

CHAPTER 1**Introduction**

Life is stochastic. Anyone who works in business or finance today knows quite well that future events are highly unpredictable. We often proceed by planning for the worst outcome while hoping for the best, but most of us are painfully aware from experience that there are many risks and uncertainties associated with business endeavors. Even engineers who grew accustomed to calculating the precisely correct answer to textbook problems in school now realize that variation plays an important role in real-world problems.

Many analysts begin creating financial models of risky situations with a base case, constructed by making their best guess at the most likely value for each of the important inputs feeding a spreadsheet model, to calculate the output values that interest them. Often, they account for uncertainty by thinking of how each input in turn might deviate from the best guess and letting the spreadsheet calculate the consequences for the outputs. Such a “what-if” analysis provides insight into the sensitivity of the outputs to one-at-a-time changes in the inputs.

Another common procedure is to calculate three scenarios: best case, worst case, and most likely. This is done by inserting the best possible, worst possible, and most likely values for each key input, then calculating the outputs of interest for each of these scenarios. Such a scenario analysis shows the ranges of possibilities for the outputs, but gives no idea of the likelihood of output values falling between the extremes. Further, the ranges provided by scenario analysis can be misleading because it’s extremely unlikely that all of the inputs will be at their absolute worst (or best) case at the same time.

What-if and scenario analysis are good ways to get started, but there are more sophisticated techniques for analyzing and managing risk and uncertainty. This book is designed to help you use the software programs Crystal Ball® and Excel® to develop models for risk analysis. The spreadsheet program Excel has dramatically changed financial analysis in the past few decades, and Crystal Ball extends the capability of Excel by allowing you to add stochastic assumptions to your spreadsheets. Adding stochastic assumptions provides a clearer picture of the possibilities for each of the outputs of interest. Reading this book and following the examples will help you use Crystal Ball to enhance your risk analysis capabilities.

Throughout the book, I use the word *stochastic* as a synonym for *random* or *probabilistic*, and as an antonym for *deterministic*. The majority of spreadsheet models in use today are deterministic, but every spreadsheet user should realize that there is some degree of uncertainty about each of the inputs to his or her models. Crystal Ball enables you to use a systematic approach to account for uncertainty in your spreadsheet models.

The first six chapters of this book demonstrate how to use Crystal Ball. The remainder of the text provides examples of using Crystal Ball models to help solve problems in corporate finance, investments, and financial risk management. The appendices provide technical details about what goes on under the hood of the Crystal Ball engine.

This chapter is an overview of financial modeling and risk analysis. Some example applications are listed in the following sections, where these tools provide insights that might not otherwise come to light, and you get a glimpse of how easy it is to assess financial risk using Crystal Ball and Excel. For a simple model that is already built and ready to run, we will interpret the output and analyze the model's sensitivity to changes in its inputs. The chapter concludes with a discussion of the benefits and limitations of risk analysis with Crystal Ball and Excel. To learn more about general principles of risk analysis, see Aven (2003), Haines (2004), or Hertz and Thomas (1984).

1.1 FINANCIAL MODELING

For the purposes of this book, *financial modeling* is the construction and use of a spreadsheet depiction of a company's or an individual's past, present, or future business operations. To learn more about deterministic financial modeling, see Proctor (2004), Sengupta (2009), or Koller, Goedhart, and Wessels (2005). For each situation where we wish to use a stochastic model, we begin with a deterministic Excel model, then add stochastic assumptions with Crystal Ball to generate stochastic forecasts. By analyzing the stochastic forecasts statistically, we can make inferences about the riskiness of the business operations described by the model. The risk analysis process became much easier and more widely available with the introduction of Crystal Ball to the marketplace in 1987.

1.2 RISK ANALYSIS

The first recorded instances of risk analysis are the practices of the Asipu people of the Tigris-Euphrates valley about 3200 B.C. (Covello and Mumpower 1985). The Asipu would serve as consultants for difficult decisions such as a proposed marriage arrangement, or the location of a suitable building site. They would list the alternative actions under consideration and collect data on the likely outcomes of each alternative. The priest-like Asipu would interpret signs from

the gods, then compare the alternatives systematically. Upon completion of their analysis, they would etch a final report to the client on a clay tablet, complete with a recommendation of the most favorable alternative (Oppenheim 1977).

According to the *Oxford English Dictionary* (2010), the term *risk analysis* means the “systematic investigation and forecasting of risks in business and commerce.” The word *risk* comes through French, Latin, and Italian from the Greek word *rhiza*, in reference to sailors navigating among cliffs. Note that although some authorities believe that *risk* is derived from the Arabian word *rizq*, meaning “subsistence,” it is difficult to explain how this meaning developed into that of “danger” (Klein 1967). If you bought this book to help you analyze business problems, I will bet that you have no trouble seeing the connection between the risks of managing a business and the perils of navigating a sailing vessel around cliffs and barely submerged rocks that can damage the hull and sink the ship.

Imagine an ancient Greek mariner piloting a ship as it approaches a cliff or point of rocks in uncharted waters. Another sailor is on lookout in the crow’s nest at the top of the mast to give the earliest possible warning about how far down into the water an outcrop from the cliff might be. A navigator nearby with sextant and compass is keeping track of where the ship has been and the direction in which it’s headed. His lookout warns him at the first sign of trouble ahead, but it is up to the pilot to decide how wide to take the turn around the cliff. Cutting the corner too close can save time but might sink the ship. Veering far from the edge is safer, but adds costly travel time.

In navigating a strait between two cliffs, the pilot’s decision is even more difficult. Being too far from one cliff can mean being too close to the opposing cliff. The pilot must weigh the risks, use judgment and instinct to carefully choose a course, and then hope for the best as vessel and crew proceed through the strait.

It is the pilot’s job to take all of the available information into account and decide how best to sail the ship in uncharted waters. The pilot wants a clear analysis of all the dangers and opportunities that lie ahead, in order to decide whether the potential time savings of the ship’s chosen course outweighs the disastrous consequences of hull damage. Even though the ship may have been through many different straits in the past, the pilot needs a systematic investigation and forecasting of the risks associated with the planned course through each new strait encountered during the voyage.

If you are running a business (or are an analyst helping to run a business), you are often in situations conceptually similar to those facing the pilot of a sailing vessel in uncharted waters. You know where your business has been, and you are always on the lookout for dangers and opportunities on the horizon. You operate in an environment fraught with uncertainty. You know that future circumstances can affect you and your business greatly, and you want to be prepared for what might happen. In many situations, you need to weigh the favorable and unfavorable consequences of some decision and then choose a course of action. Similar to a ship’s pilot, it is your job to decide how best to navigate the straits of your business environment. What do you do?

Fortunately, mathematicians such as Simon LaPlace and Blaise Pascal developed the fundamental underpinnings of risk analysis in the seventeenth century by devising the mathematical methods now used in probability theory (Ore 1960). From these precepts came the science of statistics. “What?” you ask, “I studied probability and statistics in college and hated every minute of them. I thought I was done with that stuff. How can it help me?”

In short, probability and statistics help you weigh the potential rewards and punishments associated with the decisions you face. This book shows you how to use Crystal Ball to add probabilistic assumptions and statistical forecasts to spreadsheet models of a wide variety of financial problems. In the end, you still must make decisions based on your best judgment and instincts, but judicious use of the methods of probability and statistics that we go through in this book will help you in several ways.

The modeling process described here enables you to investigate many different possibilities, hone your intuition, and use state-of-the-art software tools that are extremely beneficial for managing risk in dynamic business environments. The risk analysis process forces you to think through the possible consequences of your decisions. This helps you gain comfort that the course of action you select is the best one to take based on the information available at the time you make the decision. Risk analysis is the quantification of the consequences of uncertainty in a situation of interest, and Crystal Ball is the tool for carrying it out.

1.3 MONTE CARLO SIMULATION

Risk analysis using Crystal Ball relies on developing a mathematical model in Excel that represents the situation of interest. After you develop a deterministic model, you replace point estimates with probability distribution assumptions and forecast the distribution of the output. The forecasted output distribution is used to assess the riskiness of the situation.

For simple models, the output distribution can be determined mathematically to give an analytic solution. For example, consider the simple cost equation

$$(\text{Total Cost}) = \$100 + \$15 \times (\text{Quantity Produced})$$

where (Quantity Produced) is modeled as a normal probability distribution with mean, $\mu = 50$, and standard deviation, $\sigma = 10$, and we want to know the probability that (Total Cost) is greater than \$900. We don't need Crystal Ball for this situation because we can easily obtain an analytic solution.

A result in probability theory holds that if a random variable X follows the normal distribution with mean, μ , and standard deviation, σ , then the random variable $Y = a + bX$ will also be normally distributed with mean, $a + b\mu$, and standard deviation, $b\sigma$. Therefore, we can easily determine that (Total Cost) is normally distributed with mean, $100 + (15 \times 50) = \$850$, and

standard deviation, $15 \times 10 = \$150$. Using a table of cumulative probabilities for the standard normal distribution, or using the Excel function `=1-NORMDIST(900,850,150,TRUE)`, we can find that the probability is 36.94 percent that (Total Cost) is greater than \$900. See the file `Analytic.xls` for these calculations, along with a Crystal Ball model that validates the solution.

In practice however, it is easy to find situations that are too difficult for most analysts to solve analytically. For example, consider a simple situation where unit sales, S , follow the Poisson distribution with mean 10; price, P , is lognormally distributed with mean \$50 and standard deviation \$10; variable cost percentage, V , has the beta distribution with parameters minimum = 0%, maximum = 100%, alpha = 2, and beta = 3; and fixed cost, $F = \$100$. Then profit, π , is calculated as

$$\pi = SP(1 - V) - F \quad (1.1)$$

in the `Profit.xls` model shown in Figure 1.1. The stochastic assumptions in `Profit.xls` are shown in Figure 1.2. For this model, it is easy to obtain a forecast distribution for profit with Crystal Ball and find the probability of making a positive profit to be approximately 77 percent (see Figure 1.3), but it is not so easy to determine the distribution mathematically and obtain the probability of positive profit by analytic solution.

Further, Crystal Ball enables us do sensitivity analysis very easily. The sensitivity chart in Figure 1.4 shows that most of the variation in profit arises from the Assumption V , the variable cost percentage. This indicates that we should work first on V when we are fine-tuning the model by improving our estimates of

	A	B	C
1	Profit.xls		
2			
3			
4	Assumptions	Notation	Value
5	Price	P	\$ 50.00
6	Unit Sales	S	10
7	Variable cost percentage	V	60%
8	Fixed cost	F	\$ 100.00
9			
10	Forecast		
11	Profit	π	\$ 100.00
12			
13	Model		
14	Revenue	\$ 500.00	
15	Variable Cost	\$ 300.00	
16	Fixed Cost	\$ 100.00	
17	Profit	\$ 100.00	

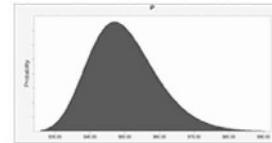
FIGURE 1.1 Simple profit model in `Profit.xls`. Cells C5:C7 are defined as Crystal Ball assumptions. Cell C11 is a Crystal Ball forecast.

Assumption: P

Cell: C5

Lognormal distribution with parameters:

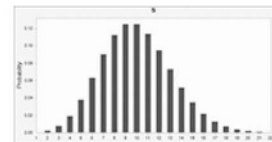
Location	\$0.00
Mean	\$50.00
Std. Dev.	\$10.00

**Assumption: S**

Cell: C6

Poisson distribution with parameters:

Rate	10.00
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**Assumption: V**

Cell: C7

Beta distribution with parameters:

Minimum	0%
Maximum	100%
Alpha	3
Beta	2

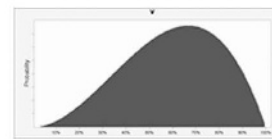


FIGURE 1.2 Crystal Ball assumptions defined in cells C5:C7 of the simple profit model.

the assumption variables. Better yet, if we are able to make management changes related to the variable cost process, then the sensitivity chart shows that we can reduce the variation of profit by reducing the variation in V .

With Crystal Ball, we obtain an approximate solution using Monte Carlo simulation to generate the output distribution. One of the features of Monte Carlo is that the more simulation trials we run, the closer our approximation is to the true distribution. The technique of Monte Carlo simulation has been used for this purpose for many years by scientists and engineers working with large and expensive mainframe computers. In combination with today's small and inexpensive personal computers, Crystal Ball and Excel bring to everyone the ability to run Monte Carlo simulations on Windows.

In statistics, one of the earliest uses of simulation (albeit without a computer), was that by the mathematical statistician William S. Gossett, who used the pen name "Student" to conceal his identity and appease his employers at Guinness brewing company. To verify his mathematical derivations, Gossett repeatedly

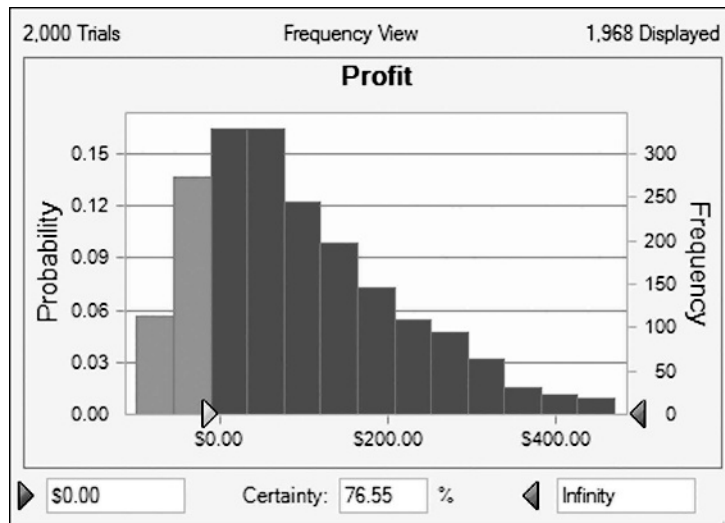


FIGURE 1.3 Forecast distribution for the simple profit model. The certainty of 76.55 percent for the range from 0.00 to infinity is the Crystal Ball estimate of the probability of positive profit, $\Pr(\pi > 0)$ for the model specified by Equation 1.1.

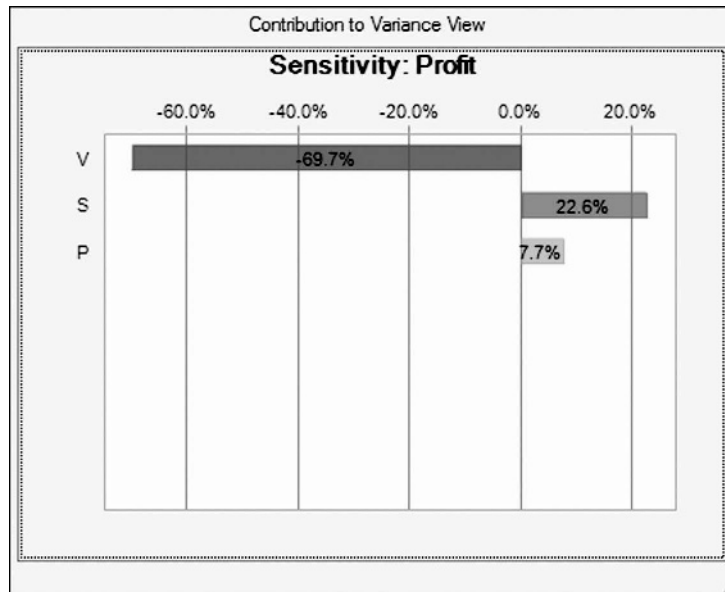


FIGURE 1.4 Sensitivity chart for the simple profit model. The input variables (assumptions) V, S, and P are listed from top to bottom in decreasing order of their impact on the output variable (forecast), profit.

drew random samples of numbers from a bowl, wrote them down, and painstakingly made his calculations. The results he obtained were within the tolerances expected from an experiment involving random sampling. Gossett's sampling experiments are conceptually similar to what we do on computers today, but Crystal Ball does for us in seconds what must have taken Gossett weeks or months to do by hand in the early 1900s.

The term *Monte Carlo* originated in a conversation between two mathematicians employed by Los Alamos National Laboratory as a code word for their secret work on the atomic bomb (Macrae 1992). John von Neumann and Stanislaw Ulam applied what we now call Monte Carlo methods to problems involving direct simulation of behavior concerned with random neutron diffusion in fissionable material (Rubinstein 1981). The name was motivated by the similarity of the computer-generated results to the action of the gambling devices used at the casinos in the city of Monte Carlo in the principality of Monaco. The term caught on and is now widely used in finance, science, and engineering.

1.4 RISK MANAGEMENT

When analyzing risk with the methods presented in this book you will be able to quantify the consequences of uncertainty by answering three main questions:

1. What can happen?
2. How likely is it to happen?
3. Given that it occurs, what are the consequences?

All good managers go through a process by which they consider these questions somehow, even if subconsciously. By taking the time to answer the questions in quantifiable terms, you will develop deeper insight into the problems that you face.

Risk analysis is part of a broader set of methods called *risk management*, which also seeks to find answers to three main questions:

1. What can be done?
2. What options are available?
3. What are the associated trade-offs in terms of costs, benefits, and risks?

It is your job as a manager or analyst to identify what can be done and what options are available, but once you have done so, the methods in this book will help you investigate the associated trade-offs in terms of costs, benefits, and risks.

Risk analysts often claim that much of the benefit of using Crystal Ball comes just from going through the process used to develop and fine-tune their models. The risk analysis process helps you develop insights into a problem more quickly than you would without it. One of the intentions of this book is to help save you

some of the time and tuition you might otherwise pay in the school of hard knocks to reach good decisions.

1.5 BENEFITS AND LIMITATIONS OF USING CRYSTAL BALL

This section describes some of the benefits and the limitations of using Crystal Ball and Excel for risk analysis. When it is applicable, diligent use of these tools yields deeper insight and understanding that will lead to better decision making. However, the tools have their limits, as described here.

1.5.1 Benefits

- Careful study of the situation being modeled usually reveals the key input factors that lead to success. Sometimes these factors will become obvious during model building. Crystal Ball has built-in sensitivity-analysis tools to help identify the key input factors.
- As mistakes are costly, it is better to evaluate alternatives before implementation. A valid model of a situation can help save much time and expense compared to experimenting with aspects of the actual situation to see what happens. This book is intended to help you build valid models.
- Computer hardware and software make simulation easy. Years ago, the use of Monte Carlo simulation was limited to those who had access to large mainframe computers and the expertise to program them. Today's personal computers have greater computational horsepower than yesterday's mainframes. Crystal Ball has been developed over time to make the addition of stochastic inputs and the calculation of output statistics as easy as possible.
- Realistic situations can be analyzed with relatively simple models. While many realistic situations have a host of potential complications, often just a few of these have the greatest effect on the outputs. Again, Crystal Ball's sensitivity-analysis features help you identify the effects of the factors having the greatest impact.
- Risk analysis can be a convincing agent for change. For those who understand the modeling process and the output produced by Crystal Ball, experimenting with the model can demonstrate very well the impact of changes to the system. When you earn the buy in of key decision makers, the model is a powerfully persuasive tool.

1.5.2 Limitations

- Validity of the input data is essential. As with any other analytic tool, the output is only as good as the input. The aphorism "garbage in, garbage out" will always be true for Crystal Ball models as it will be for every computer program or mathematical model.

- If you can't model it, you can't simulate it. Your ability to build Crystal Ball models is subject to the limitations of Excel. If you cannot build an Excel spreadsheet to represent the situation, then you cannot use Crystal Ball for simulation. Fortunately, the hundreds of functions built into Excel make it versatile, and Crystal Ball allows you to use Excel's Visual Basic for Applications capabilities if necessary for specialized purposes where Excel's built-in functions don't suffice.
- Risk analysis requires expert insight to make decisions. Crystal Ball will not make decisions for you. It will help you gain insight into the problem, but you must still reach conclusions and make decisions based on your best judgment and intuition about the situation you are analyzing.
- Crystal Ball gives approximate rather than exact solutions. This "limitation" is mostly an academic criticism. Many purists prefer to use only models that avail themselves to exact solutions. When confronted by a realistic complication that precludes an exact solution, they simply assume away the complication. Most practitioners, however, wish to include realistic complications and are happy to accept the trade-off of getting an approximate solution with simulation. The limitation is that they might have to run the model longer to obtain the desired precision. However, most practitioners prefer an approximate solution to a realistic problem over an exact solution to an oversimplified problem that is only a rough approximation to reality.