



MONTE CARLO SIMULATION/RISK ANALYSIS ON A SPREADSHEET: REVIEW OF THREE SOFTWARE PACKAGES

Sam Sugiyama

INTRODUCTION

Analysts must deal with uncertainty in virtually every forecast they generate. One approach to assessment of uncertainty is Monte Carlo simulation. In my earlier *Foresight* article (Sugiyama, 2007), I provided an overview and illustration of how Monte Carlo simulation can enrich the forecasting process. Here I review the three major software offerings on the market today.

- Crystal Ball (Version 7.3.1 Professional) from Oracle (formerly Decisioneering),
- @RISK and its companion RiskOptimizer (5.0 Industrial - prerelease version) from Palisade, and
- Risk Solver (8.0 - beta) and its companion optimization software, Premium Solver Platform (8.0 - beta) from Frontline Systems, Inc.

The Web sites: www.crystalball.com, www.palisade.com, www.solver.com/risksolver.htm

This review addresses four characteristics of the software: ease of use/interface/resources available for learning the software, analytical capabilities, speed, and ability to perform optimization under uncertainty.

These days our computers are already loaded with many software packages. When considering an expansion of this repertoire, analysts will demand easy-to-learn functionality that meaningfully extends capabilities and features fast, smooth execution. Also

as spreadsheet limits are growing, especially with the introduction of Excel 2007, extremely large models are becoming feasible, and these accentuate the need for computational precision and speed.

ESSENTIAL SOFTWARE FEATURES

Risk analysis/Monte Carlo simulation software should offer:

- an intuitive interface,
- a good base-set of probability distributions from which to choose, and
- a straightforward means of collaboration between analysts and decision makers.

Technically, the program should be able to:

- run thousands of cases, permitting the analyst to examine the likelihood of extreme or “tail” events,
- model statistical interdependence between uncertain variables (correlated random draws),
- identify the uncertain variables that most affect the variation in the results distribution,
- clearly display the results distributions, and
- address optimization under uncertainty.

The good news is that these three software packages perform well on all the above criteria; even better is that each of the products has a new release (2007).

DISTINGUISHING FEATURES

Does any one of the three software packages stand out in a given dimension of the testing? The answer is yes, for each of them.



Sam Sugiyama is Principal of EC RISK USA & EUROPE. He is an economist with over 30 years of training and industry experience in quantitative analysis and modeling. Since 1990, he has been assisting clients in a variety of industries to develop forecast solutions and to effectively control risk. Sam also has taught courses in applied statistics, econometrics, and economic principles at universities in the northwest, including Weber State College, University of Utah, Lewis & Clark College, and Portland State University. Sam earned a PhD in Economics from the University of Utah in 1981.

Figure 1a. The Crystal Ball Ribbon Bar

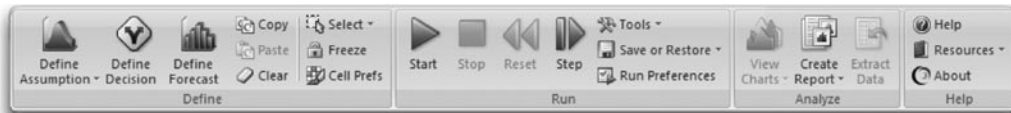


Figure 1b. The @RISK Ribbon Bar



Figure 1c. The Risk Solver Ribbon Bar



Crystal Ball, in my opinion, is the easiest to use and has the best set of resources – an excellent user guide, reference manuals, an abundance of illustrative models and many texts (see the Web site, www.crystalball.com), including a very well-written offering by John Charnes (2007).

Crystal Ball is the most complete package for simulation and optimization, integrating the functionality to perform Monte Carlo simulation, optimization, and even time-series forecasting as risk sub-models.

@RISK has the best procedure for identifying the key variables affecting the range and shape of the results. This is its *regression sensitivity option*. In addition, the new version – @RISK 5.0 – contains many upgrades, including a significantly improved interface that makes Monte Carlo modeling a simple drag-and-drop exercise. Each function is just an icon-click away on the @RISK ribbon bar. In addition, my tests show that version 5.0 is over twice as fast as its predecessor version (4.5.7).

@RISK is a close second to Crystal Ball in terms of resources. Many texts and examples are available (see www.palisade.com). Its demos and tutorials are straightforward and nicely packaged.

Risk Solver is the newest entrant into the market for Monte Carlo simulation add-ins. It is produced by Frontline Systems, Inc., the developers of the Solver in Excel. Everyone who has Excel has Solver. (Solver finds values of decision variables [adjustable cells] that

yield optimal values on some objective that is subject to restrictions.)

Risk Solver has several distinguishing features. First, input and output distributions can be viewed by simply moving your cursor over the Excel cell and double-clicking. Second, it is extraordinarily fast, which gives it a substantial advantage for handling large models. Third, it offers the most advanced functionality for optimization, which I'll discuss later.

Risk Solver also makes it easiest to define simulation results as an input distribution (which they call a *stochastic information packet*, or SIP) and as an uncertain model subset (which they call a *stochastic library unit with relationships preserved*, or SLURP), for use in another simulation. This capability is a powerful means to maintain consistency across an organization for key analytical components. It also enables the analyst to efficiently model a *portfolio of projects*. The speed of Risk Solver makes this a feasible capability in the current version, 7.

Figures 1a, 1b, and 1c, the main menus, illustrate the breadth of the functionality in the three programs.

HOW MUCH DOES SPEED MATTER?

In small models, not much. But larger models are becoming more commonplace. With the introduction of Excel 2007, ever larger models will be tasked with assessing risk. Simulation optimization, in which multiple simulations are performed, is another endeavor

requiring effective speed. Finally, there is increasing attention to the tails of distributions, and good resolution in the tails requires a large number of trials, making speed a consideration. For example, insurance analysts focus on the tails of distributions to determine the appropriate premiums to charge. The medical profession needs distributions well-defined in the tails to evaluate drugs, medical devices, and disease.

I performed two speed tests: one is based on a model in which a company produces and sells in three markets. The uncertain variables for each market are unit price, unit cost, and amount sold. There is no statistical interdependence among the uncertain variables and no alternative assumptions for the fixed parameters in the profit calculation (e.g. the discount rate). The model is illustrated in Table 1.

I ran 100,000 iterations so as to emulate the speed running a case where fine resolution in the tails is required.

The second test extends the three-market model to incorporate statistical interdependence and 11 alternative unit cost discounts from the supplier for market 3. I ran 10,000 iterations for each alternative, requiring the software to run 110,000 iterations.

Table 2 shows the test results in seconds: the most striking result is how much faster Risk Solver is. I performed similar tests with an optimization analysis, and

Table 1. A Three-Market Model

	A	B	C	D	E	F	G
1							
2		Uncertain	Uncertain	Uncertain			Results
3		Market Price	Amt Produced & Sold	Unit Cost	Total Revenue	Total Cost	Profit
4	mkt 1	\$ 95	1,000	\$ 85	\$ 95,000	\$ 85,000	\$ 10,000
5	mkt 2	\$ 45	400	\$ 35	\$ 18,000	\$ 14,000	\$ 4,000
6	mkt 3	\$ 90	1,000	\$ 87	\$ 90,000	\$ 87,000	\$ 3,000
7	Portfolio						\$ 17,000
8							
9							
10	Mkt Price (Lognormal)	Mean	Std Dev	Min	Max		
11	mkt 1 mkt price	95	8	80	120		
12	mkt 2 mkt price	45	5	35	65		
13	mkt 3 mkt price	90	15	70	125		
14							
15	Amt Produced & Sold (Pert)	Min	ML	Min			
16	mkt 1 amt sold	800	1000	1150			
17	mkt 2 amt sold	340	400	450			
18	mkt 3 amt sold	900	1000	1150			
19							
20	Unit Cost (Normal)	Mean	Std Dev	Min	Max		
21	mkt 1 unit cost	85	5	70	105		
22	mkt 2 unit cost	35	5	25	55		
23	mkt 3 unit cost	87	10	70	130		

Table 2. Speed Test Results

Software	Simple Model	Extended Model
@RISK 5.0	63	78
Crystal Ball 7.3.1	34	37
Risk Solver 8.0	6	6

the differences there were even greater. Risk Solver’s speed advantage stems from the use of its Polymorphic Spreadsheet Interpreter instead of the Excel interpreter for performing recalculations in Excel.

SIMULATION AND OPTIMIZATION

Our extended model raises an issue of optimization: what is the optimal unit cost discount in each market? Using Monte Carlo simulation (without linkage to optimization software), the problem can be addressed through *multiple simulations*. All three software packages have the capability to perform multiple simulations, with the results revealing the effect of alternative decisions. The illustrative model requires a simulation for each of the 11 assumptions about the discount parameter.

Multiple Simulations: In @RISK, you specify the alternative parameter assumptions using a RiskSimtable() function, as illustrated in Table 3. The function RiskSimtable(G22:G32) is entered in G21. Alternative discounts from 0 to 50% are specified in this cell range. Cell B23, the mean of “mkt 3” unit cost, is changed from a constant to “= 87*(1-G21)” to implement the effect of different unit cost discount rates on unit cost. (My assumption is that the discount will affect only the **mean** unit cost.)

The Risk Solver implementation of multiple simulations is nearly identical to that of @RISK and, in Crystal Ball, the alternative assumptions are handled via a Decision Table.

Simulation Optimization: Multiple simulations, which require only Monte Carlo software, will show the bottom-line distributions under the alternative parameter

Table 3. The RiskSim Table in @RISK

	Uncertain	Uncertain	Uncertain			Results	
	Market Price	Amt Produced & Sold	Unit Cost	Total Revenue	Total Cost	Profit	
4	mkt 1	\$ 95	1,000	\$ 85	\$ 95,000	\$ 85,000	\$ 10,000
5	mkt 2	\$ 45	400	\$ 35	\$ 18,000	\$ 14,000	\$ 4,000
6	mkt 3	\$ 90	1,000	\$ 87	\$ 90,000	\$ 87,000	\$ 3,000
7	Portfolio						\$ 17,000

Mkt Price (Lognormal)	Mean	Std Dev	Min	Max
mkt 1 mkt price	95	8	80	120
mkt 2 mkt price	45	5	35	65
mkt 3 mkt price	90	15	70	125

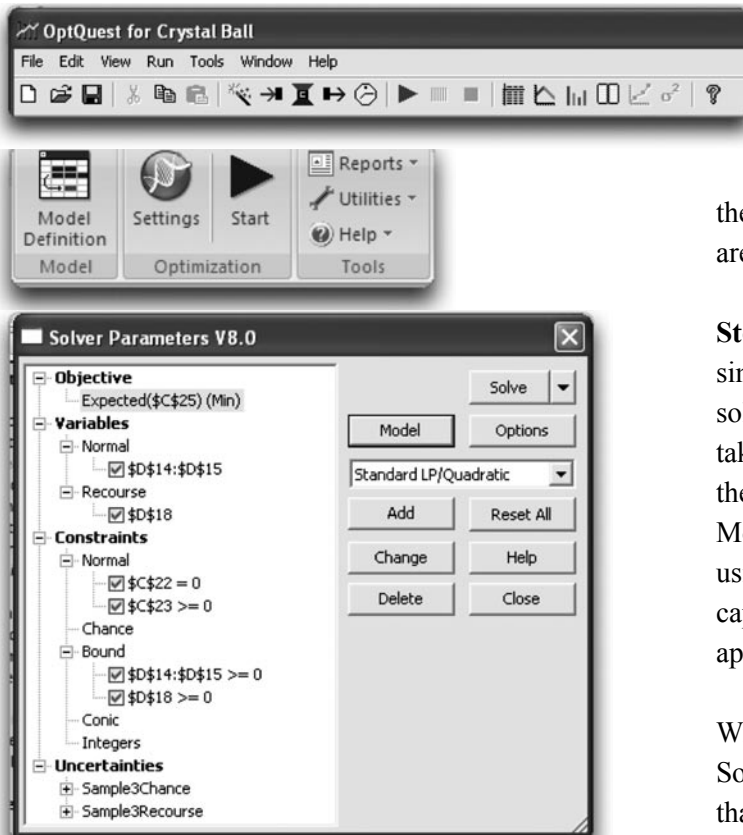
Amt Produced & Sold (Pert)	Min	ML	Max
mkt 1 amt sold	800	1000	1150
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mkt 3 amt sold	900	1000	1150

Unit Cost (Normal)	Mean	Std Dev	Min	Max
mkt 1 unit cost	85	5	70	105
mkt 2 unit cost	35	5	25	55
mkt 3 unit cost	87	10	70	130

@RISK Correlation	mkt 1 / Market Price	mkt 2 / Market Price	mkt 3 / Market Price
mkt 1 / Market Price	1		
mkt 2 / Market Price	0.86	1	
mkt 3 / Market Price	0.629	0.411	1

values. With these results, the analyst can compare distributions and identify the most favorable alternative. The real problem we have, however, is determining which alternative course of action (unit cost discount, in our illustrative example) is best, a problem that can be addressed more efficiently through *optimization*: what we really seek is the optimal discount, given a specified set of conditions (constraints).

Figure 2. The Main Menus of the Optimizers



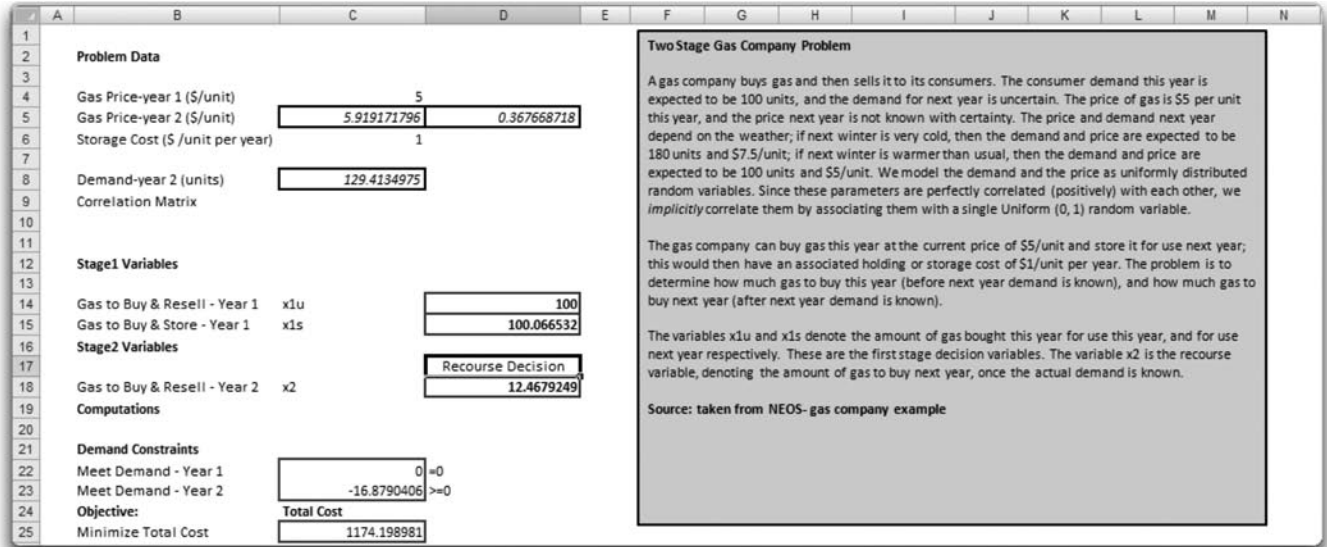
By linking a Monte Carlo program with optimization software, we can perform *simulation optimization*, which essentially removes the necessity of running multiple simulations.

All three packages have the simulation optimization capability. It is built into Crystal Ball and is called OptQuest. For @RISK, there is the companion Risk Optimizer, and Risk Solver has the companion Premium Solver Platform Stochastic (PSPS), which is an upgraded version of the Excel add-in. The analyst specifies the objectives and constraints for optimization in the optimization software and the Monte Carlo software performs the simulations. The main menus for the three optimizers are shown in Figure 2.

Stochastic Programming: The combination of simulation and optimization has worked well, but solving a problem through simulation optimization can take many hours or even days, and this is in addition to the significant time investment in model development. Moreover, there are problems that cannot be solved using the currently-configured simulation optimization capabilities of the three packages. But there now appears to be a better approach.

With its introduction of Risk Solver and Premium Solver, Frontline offers a more general framework than is permitted by simulation optimization. Many

Figure 3. Recourse Decision Example from Premium Solver



optimization problems solved using simulation can now be solved more efficiently. For example, the standard portfolio optimization problem, subject to constraints, can be solved in a fraction of a second using Premium Solver, whereas it would take a few minutes of processing using either RiskOptimizer or Optquest. The really attractive feature within Premium Solver is that it will diagnose your model and, in many cases, transform it automatically to a more directly-solvable model.

The more general framework treats every analysis as a decision problem, encompassing both optimization under certainty and optimization under uncertainty. The second category includes decisions that (1) cannot be deferred and (2) can be deferred until some or all of the uncertainties have been resolved. The latter are called *recourse decisions*. Simulation optimization can solve many problems with non-deferrable decisions but cannot correctly address recourse decisions, which are an important type of real-world problem.

Figure 3 provides an example of a recourse decision taken from Premium Solver. If the supplier waits until the following year, he can make a more informed decision and reduce costs. To convert the problem to one with a recourse decision, we (1) identify the recourse variable and (2) direct the Premium Solver

to transform the stochastic model. The PSPS solution without recourse yields a cost of \$1,446 in the amount of gas to buy and resell in year 2 while the solution, with recourse implemented, is \$1,275. (Figures not shown)

The technique for recourse decisions that is illustrated here is *stochastic programming*. In this example a recourse decision model has been solved by transforming the model into a programming model that minimizes cost, subject to uncertain constraints. For an introduction to SP, see the Web site of the Community on Stochastic Programming (COSP) at www.stoprog.org.

Of the three packages reviewed here, the stochastic programming functionality is available only in Premium Solver with its stochastic library routines (the SIPS and SLURPS defined earlier). Moreover, Premium Solver offers more efficient approaches than simulation optimization for certain types of non-recourse decisions. The program builds in “analysis detectors” that guide the user toward selection of an appropriate model structure and enables transformations of models into structures that are amenable to solver algorithms, with their far greater speed.

For comprehensive solutions to optimization problems, the capabilities of Risk Solver and the Premium Solver platform are the best in show.

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Sugiyama, S. (2007). Forecast uncertainty and Monte Carlo simulation, *Foresight: The International Journal of Applied Forecasting*, Issue 6 (Spring 2007), 29-37.

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COMMENTARY

Kevin Weiner, Marketing Communications,
Crystal Ball Global Business Unit

Since 1986, Oracle's (formerly Decisioneering) Crystal Ball software has strived to produce the highest quality, most practical, and most accessible Monte Carlo software available. We are very pleased that Dr. Sugiyama endorsed these strengths: "Crystal Ball, in my opinion, is the easiest to use and has the best set of resources available to the user." Analysts and engineers are attracted to Crystal Ball's strong functionality, intuitive interface, and highly visual output. And Crystal Ball is chosen by more than 800 universities world wide because educators are confident that it is the best tool for teaching the basics and benefits of simulation. We offer more manuals, tutorials, example models, and textbooks than competitors, and support our user community with forums, conferences and seminars.

One shortcoming of technical reviews is that they tacitly treat software companies as interchangeable. Quantifying customer experience is not so simple as measuring simulation speed. Purchasers of business-critical software know that how a company treats and supports its customers is just as important as the features it offers. This is what sets us apart. We believe that the software sale is only the beginning. Customers often tell us that they choose Crystal Ball as a long-

term vendor because of the friendliness and integrity of our people.

Recently, Crystal Ball was acquired by Oracle, a company with a tradition of acquiring best-in-breed companies from around the world. Our software is now backed by Oracle's world-class technical support.

COMMENTARY

Randy Heffernan, Vice President, Palisade

We found minimal coverage of @RISK 5.0 and its differences with the alternative products. For example, in @RISK all distributions – the building blocks of any Monte Carlo model - are true Excel functions, which may be entered, copied and pasted just as Excel functions. Distributions and arguments can be viewed in the Excel formulas. Crystal Ball distributions are entered through dialogs external to Excel.

@RISK 5.0 uses a graphing engine that processes simulation data very quickly. It has many graph types, such as box-plots and animated scatter plots, not found in the other products. Its new interface allows you to quickly browse through simulation results with graphs linked to their cells in Excel. A Summary "dashboard" window displays thumbnail graphs and statistics updated live during a run.

Only @RISK 5.0 includes the powerful Compound function, allowing frequency-severity modeling in a single function, a step that would require thousands of distributions in other products. It also is the only program to include functions, such as RiskTheo, RiskMakeInput, and RiskSensitivity, that allow Excel users to develop the most advanced models.

Unlike Risk Solver, @RISK simulations are calculated 100% within Excel. Palisade does not attempt to rewrite Excel in an external recalcuator to gain speed. A single recalculation from an unsupported or poorly

reproduced macro or function can dramatically change your results, and Risk Solver's recalcuator does not provide 100% Excel compatibility. @RISK harnesses the power of multiple CPUs and multi-core processors to give fast, accurate answers.

@RISK 5.0 also includes the @RISK Library, a SQL database that lets you share distributions and simulation results with other @RISK users. This ensures consistency in modeling across an organization. Portfolios of simulation runs and their associated Excel models can be archived in the @RISK Library and their results compared.

@RISK 5.0 is available by itself or integrated with Palisade's DecisionTools Suite, which offers decision analysis with PrecisionTree, statistics and forecasting with StatTools, and neural networks with NeuralTools. With these products Palisade offers the widest range of complementary tools for Monte Carlo modelers.

COMMENTARY

Daniel Fylstra, President, Frontline Systems

We're pleased that several key advantages of Risk Solver – its speed, optimization power, and support for risk models throughout a large organization – appeared in this review. In addition, a unique advantage of Risk Solver is Interactive Simulation – “what if” with uncertainty, for quick insights. Each time you change a number on the worksheet, a new simulation occurs immediately, and updated charts and summary statistics appear. In contrast, Crystal Ball and @RISK are designed for slower, “batch mode” simulations. Risk Solver's lightning speed makes Interactive Simulation practical.

Since Risk Solver is new in 2007 (its version number matches our Premium Solver), whereas Crystal Ball and @RISK have been around for nearly 20 years, at present there are more learning resources available for

these older products. But anyone reading this review can easily learn Risk Solver with its online Help, 31 built-in Excel examples, and 264-page User Guide. We're pleased that new editions of several textbooks, training seminars, and more are already in development for Risk Solver. We have more exciting developments in store for users who want to find the best solutions to models with uncertainty! Learn more at www.solver.com/risksolver.

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