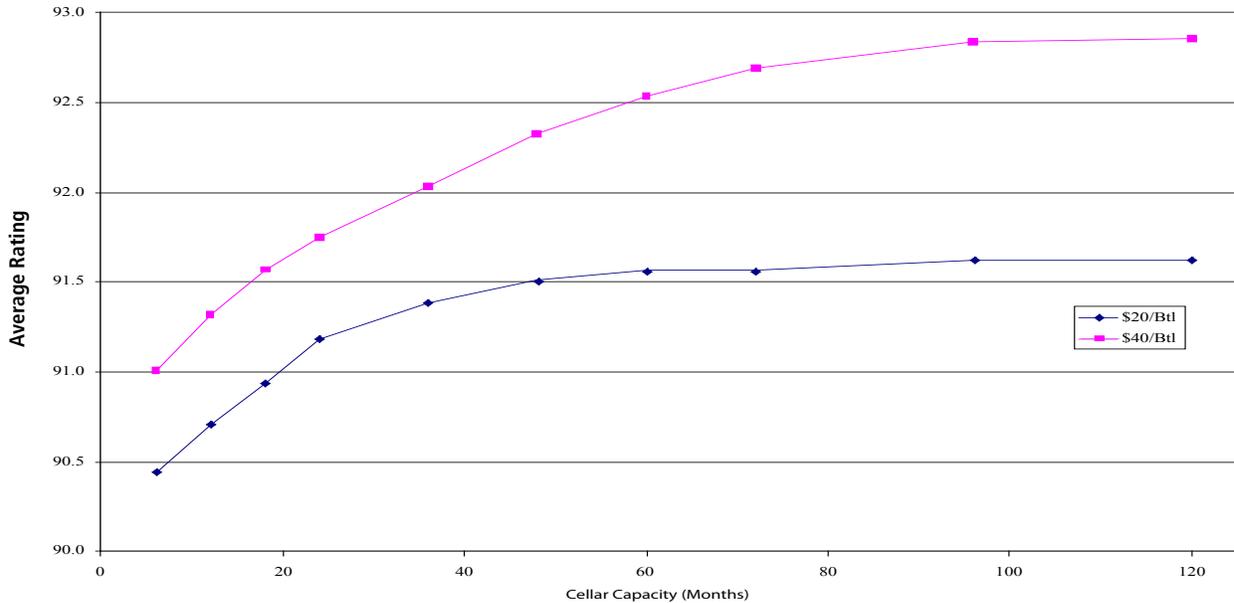
tion, with many bottles there are many alternatives. Finally, we have already described the extensive range of criteria that can be relevant in cellaring wine. Compared to optimizing a wine cellar, then, playing chess is easy.

Personal Wine Cellar Scenarios

In this section, we present the results from twenty scenarios, which we selected to illustrate how the constraints affect the optimal cellar management plan. We made certain assumptions for the twenty scenarios, although none of these are a requirement of the Personal Wine Cellar Optimizer. Our aim in making these assumptions is to keep the scenarios relatively simple. These assumptions are as follows:

- the cellar has a life of 20 years;
- the cellar starts empty;
- the cellar finishes empty at the end of its life;
- the owners consume 30 bottles of wine per month from the cellar;
- wine is cellared only for consumption, not investment resale;
- only red wine is consumed, in standard-sized 750-ml bottles;
- wine availability is consistent across years;
- wine is available for purchase within one year of its initial release;
- no aged (back-vintage) wine is purchased on the auction market;
- future budget increases match wine cost increases;
- no additional funds, other than the monthly budgets, are available to stock the cellar (which means there is no additional “initial stocking” budget available);
- the monthly wine budget can be exceeded by up to 30 percent, but the budget must be observed every quarter;
- short-hold wines are those that will be consumed within one year of purchase, medium-hold wines are consumed between one and five years of purchase, and long-hold wines will be cellared at least five years before being consumed;
- the only criterion that matters is the quality of the wines consumed; and
- six wine types are available every year, having the drinkability curves shown in Exhibit 1, with prices and purchase quantities reported in Exhibit 3.

As Exhibit 3 shows, we allow smaller purchase quantities for the more expensive wines, since the monthly wine budget could preclude purchasing the more expensive wines in cases of 12 bottles. The price-per-bottle values in Exhibit 3 were calculated using the relationship identified earlier for

EXHIBIT 4**Average rating score at time of wine consumption by cellar capacity and budget level**

price and rating score of the red wines in *Wine Spectator's* top 100 list for 2007. Obviously, depending on the available budget, not every wine type would be purchased every month.

The twenty scenarios we examined are based on two levels of budget and ten levels of cellar capacity. We examine cellar capacities of 6, 12, 18, 24, 36, 48, 60, 72, 96 and 120 months of consumption (i.e., capacities of 180, 360, 540, 720, 1,080, 1,440, 1,800, 2,160, 2,880, and 3,600 bottles) and budgets of \$20 and \$40 per bottle.

Exhibit 4 illustrates the effect on the average rating of the wine consumed for the several cellar capacities and budgets. As expected, the higher budget of \$40 per bottle enables the consumption of better wines, regardless of cellar capacity. In general, increasing the cellar capacity also enables the consumption of better wines. Perhaps the most interesting feature of both the budget levels is that there is a point where further increases in cellar capacity offer little or no improvement in the quality of wine consumed. With the lower budget level, wine quality essentially reaches its maximum with a cellar capacity of about 5 years (60 months) of consumption (= 1,800 bottles), while the maximum quality for the higher budget is reached at a cellar capacity of approximately 8 years of consumption (96 months, or 2,880 bottles). Obviously, then, cellar capacity and wine budget are

two key factors influencing the quality of wine that can be consumed, and wine quality improves to the greatest extent if both can be increased.

As might be expected, the ideal wine consumption changes across the budget levels and cellar capacities. The ideal consumption plans are illustrated in Exhibit 5. These plans are aggregates over the twenty-year life of the cellar. Later we illustrate how the consumption of wine changes over time. The data in Exhibit 5 show that, in general, as the capacity of the cellar grows, medium-hold and long-hold wine are substituted for short-hold wines. In other words, consumption of medium-hold and long-hold wines increases, while there is a decrease in the consumption of short-hold wines. The exhibit also illustrates that at the higher wine budget, this replacement occurs more rapidly. We note, though, that the ideal consumption plans illustrated in Exhibit 5 are averages across the entire twenty-year life of the cellar, and will be different with longer or shorter cellar lives.

An interesting phenomenon is how the ideal cellar composition changes over time, for a particular budget and cellar-capacity scenario. An example of this is shown in Exhibit 6, for a cellar with 24 months of capacity (= 720 bottles) and a budget of \$20 per bottle. It is easy to identify phases in the life-cycle of the cellar, based on what is happening with the long-hold wines. The first three years (quarters 1-12) can

EXHIBIT 5

Total wine consumption by cellar capacity and budget level

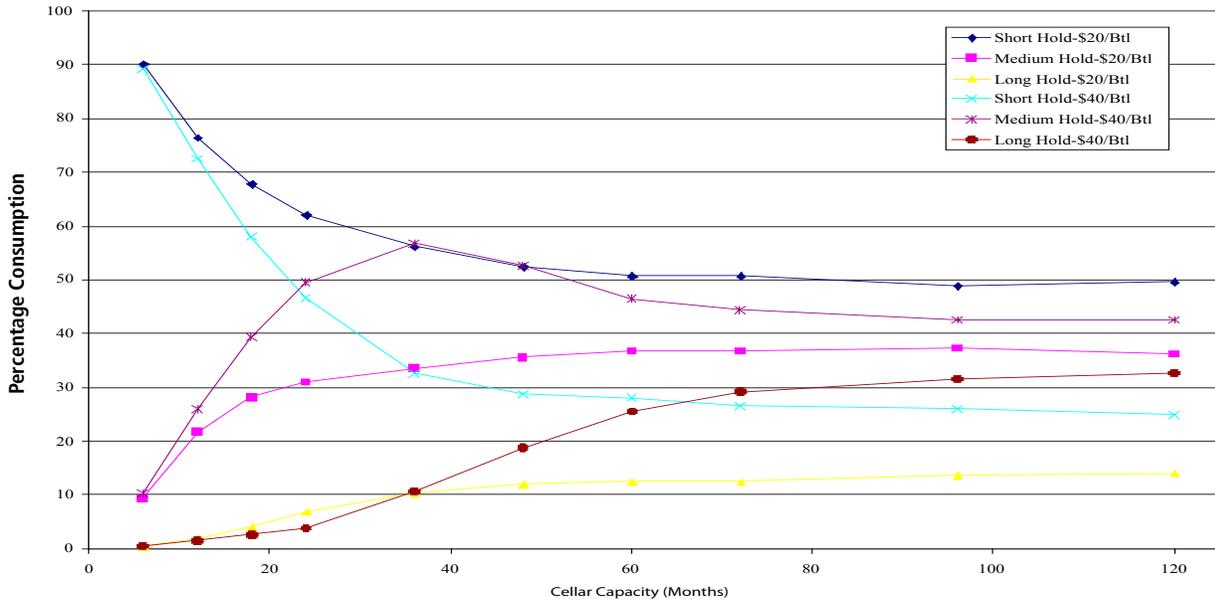


EXHIBIT 6

Cellar inventory composition over time for a cellar capacity of 24 months (720 bottles) and a wine budget of \$20 per bottle for a cellar with a 20-year life

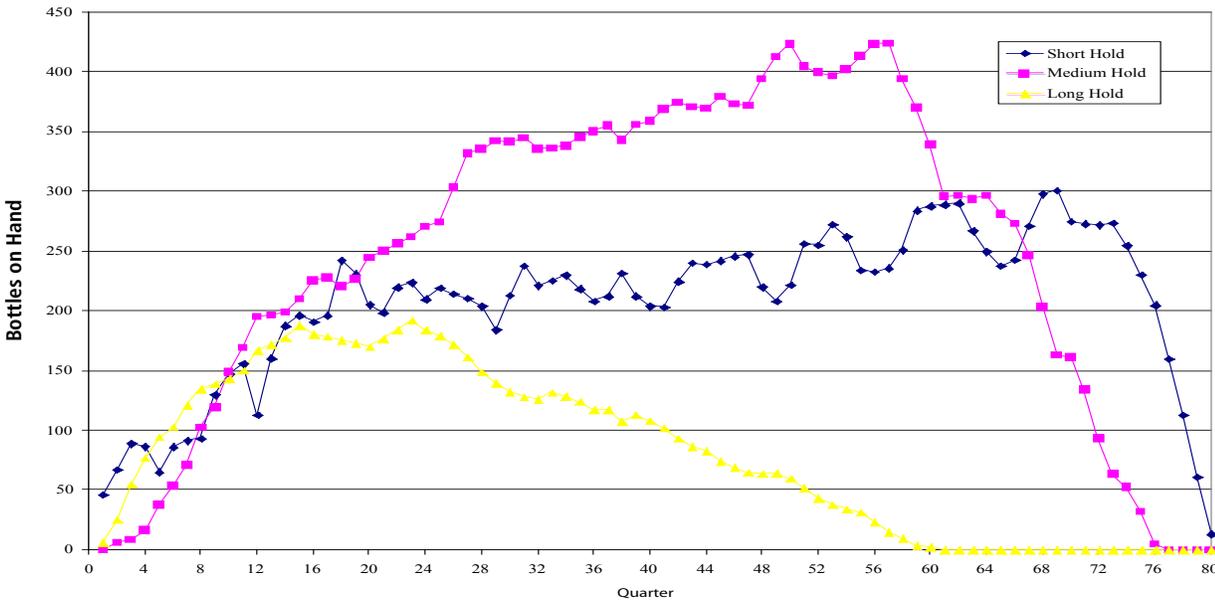


EXHIBIT 7

Wine consumption over time for a cellar capacity of 24 months (720 bottles) and a wine budget of \$20 per bottle for a cellar with a 20-year life

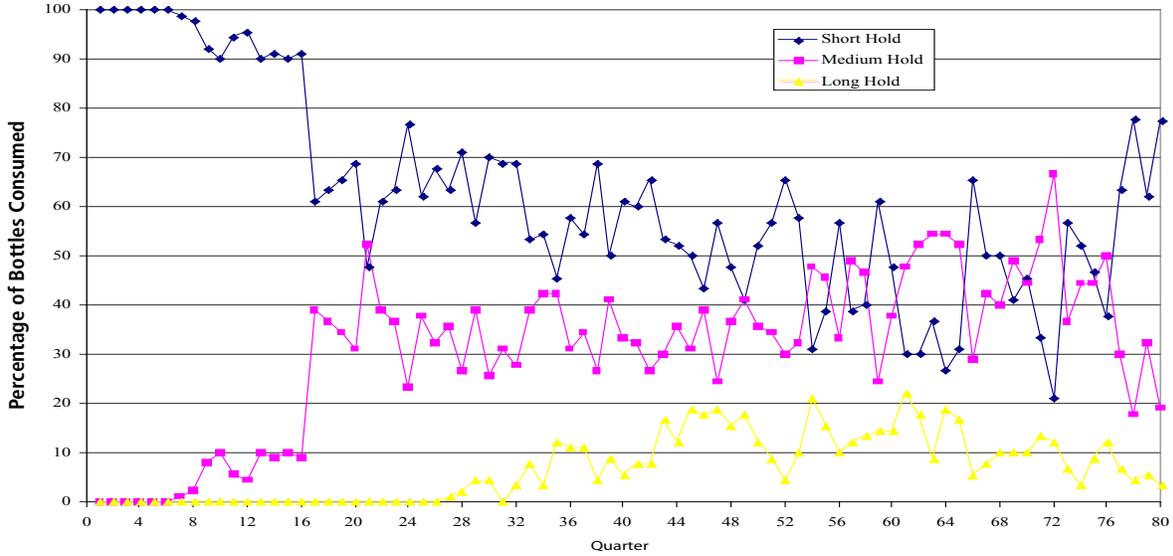


EXHIBIT 8

Wine purchases over time for a cellar capacity of 24 months (720 bottles) and a wine budget of \$20 per bottle for a cellar with a 20-year life

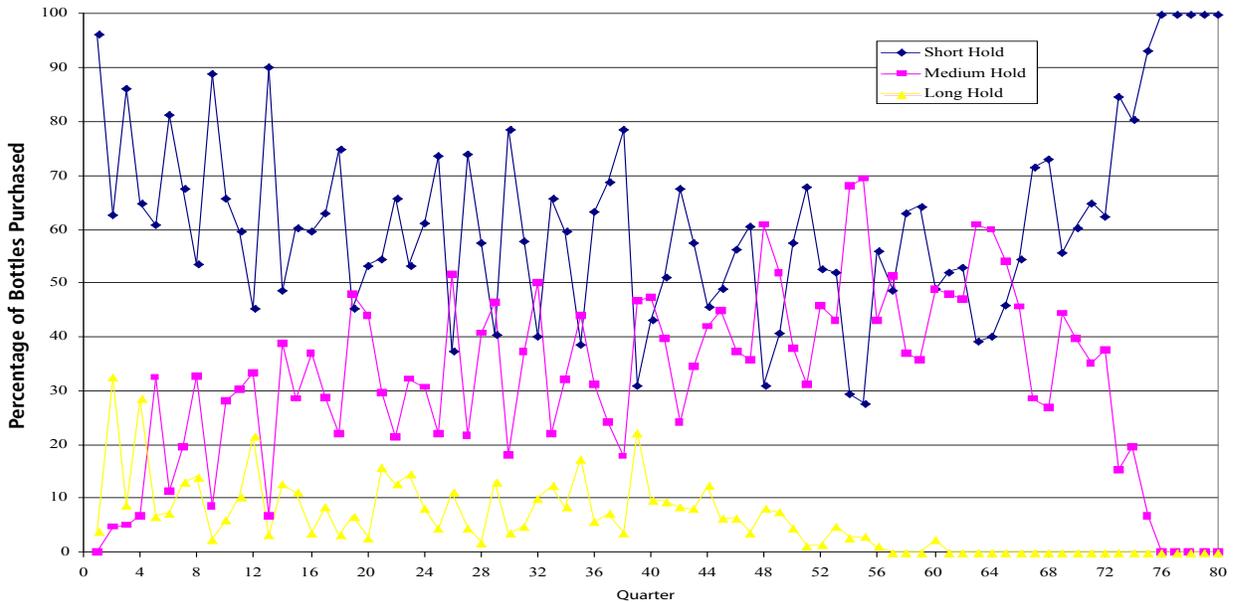
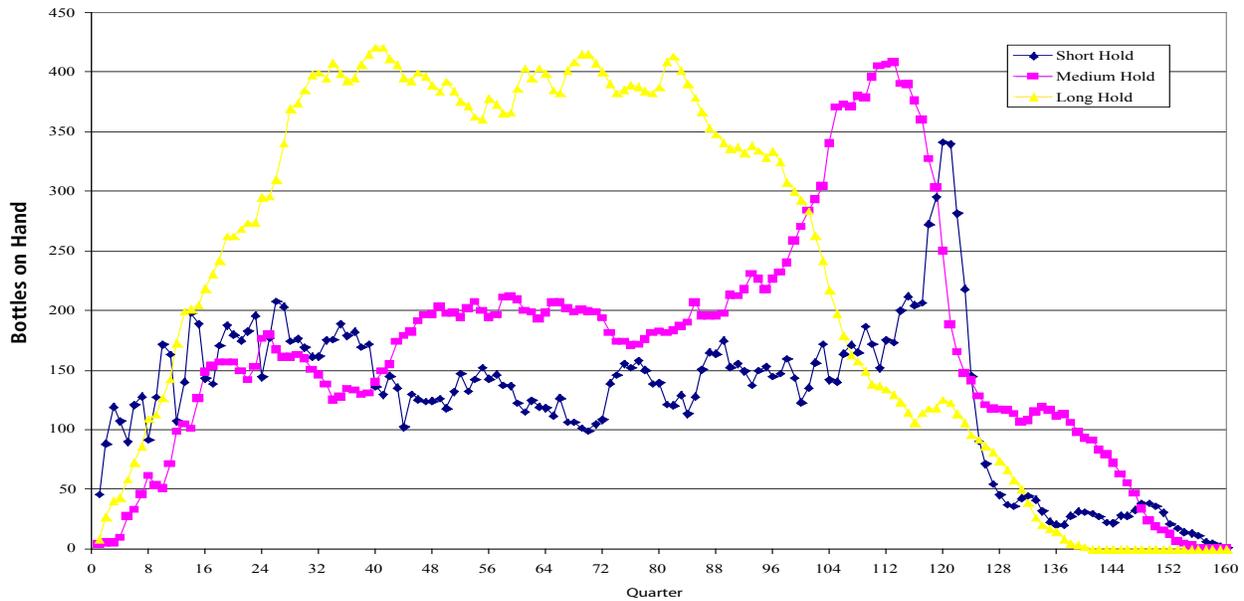


EXHIBIT 9**Wine inventory over time for a cellar capacity of 24 months (720 bottles) and a wine budget of \$20 per bottle for a cellar with a 40-year life**

be considered as the building phase of the cellar, since the inventory of short-, medium-, and long-hold wines are all increasing. Years three to six (quarters 13-24) could be considered as a maintenance phase, since during this period the long-hold (long-maturation wines) are in balance (as much is being added as is being consumed). We note, though, that the cellar inventory of medium-hold wines continues to increase through this period. Phase 3—decline—lasts fourteen years (quarters 25-80). In this phase, the long-hold wines that had been cellared early are reaching maturity and are consumed more rapidly than they are replaced. For the first part of phase 3, the medium-hold wines continue to increase, but in the end of the phase there is a net consumption of medium-hold and short-hold wines. Clearly, the length of the phases depends on the cellar life. Our outcomes would be different if the cellar life were changed from the twenty years of this scenario and the cellar was, say, being managed as an heirloom for the owner's children.

Exhibit 7 shows the consumption plan corresponding to the cellar inventory plan illustrated in Exhibit 6. In general, the consumption of short-hold wines starts high and declines as medium-hold wines come on line, and declines even further as long-hold wines come on line. At

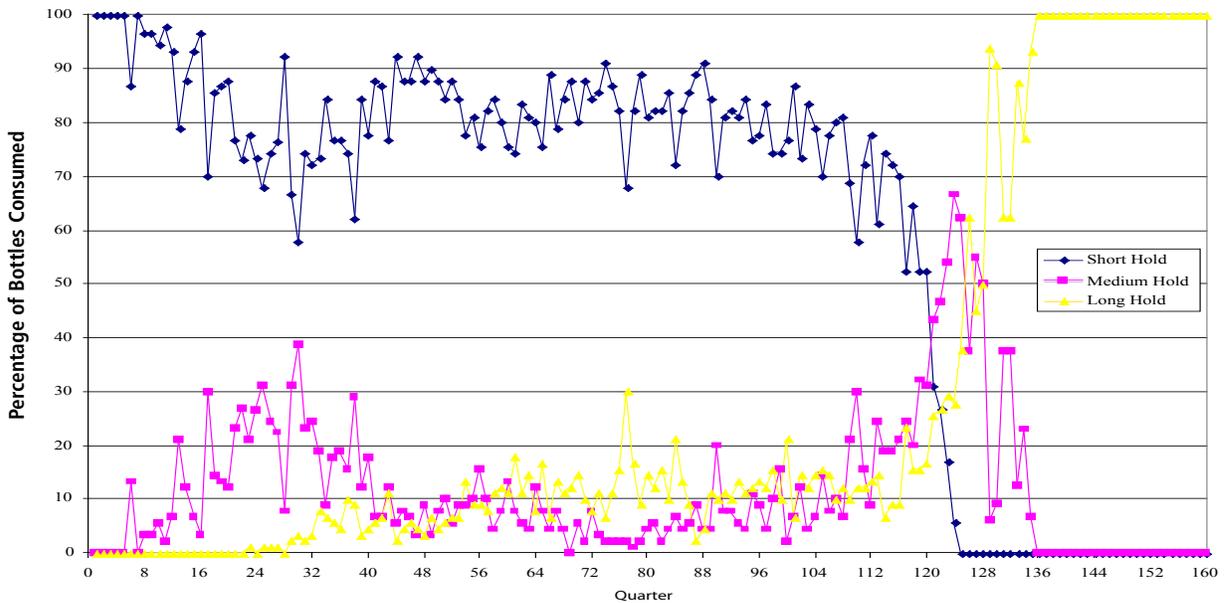
their peak, long-hold wines comprise about 15 percent of the consumption.

The purchase plan corresponding to Exhibits 6 and 7 is presented in Exhibit 8. Short-hold wines constitute the majority of wine purchases throughout the life of this hypothetical cellar. Long-hold purchases are the highest in the first year (excluding the first quarter), then settle in at about 10 percent of purchases. No long-hold wines are purchased in the last five years of the life of the cellar.

To explore how cellar life affects the cellar management plan, we repeated the analysis shown in Exhibits 6, 7, and 8 for a cellar with a forty-year life. A different management plan emerges, as shown in Exhibits 9, 10, and 11. As can be seen in Exhibit 9, the build phase now lasts about 8 years (32 quarters), since the long-hold wines are still increasing over that period. The maintenance phase lasts approximately 13 years (quarters 33-84), while the decline phase last approximately 19 years (quarters 84-160). Moreover, during the maintenance phase, much more of the cellar capacity is dedicated to long-hold wines in the forty-year cellar than in the twenty-year cellar. An interesting feature of the consumption plan shown in Exhibit 10 is that in the final two years of the cellar's life, only long-hold wines are consumed. Given the differences in plans across different cellar lives, our best

EXHIBIT 10

Wine consumption over time for a cellar capacity of 24 months (720 bottles) and a wine budget of \$20 per bottle for a cellar with a 40-year life



advice is to consider all the characteristics of a particular cellar when optimizing its management plan. Comparing the purchasing plans in Exhibits 8 and 11, one sees that with the longer cellar life, purchases of medium-hold and long-hold wines are more similar than in the short-lived cellar, where medium-hold purchases generally dominate the long-hold purchases.

Actual Cellar Example

This section illustrates the use of the Personal Wine Cellar Optimizer for an actual cellar. This cellar has a capacity of 33 months of consumption, had been in operation for one year at the time of the test, and at the end of the year was at 69 percent of its capacity. The wine budget is limited to the equivalent of \$28 per bottle, but additional funds were available in the “initial stocking” phase of twelve months. The same six price categories of wines listed in Exhibit 3 were used to identify the recommended cellar composition. Exhibit 12 shows how the actual cellar inventory compares to the inventory recommended by the Personal Wine Cellar Optimizer. While the cellar has about the right amount of long-hold wine, it is overrepresented with medium-hold bottles and underrepresented with short-hold wines. This becomes important in that the medium-hold wines will probably end up constituting more of the near-term con-

sumption than is ideal for maximizing the overall performance of the cellar.

The Personal Wine Cellar Optimizer can perform numerous analyses to assist with cellar management decisions. For example, one could compare the benefit of expanding the cellar to the benefit to be gained simply by using those funds to increase the monthly wine budget. Alternately, one could explore the option of building the cellar more quickly by allocating more funds during the build period than will be spent during the maintenance period.

Extensions and Other Considerations

There are a number of factors that are outside the scope of the analysis we presented. One important consideration is the “stellar vintage,” 2005 Bordeaux being an example, where the wines are reputed to be the best in a generation. Our inclination when such an opportunity occurs is to throw the budget out the window and buy as much of these vintages as one can stock. The Personal Wine Cellar Optimizer certainly can handle such “stellar years,” but the wisdom of such impulsive purchases remains to be tested.

Restaurants offer some interesting twists to the optimization of a wine cellar, as does the aim of treating a personal wine cellar as an investment and reselling the wines for a premium in the future. In the restaurant context, the key additional characteristics are the mark-ups on wine and the

EXHIBIT 11

Wine purchases over time for a cellar capacity of 24 months (720 bottles) and a wine budget of \$20 per bottle for a cellar with a 40-year life

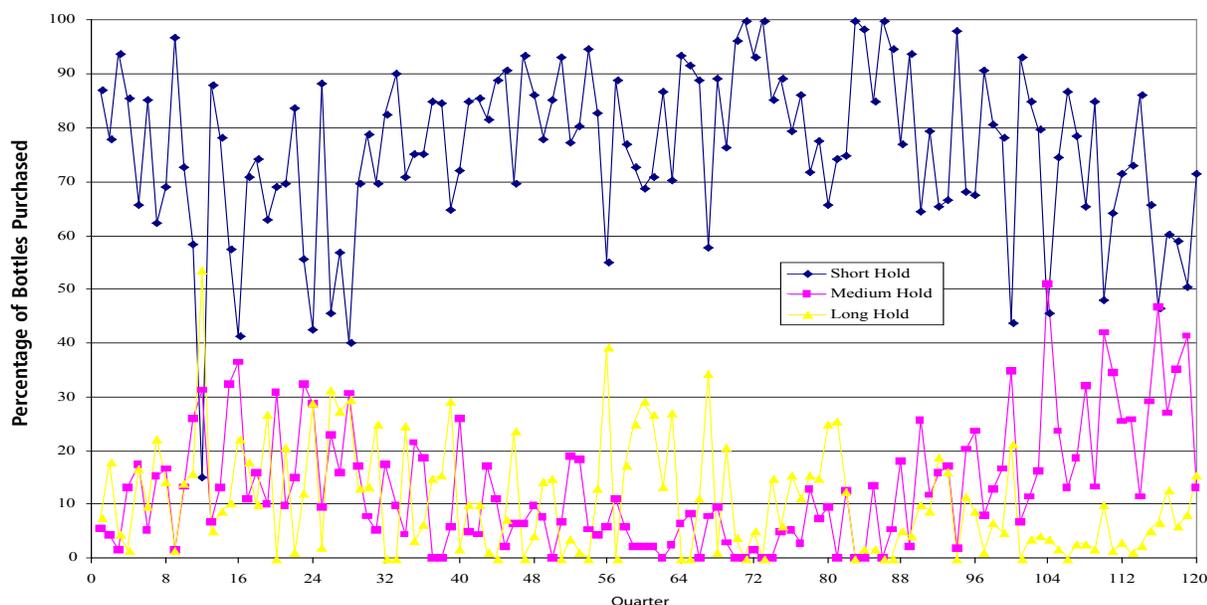


EXHIBIT 12

Differences between the recommended cellar composition and its actual composition

Maturation	Recommended Composition	Actual Composition
Short	29.7%	10.5%
Medium	18.9%	36.1%
Long	51.3%	53.4%

vagaries of customer demand. With personal investment cellars, the issue of what to buy is particularly important, since wines vary greatly in their appreciation over time. At present, the Personal Wine Cellar Optimizer is not suitable for these environments, but work is ongoing to extend the tool's capabilities.

Our objective in this report has been to show how one can manage a personal wine cellar scientifically, and by doing so improve the performance of the cellar. There are obviously many factors related to the cellar, and so the strategies for our sample cases should be considered as illustrative and not considered hard-and-fast rules. Ideally, one would develop a cellar management plan that is specific to the nuances of an individual cellar and the goals of and constraints on its owner. ■

How the Personal Wine Cellar Optimizer Optimizes a Wine Cellar

The Personal Wine Cellar Optimizer (PWCO) takes the existing cellar composition as its starting point. The PWCO then builds a purchase and consumption plan that observes all the hard constraints imposed by the budget and cellar capacity. Wines are selected for purchase randomly, but purchases are biased towards better value wines (i.e., higher quality and lower costs). Wine consumption is scheduled in a way that cellar capacity is not violated, but with a preference for drinking the wine at or near its peak, as well as spreading the consumption over time. Once a "plan" is complete, it is given a score based on how well it meets the relevant objectives. At that point, some of the plan is discarded, meaning that some of the planned purchases (and related consumption) are dropped, yielding a partial plan. A new plan is then constructed based on the partial plan. That plan is evaluated, and the process repeats.

The PWCO implements what might best be described as an "intelligent, but randomized search" for the best plan. The "intelligent" part involves the rules used to select wine for purchase and consumption (such as selecting high value wines). The randomness is important in ensuring that a variety of plans are developed (which would not occur without some element of randomness). The PWCO also implements a search process that allows it occasionally to accept an inferior plan, with the goal of later making further improvements. This allows the PWCO to avoid "local minima"—plans that might be superior to others that are similar, but that are not the best overall plan.

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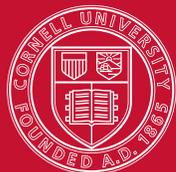
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