being applicable only for European options without dividends. In addition, American option approximation models are very complex and difficult to create in a spreadsheet. The BSM *cannot* account for American options, options based on stocks that pay dividends (the GBM model can, however, account for dividends in a European option), forfeitures, underperformance, stock price barriers, vesting periods, changing business environments and volatilities, suboptimal early exercise behavior, and a sleuth of other conditions. Monte Carlo simulation when used alone is another option valuation approach, but is restricted only to European options. Simulation can be used in two different ways: solving the option's fair-market value through path simulations of stock prices or used in conjunction with other approaches (e.g., binomial lattices and closed-form models) to capture multiple sources of uncertainty in the model.

Binomial lattices are flexible and easy to implement. They are capable of valuing American-type stock options with dividends but require computational power. Software applications should be used to facilitate this computation. Binomial lattices can be used to calculate American options paying dividends and can be easily adapted to solve ESOs with exotic inputs and used in conjunction with Monte Carlo simulation to account for the uncertain input assumptions (e.g., probabilities of forfeiture, suboptimal exercise behavior, vesting, underperformance) and to obtain a high precision at statistically valid confidence intervals. Based on the analyses throughout this case study, it is recommended that the use of a model that assumes an ESO is European style, when, in fact, the option is American style with the other exotic variables, should not be permitted as this substantially overstates compensation expense. Many factors influence the fair-market value of ESOs, and a binomial lattice approach to valuation that considers these factors should be used. With due diligence, real-life ESOs can absolutely be valued using the customized binomial lattice approach as shown in this case study, where the methodology employed is pragmatic, accurate, and theoretically sound.

CASE 6: INTEGRATED RISK ANALYSIS MODEL—HOW TO COMBINE SIMULATION, FORECASTING, OPTIMIZATION, AND REAL OPTIONS ANALYSIS INTO A SEAMLESS RISK MODEL

One of the main questions in risk analysis is how the individual software applications in our Risk Simulator and Real Options Super Lattice Solver suite can be applied in concert with one another. This case study attempts to illustrate how an integrated risk management model can be constructed using the Real Options Super Lattice Solver and Risk Simulator's Monte Carlo *Simulation*, *Forecasting*, and *Optimization* tools. Figure 11.34 shows an integrated model process of how time-series forecasting, returns on investment, Monte

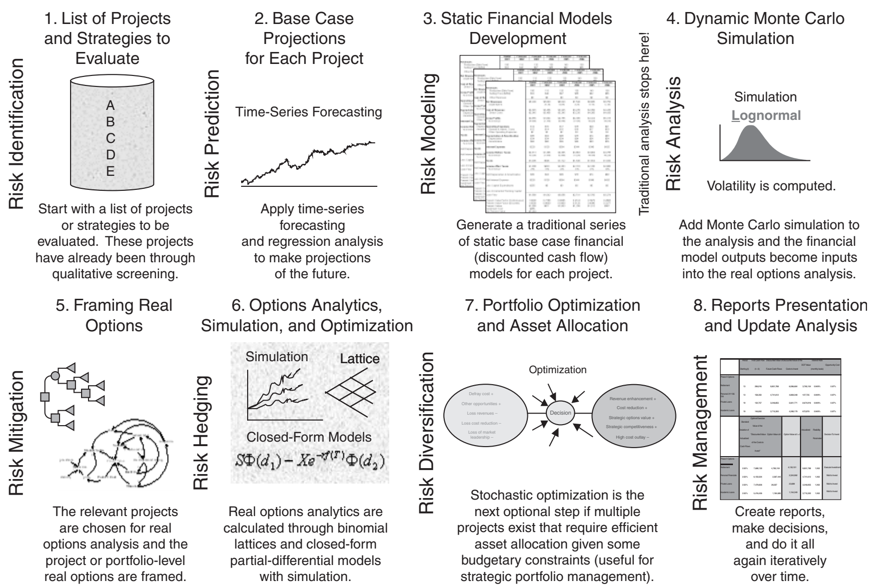


FIGURE 11.34 Integrated Risk Management Process

Carlo simulation, real options, and portfolio optimization are linked within one nicely integrated analytical package. Refer to the software's user guide for more hands-on details as this case study is only meant to illustrate the practical applications of these approaches.

Forecasting

Suppose that some historical annualized revenue data dating from 1985 to 2004 exists. The first task in the modeling is to forecast the next five years of this project or product in question.

In Risk Simulator's *Forecasting* tool, select the area G7 to G26 of the data area (Figure 11.35). Suppose that you know from experience that the seasonality of the revenue stream peaks every four years. Enter the seasonality of four and specify the number of forecast periods to five. The *Forecasting* tool automatically selects the best time-series model to forecast the results. Figure 11.36 illustrates the different forecasting tools available in Risk Simulator. The time-series analysis module is chosen, and running this module on the historical data will generate a report with the five-year forecast revenues (Figure 11.37) that are complete with Risk Simulator assumptions.

	D	E	F	G	H
2		**Forecasting**			
3					
4		Periodicity:		Annual	
5		Seasonality:		4 Years	
6			Year	Revenues	
7		Historical Data	1985	$684.20	
8			1986	$584.10	
9			1987	$765.40	
10			1988	$892.30	
11			1989	$885.40	
12			1990	$677.00	
13			1991	$1,006.60	
14			1992	$1,122.10	
15			1993	$1,163.40	
16			1994	$993.20	
17			1995	$1,312.50	
18			1996	$1,545.30	
19			1997	$1,596.20	
20			1998	$1,260.40	
21			1999	$1,735.20	
22			2000	$2,029.70	
23			2001	$2,107.80	
24			2002	$1,650.30	
25			2003	$2,304.40	
26			2004	$2,639.40	

FIGURE 11.35 Historical Time-Series Data

Monte Carlo Simulation

The second worksheet, Valuation Model, shows a simple DCF that calculates the relevant NPV and IRR values as seen in Figure 11.38. Notice that the output of the forecast worksheet becomes an input into this valuation model worksheet. For instance, cells D19 to H19 (Figure 11.38) are linked from the first forecast worksheet (Figure 11.37). The model uses two discount rates for the two different sources of risk (market risk-adjusted discount rate of 12 percent for the risky cash flows, and a 5 percent cost of capital to account for the private risk of capital investment costs). Further, different discounting conventions are included (midyear, end-year, continuous, and discrete discounting), as well as a terminal value calculation assuming a constant growth model. Finally, the capital implementation costs are separated out of the model (row 46) but the regular costs of doing business (direct costs, cost of goods sold, operating expenses, etc.) are included in the computation of free cash flows. That is, this project has two phases, the first phase in year 2005 costs $5 and the second larger phase costs $2,000. The statistic NPV shows a positive value of $123.14 while the IRR is 15.68 percent, both exceeding the zero-NPV and firm-specific hurdle rate of 15 percent required rate of return. Therefore, at first pass, the project seems to be profitable and justifiable. However, risk has not been considered.

Without applying risk analysis, one cannot determine the chances this NPV and IRR are expected to occur. Figure 11.39 illustrates the same model but now with Risk Simulator input assumptions and output forecasts applied (highlighted cells). This is done by clicking on *Simulation* and selecting *New Simulation Profile*. Then, select the cells you wish to simulate (e.g., D20) and click on *Simulation* and select *Set Assumption*. For illustration purposes, select the *Triangular Distribution* and link to the input parameters

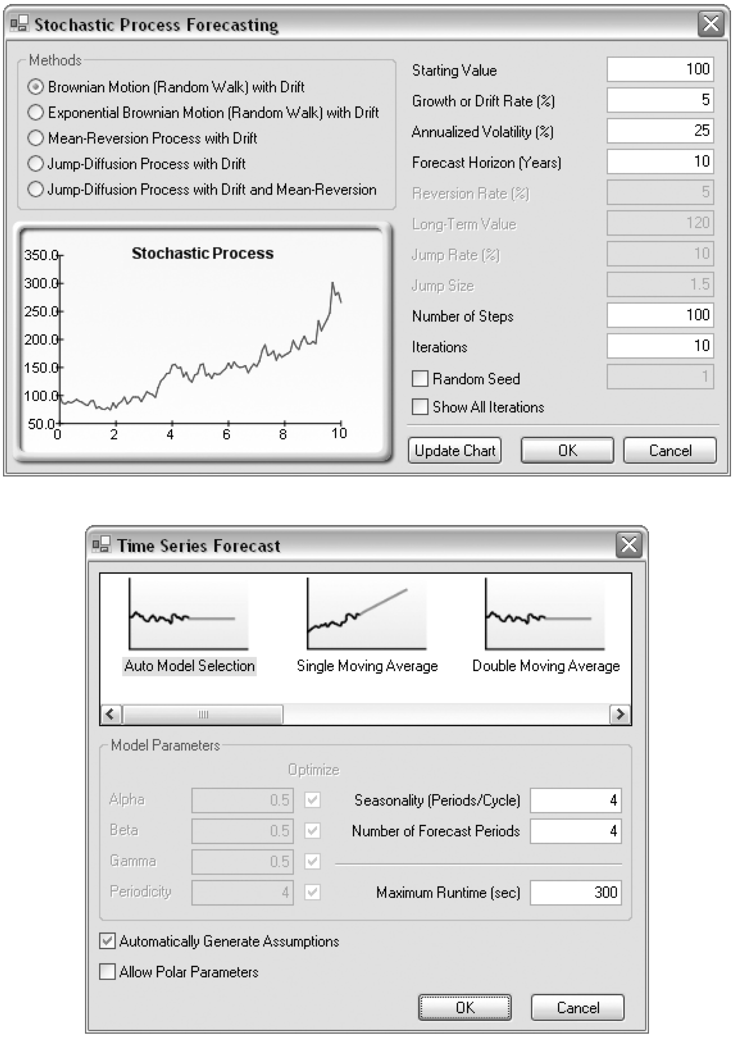
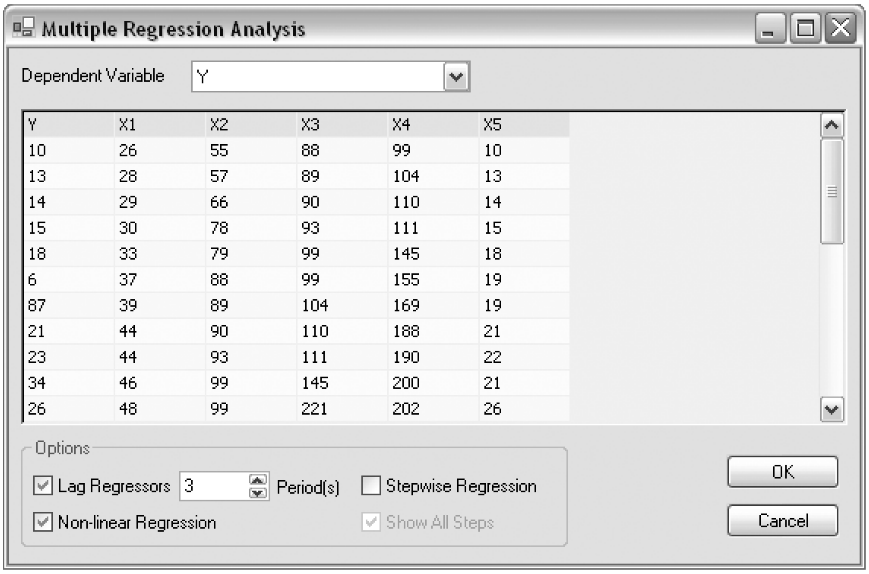


FIGURE 11.36 Forecasting Tool in Risk Simulator

to the appropriate cells. Figure 11.39 illustrates a sample assumption applied to cell D20. Continue the process to define input assumptions on all relevant cells. Then select the output cells such as NPV, IRR, and so forth (cells D14, D15, H14, and H15) and set them as forecasts (i.e., select each cell and click on *Simulation* | *Set Forecast* and enter the relevant variable names).

The model is then simulated for 5,000 thousand trials and the results are shown in Figures 11.40 to 11.43. As can be seen, there is a 76.40 percent probability of breaking even or better (Figure 11.40). In other words, there is



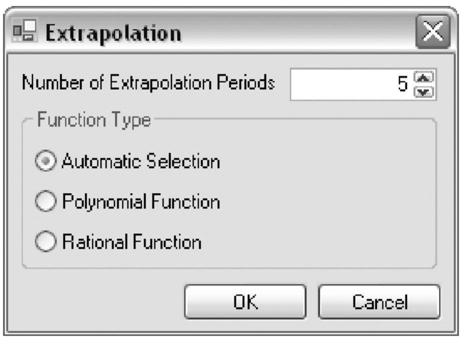


FIGURE 11.36 (*Continued*)

Time-Series Analysis (Holt-Winters Seasonal Multiplicative)

Summary Statistics

Alpha, Beta, Gamma	RMSE	Alpha, Beta, Gamma	RMSE
0.00, 0.00, 0.00	914.824	0.60, 0.60, 0.60	113.974
0.10, 0.10, 0.10	415.322	0.70, 0.70, 0.70	138.884
0.20, 0.20, 0.20	187.202	0.80, 0.80, 0.80	171.881
0.30, 0.30, 0.30	118.795	0.90, 0.90, 0.90	202.578
0.40, 0.40, 0.40	101.794	1.00, 1.00, 1.00	319.759
0.50, 0.50, 0.50	102.143		

Best Fit (Alpha, Beta, Gamma) = 0.2431, 0.9990, 0.7798

Time-Series Analysis Summary

When both seasonality and trend exist, more advanced models are required to decompose the data into their base elements: a base-case level (L) weighted by the alpha parameter; a trend component (b) weighted by the beta parameter; and a seasonality component (S) weighted by the gamma parameter. Several methods exist but the two most common are the Holt-Winters' additive seasonality and Holt-Winters' multiplicative seasonality methods. In the Holt-Winter's multiplicative model, the base case level and trend are added together and multiplied by the seasonality factor to obtain the forecast fit.

The best-fitting test for the moving average forecast uses the root mean squared errors (RMSE). The RMSE calculates the square root of the average squared deviations of the fitted values versus the actual data points.

Mean Squared Error (MSE) is an absolute error measure that squares the errors (the difference between the actual historical data and the forecast-fitted data predicted by the model) to keep the positive and negative errors from canceling each other out. This measure also tends to exaggerate large errors by weighting the large errors more heavily than smaller errors by squaring them, which can help when comparing different time-series models. Root Mean Square Error (RMSE) is the square root of MSE and is the most popular error measure, also known as the quadratic loss function. RMSE can be defined as the average of the absolute values of the forecast errors and is highly appropriate when the cost of the forecast errors is proportional to the absolute size of the forecast error. The RMSE is used as the selection criteria for the best-fitting time-series model.

Mean Absolute Percentage Error (MAPE) is a relative error statistic measured as an average percent error of the historical data points and is most appropriate when the cost of the forecast error is more closely related to the percentage error than the numerical size of the error. Finally, an associated measure is the Theil's U statistic, which measures the naivety of the model's forecast. That is, if the Theil's U statistic is less than 1.0, then the forecast method used provides an estimate that is statistically better than guessing.

Period	Actual	Forecast Fit
1	684.20	
2	584.10	
3	765.40	
4	892.30	
5	885.40	684.20
6	677.00	667.57
7	1006.60	935.44
8	1122.10	1198.07
9	1163.40	1112.43
10	993.20	887.91
11	1312.50	1348.38
12	1545.30	1546.54
13	1596.20	1572.45
14	1260.40	1299.19
15	1735.20	1704.74
16	2029.70	1976.22
17	2107.80	2026.03
18	1650.30	1637.29
19	2304.40	2245.93
20	2639.40	2643.07
Forecast 21		2713.66
Forecast 22		2114.75
Forecast 23		2900.37
Forecast 24		3293.75
Forecast 25		3346.46

Error Measurements	
RMSE	71.8164
MSE	5157.5910
MAD	53.4084
MAPE	4.50%
Theil's U	0.3055

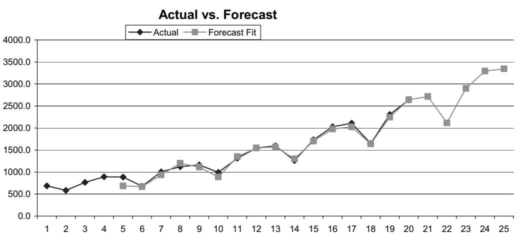


FIGURE 11.37 Forecast Results

no guarantee the project will always make money. In fact, about one out of four times, the project will be making a loss. If the corporate IRR hurdle rate is higher, say at 15 percent, there is only a 42.20 percent probability that the project exceeds this required threshold (Figure 11.41). In fact, when quantifying the single-point NPV estimate of $123.14, there is only a 36.40 percent probability that the project will exceed expectations or a 63.60 percent probability it will be below expectations as captured by the single-point NPV estimate (Figure 11.42).

In fact, Figure 11.43 shows a noble truth in risk analysis: The *expected value is often not the same as the value expected*. That is, the expected value or mean of the distribution of NPV outcomes is $100.83, a far cry from the value expected of $123.14 using a single-point estimate.

Valuation Model

Global Inputs

Discount Rate (Cash Flow)	12.00%	Valuation Year	2004
Discount Rate (Cost)	5.00%	Discounting Convention	End-Year Continuous
Tax Rate	30.00%		
Terminal Growth Rate	3.00%		

Results

Present Value (Cash Flow)	$1,849.31	Payback Period	3.41 Years
Present Value (Capital Cost)	$1,726.17	Discounted Payback Period	4.55 Years
Net Present Value (NPV)	$123.14	NPV with Terminal Value	$3,273.11
Internal Rate of Return (IRR)	15.68%	IRR with Terminal Value	42.49%

	2005	2006	2007	2008	2009
Revenue	$2,713.66	$2,114.75	$2,900.37	$3,293.75	$3,346.46
Cost of Revenue	$800.00	$850.00	$900.00	$950.00	$1,000.00
Gross Profit	$1,913.66	$1,264.75	$2,000.37	$2,343.75	$2,346.46
Operating Expenses	$600.00	$700.00	$800.00	$900.00	$1,000.00
Depreciation Expense	$200.00	$300.00	$400.00	$500.00	$600.00
Interest Expense	$30.00	$30.00	$30.00	$30.00	$30.00
Income Before Taxes	$1,083.66	$234.75	$770.37	$913.75	$716.46
Taxes	$325.10	$70.43	$231.11	$274.13	$214.94
Income After Taxes	$758.56	$164.33	$539.26	$639.63	$501.52
Non-Cash Expenses	$0.00	$0.00	$0.00	$0.00	$0.00
Free Cash Flow	$758.56	$164.33	$539.26	$639.63	$501.52
Capital Cost	*$5.00*		*$2,000.00*		

Cash Flow Analysis:

	Year 0	*Year 1*	*Year 2*	*Year 3*	*Year 4*	*Year 5*	*Future Years*
	($1,726.17)	*$758.56*	*$164.33*	*$539.26*	*$639.63*	*$501.52*	*$5,739.64*
Payback					*3.41*		*3.41*
Discounted Payback						*4.55*	*4.55*
Discounted Free Cash Flows		*$672.78*	*$129.26*	*$376.23*	*$395.79*	*$275.24*	*$3,149.98*
Discounted Capital Cost		*$4.76*	*$0.00*	*$1,721.42*	*$0.00*	*$0.00*	

FIGURE 11.38 Static Discounted Cash Flow Model

Imagine if you have 20 projects that have similar NPV and IRR values (and similar qualitative strategic values to the firm). It would be impossible to select the best project. However, with the use of Monte Carlo simulation with Risk Simulator, one can delineate the similar projects through their respective risk structures. That is, the first project has a 76.40 percent chance of breaking even, while the second project has only a 35.50 percent chance, and so forth. This way risk analysis is performed and the project with the lowest risk should be chosen. Monte Carlo simulation when applied here will help the decision maker isolate, identify, value, prioritize, and decide on which projects to execute while considering the potential downside of the projects.

Real Options

The next stop is real options analysis. In the previous simulation applications, risk was quantified and compared across multiple projects. The problem is, so what? That is, we have quantified the different levels of risks in different

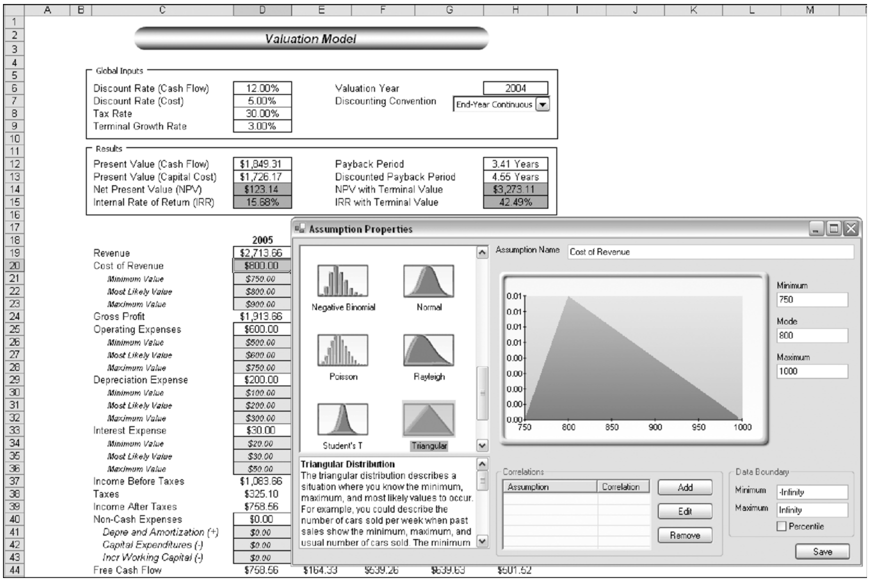


FIGURE 11.39 Simulated Discounted Cash Flow Model

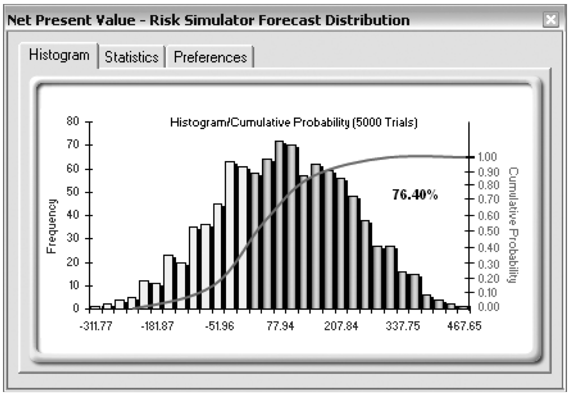


FIGURE 11.40 Probability of at Least Breaking Even

projects. Some are highly risky, some are somewhat risky, and some are not so risky. In addition, the relevant returns are also pretty variable as compared to the risk levels. Real options analysis takes this to the next step. Looking at a specific project, real options identifies if there are ways to mitigate the downside risks while taking advantage of the upside uncertainty. In applying

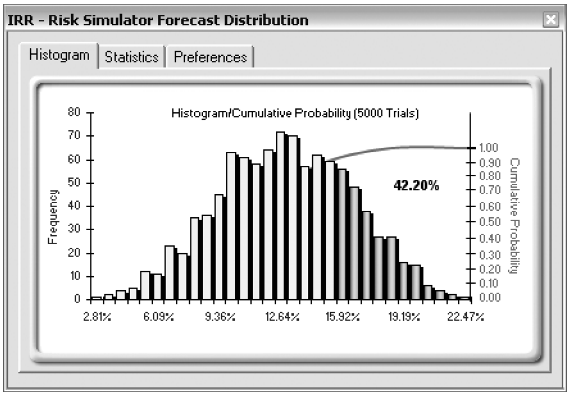


FIGURE 11.41 Probability of Exceeding IRR Hurdle Rate

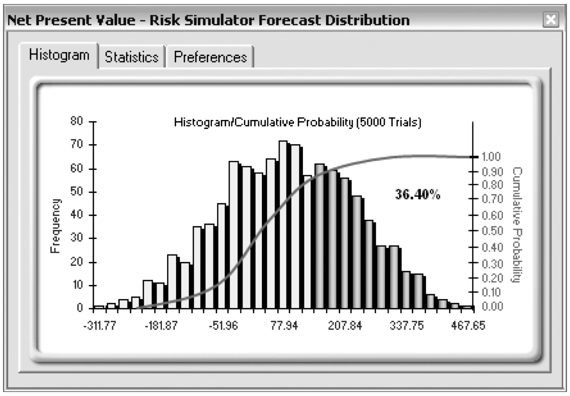


FIGURE 11.42 Probability of Exceeding NPV Expected

Risk Simulator, we have only quantified uncertainties, not risks! Downside uncertainty, if it is real and affects the firm, becomes a risk, while upside uncertainty is a plus that firms should try to capitalize on.

At this point, we can either solve real options problems using the *Multiple Asset Super Lattice Solver* (Figure 11.44) or applying its analytics directly in Excel by using the *SLS Functions* (Figures 11.45 and 11.46). The *MSLS* is used to obtain a quick answer but if a distribution of option values is required, then use the *SLS Functions* and link all the inputs into the function—we use the latter in this case study. Figure 11.45 shows the real options analysis model where the inputs to this model are the outputs from the DCF

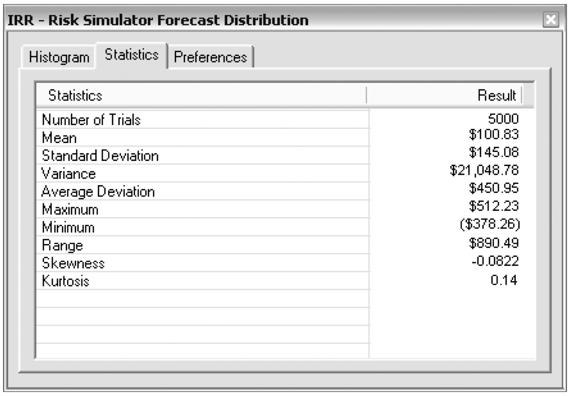


FIGURE 11.43 Calculated NPV Statistics

model in the previous step. For instance, the free cash flows are computed previously in the DCF. The Expanded NPV value in cell C21 is obtained through the SLS Function call (Figure 11.46). Simulation was used to also obtain the volatility required in the real options analysis.

The MSLS results indicate an expanded NPV of $388.10, while the previous NPV was $123.14. This means that there is an additional $264.97 expected value in creating a two-staged development of this project, rather than

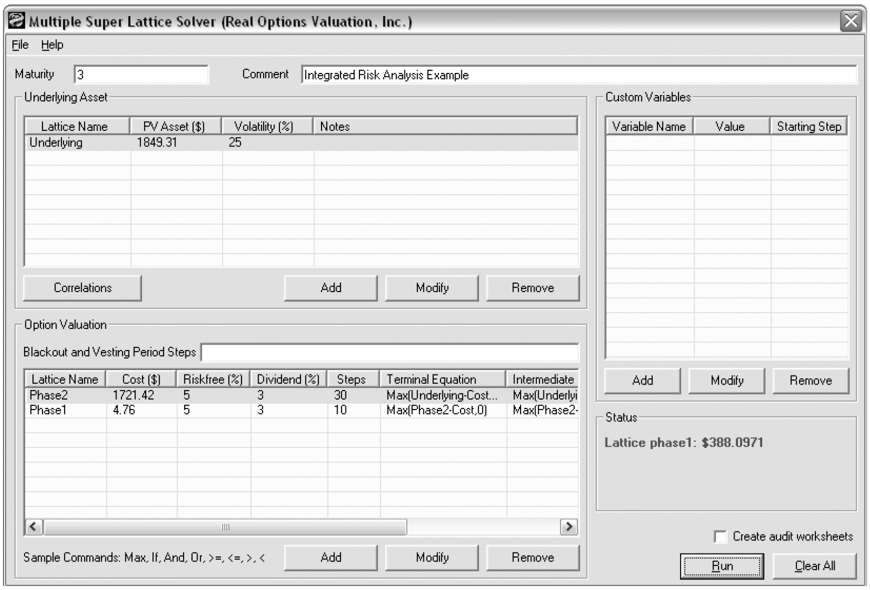


FIGURE 11.44 MSLS Analysis Results

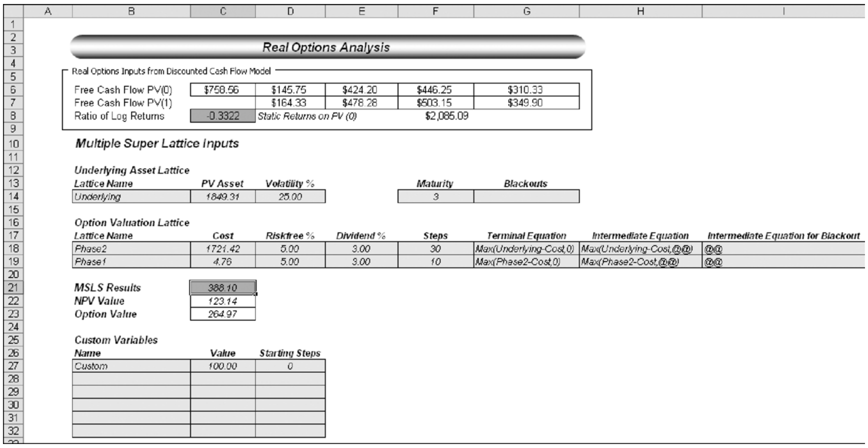


FIGURE 11.45 Worksheet-Based Real Option Analysis Functions

jumping in first and taking all the risk. That is, NPV analysis assumed that one would definitely invest all $5 in year 1 and $2,000 in year 3 regardless of the outcome (see Figure 11.47). This view of NPV analysis is myopic. Real options analysis, however, assumes that if all goes well in Phase I ($5), then continue on to Phase II ($2,000). Therefore, due to the volatility and uncertainty in the project (as obtained by Monte Carlo simulation), there is a chance that the $2,000 may not even be spent as Phase II never materializes (due to a bad outcome in Phase I). In addition, there is a chance that a valuation free

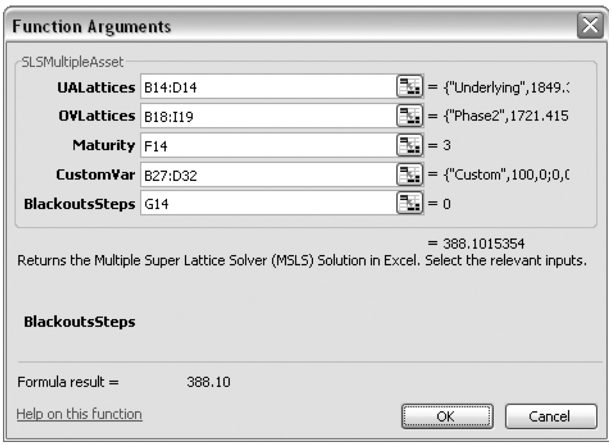


FIGURE 11.46 SLS Function for Cell C21

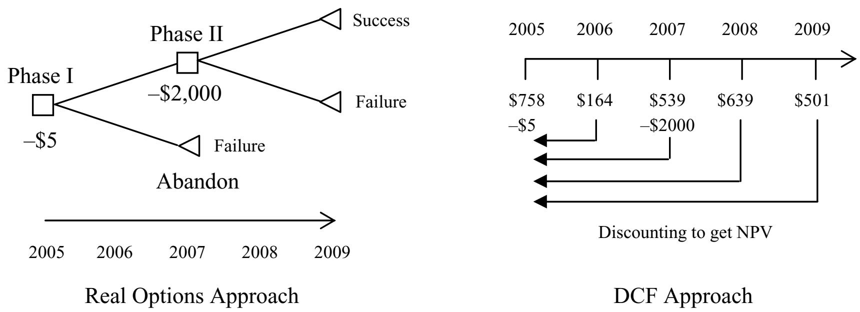


FIGURE 11.47 Graphical Representation of Real Options versus DCF Approaches

cash flow exceeding $1,849 may occur. The expected value of all these happenstances yields an expanded NPV of $388.10 (this is the expected value of the project after accounting for the downside risk mitigation and upside potential after a two-phased stage-gate development process is implemented). The fact that there is an option value means that it is better to perform a stage-gate development process than to take all the risks immediately and invest everything.

Notice that in the real options world, it is an option to execute Phase II, not a requirement, while in the DCF world all investments have been decreed in advance, and, thus, will and must occur. Therefore, management has the legitimate flexibility and ability to abandon the project after Phase I and not continue on Phase II if the outcome of the first phase is bad. Based on the volatility calculated in the real options model, there is a chance Phase II will never be executed, there's a chance that the cash flows could be higher and lower, and there is a chance that Phase II will be executed if the cash flows make it profitable. Therefore, the net expected value of the project after considering all these potential avenues is the option value calculated previously. In this example as well, we assumed a 3 percent annualized dividend yield, indicating that stage-gating the development and taking our time, the firm loses about 3 percent of its PV Asset per year (lost revenues and opportunity costs as well as lower market share due to waiting and deferring action).

Optimization

The next step is portfolio optimization, that is, how to efficiently and effectively allocate a limited budget (budget constraint and human resource constraints) across many possible projects while simultaneously accounting for their uncertainties, risks, and strategic flexibility, and all the while maximizing the portfolio's NPV. To this point we have shown how a single integrated model can be built utilizing simulation, forecasting, and real options. Table 11.26 illustrates a summary of 20 projects (here we assume that you have

TABLE 11.26 Summary of Projects Ready for Optimization

	Project Name	ENPV ($)	NPV ($)	Cost ($)	Risk (%)	Return-to-Risk Ratio	Profitability Index
1	Project A	388.10	123.14	1,732.44	25.00	1552.41	1.07
2	Project B	1,954.00	245.00	859.00	98.00	1993.88	1.29
3	Project C	1,599.00	458.00	1,845.00	97.00	1648.45	1.25
4	Project D	2,251.00	529.00	1,645.00	45.00	5002.22	1.32
5	Project E	849.00	564.00	458.00	109.00	778.90	2.23
6	Project F	758.00	135.00	52.00	74.00	1024.32	3.60
7	Project G	2,845.00	311.00	758.00	198.00	1436.87	1.41
8	Project H	1,235.00	754.00	115.00	75.00	1646.67	7.56
9	Project I	546.00	251.00	364.00	129.00	423.26	1.69
10	Project J	2,250.00	785.00	458.00	85.00	2647.06	2.71
11	Project K	549.00	35.00	45.00	48.00	1143.75	1.78
12	Project L	421.00	75.00	185.00	145.00	290.34	1.41
13	Project M	516.00	451.00	48.00	28.00	1842.86	10.40
14	Project N	499.00	458.00	351.00	94.00	530.85	2.30
15	Project O	859.00	125.00	421.00	65.00	1321.54	1.30
16	Project P	884.00	458.00	124.00	39.00	2266.67	4.69
17	Project Q	956.00	124.00	521.00	154.00	620.78	1.24
18	Project R	854.00	164.00	512.00	210.00	406.67	1.32
19	Project S	195.00	45.00	5.00	12.00	1625.00	10.00
20	Project T	210.00	85.00	21.00	10.00	2100.00	5.05
	Total	$20,618.10	$6,175.14	$10,519.44			

recreated the simulation, forecasting, and real options models for each project), complete with their expanded NPV, NPV, Cost, Risk, Return-to-Risk Ratio, and Profitability Index.

To simplify our analysis and to illustrate the power of optimization under uncertainty, the returns and risk values for projects B to T are simulated, instead of rebuilding this 19 other times.

Then, in Table 11.27, the individual project's human resource requirements as measured by full-time equivalences (FTE) are included. We simplify the problem by listing only the three major human resource requirements: engineers, managers, and salespeople. Their FTE requirements are simulated using Risk Simulator, as are their individual salary costs.

Finally, decision variables (Allocation column in Table 11.27) are constructed, with a minimum of 0 and a maximum of 1, with a discrete step of 1. That is, a project can have an allocation of 1 or 0, representing a go or no-go decision. Table 11.28 shows all 20 projects and their rankings sorted by returns, risk, cost, returns-to-risk ratio, and profitability ratio. Clearly, it is fairly difficult to determine simply by looking at this matrix which projects are the best to select in the portfolio. Figure 11.48 shows this matrix in

TABLE 11.27 Project Allocation and FTE Equivalences

	FTE Equivalence		
Allocation	**Engineers**	**Managers**	**Sales**
1	3.0	4.0	5.0
1	3.0	4.0	5.0
1	3.0	4.0	5.0
1	3.0	4.0	5.0
1	3.0	4.0	5.0
1	4.0	5.0	5.0
1	4.0	5.0	5.0
1	4.0	5.0	5.0
1	4.0	5.0	5.0
1	4.0	5.0	5.0
1	5.0	4.0	4.0
1	5.0	4.0	4.0
1	5.0	4.0	4.0
1	5.0	4.0	4.0
1	5.0	4.0	4.0
1	4.0	3.0	4.0
1	4.0	3.0	4.0
1	4.0	3.0	4.0
1	4.0	3.0	4.0
1	4.0	3.0	4.0
$18,900,000	$6,400,000	$8,000,000	$4,500,000

graphical form, where the size of the balls is the cost of implementation, the *x*-axis shows the total returns including flexibility, and the *y*-axis lists the project risk as measured by volatility of the cash flows of each project. Again, it is fairly difficult to choose the right combinations of projects at this point. Optimization is hence required to assist in our decision making.

To set up the optimization process, first select each of the allocation values in Table 11.27 and set the relevant decision variables by clicking on *Simulation* | *Set Decision Variable* (alternatively, you can create one decision variable and copy/paste). Then, click on *Simulation* | *Optimization* and enter the optimization preferences (Figure 11.49).

The linear constraint is such that the total budget value for the portfolio has to be less than $3,500. Next, select Portfolio NPV as the objective to maximize. Set the optimization to run for at least 60 minutes.

The following sections illustrate the results of the optimization under uncertainty and the results interpretation. Further, we can add an additional

TABLE 11.28 Project Selection Metrics Ranking

Project Name	ENPV	NPV	Cost	Risk	Return-to-Risk Ratio	Profitability Index	Optimizer (Go/No-Go)
Project A	18	16	19	3	10	20	1
Project B	4	11	17	14	5	17	1
Project C	5	5	20	13	7	18	1
Project D	2	4	18	6	1	14	1
Project E	11	3	12	15	15	9	1
Project F	12	13	5	9	14	6	1
Project G	1	9	16	19	11	12	1
Project H	6	2	6	10	9	3	1
Project I	14	10	10	16	18	11	1
Project J	3	1	12	11	2	7	1
Project K	13	20	3	7	13	10	1
Project L	17	18	8	17	20	13	1
Project M	15	8	4	4	6	1	1
Project N	16	5	9	12	17	8	1
Project O	9	14	11	8	12	16	1
Project P	8	5	7	5	3	5	1
Project Q	7	15	15	18	16	19	1
Project R	10	12	14	20	19	15	1
Project S	20	19	1	2	9	2	1
Project T	19	17	2	1	4	4	1

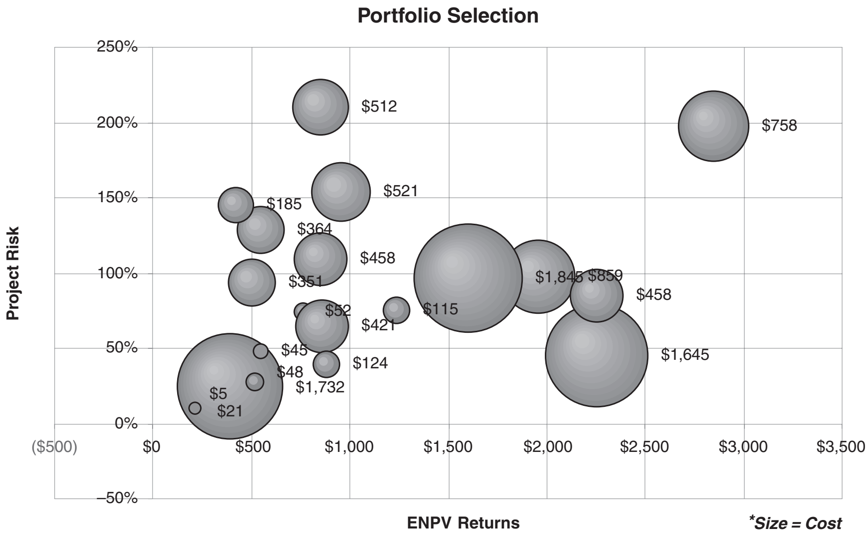


FIGURE 11.48 Graphical Representation of Project Selection Metrics

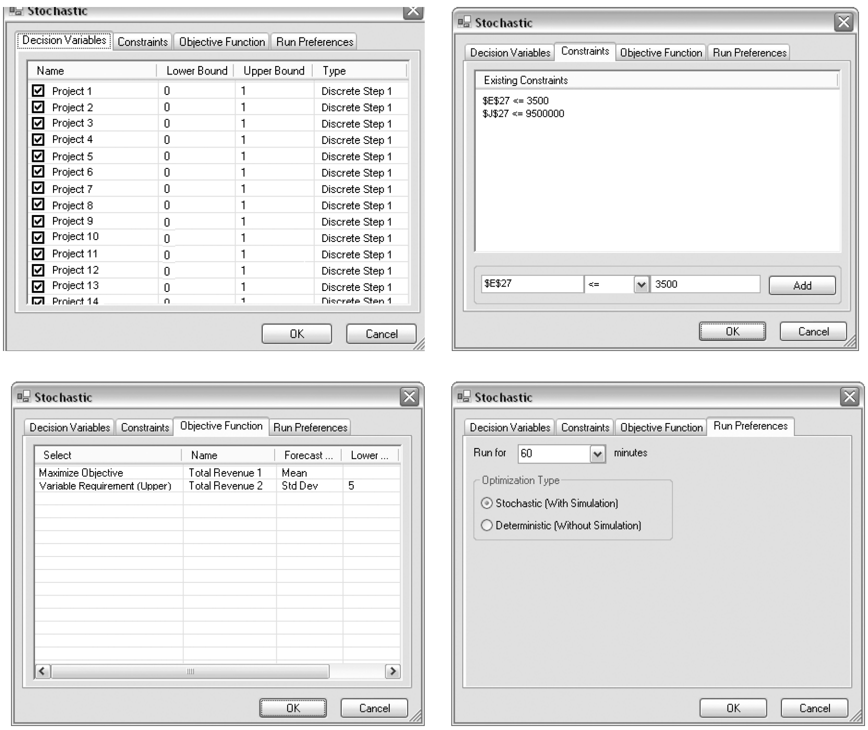


FIGURE 11.49 Optimization Preferences

constraint where the total FTE cannot exceed $9,500,000. We added in a variable requirement because by doing so, we can marginally increase the portfolio risk and see what additional returns the portfolio will obtain. In each run, with a variable requirement inserted, an efficient frontier will be generated. This efficient frontier is generated by connecting a sequence of optimal portfolios under different risk levels. That is, for a particular risk level, points on the frontier are the combinations of projects that maximize the returns of the portfolio. Similarly, these are the points where given a set of returns requirements, these combinations of projects provide the least amount of portfolio risk.

Optimization Results

For the first run, the following parameters were used:

Objective: Maximize Portfolio Returns
Constraint: Total Budget Allocation = $3,500M
Requirement: Total FTE Allocation = $9,500,000
Variable Requirement: 1 to 5 on Portfolio Risk

The results are shown in Figure 11.50 and Table 11.29 to Table 11.31. Figure 11.50 shows a portfolio efficient frontier, where, on the frontier, all the portfolio combinations of projects will yield the maximum returns (portfolio NPV) subject to the minimum portfolio risks. Clearly portfolio P1 is not a desirable outcome due to the low returns. So, the obvious candidates are P2 and

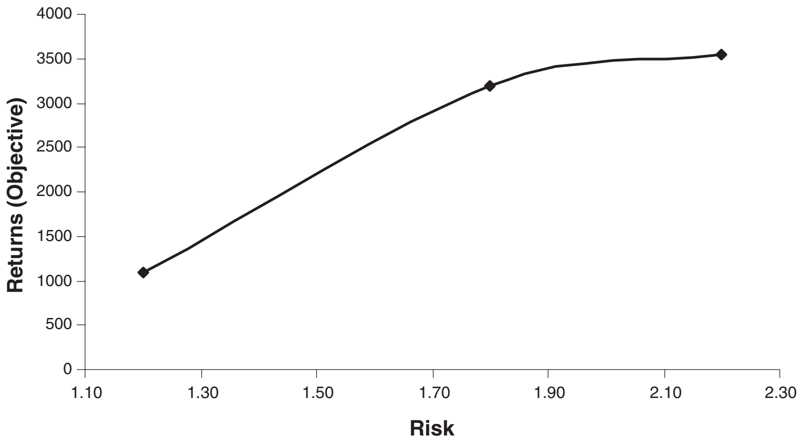


FIGURE 11.50 Efficient Frontier

TABLE 11.29 Project Selection for Portfolio 2

Project Name	ENPV	NPV	Cost	Risk	Return-to-Risk Ratio	Profitability Index	Optimizer (Go/No-Go)
Project A	18	13	19	2	4	20	0
Project B	4	11	17	14	6	17	0
Project C	5	5	20	13	8	18	0
Project D	2	4	18	6	1	14	1
Project E	11	3	12	15	15	9	1
Project F	12	14	5	9	14	6	1
Project G	1	9	16	19	11	12	0
Project H	6	2	6	10	9	3	1
Project I	14	10	10	16	18	11	0
Project J	3	1	12	11	2	7	1
Project K	13	20	3	7	13	10	0
Project L	17	18	8	17	20	13	0
Project M	15	8	4	4	7	1	1
Project N	16	5	9	12	17	8	0
Project O	9	15	11	8	12	16	0
Project P	8	5	7	5	3	5	0
Project Q	7	16	15	18	16	19	0
Project R	10	12	14	20	19	15	0
Project S	20	19	1	3	10	2	0
Project T	19	17	2	1	5	4	0

TABLE 11.30 Project Selection for Portfolio 3

Project Name	ENPV	NPV	Cost	Risk	Return-to-Risk Ratio	Profitability Index	Optimizer (Go/No-Go)
Project A	18	13	19	2	4	20	0
Project B	4	11	17	14	6	17	0
Project C	5	5	20	13	8	18	0
Project D	2	4	18	6	1	14	1
Project E	11	3	12	15	15	9	1
Project F	12	14	5	9	14	6	1
Project G	1	9	16	19	11	12	0
Project H	6	2	6	10	9	3	1
Project I	14	10	10	16	18	11	1
Project J	3	1	12	11	2	7	1
Project K	13	20	3	7	13	10	1
Project L	17	18	8	17	20	13	0
Project M	15	8	4	4	7	1	1
Project N	16	5	9	12	17	8	0
Project O	9	15	11	8	12	16	0
Project P	8	5	7	5	3	5	0
Project Q	7	16	15	18	16	19	0
Project R	10	12	14	20	19	15	0
Project S	20	19	1	3	10	2	0
Project T	19	17	2	1	5	4	1

TABLE 11.31 Summary of Results from Optimization Run I

Portfolio Characteristics	Portfolio 2 (P2)	Portfolio 3 (P3)
Expected NPV (Mean)	$3,208	$3,532
Expected risk (Mean)	182%	218%
Budget used	$2,776	$3,206
90 percentile FTE total cost	$6,368,000	$9,423,000
90% confidence interval for NPV	$2,964 to $3,443	$3,304 to $3,764
90% confidence range for NPV	$479	$460
90% confidence interval for risk	167% to 197%	203 to 234%
90% confidence range for risk	30%	31%
Projects selected	D, E, F, H, J, M	D, E, F, H, I, J, K, M, T

P3. These two portfolios are analyzed in detail in Tables 11.29 to 11.31. It is now up to management to determine what risk–return combination it wants; that is, depending on the risk appetite of the decision makers, these three portfolios are the optimal combinations of projects that maximize returns subject to the least risk, considering the uncertainties (simulation), strategic flexibility (real options), and uncertain future outcomes (forecasting). To summarize the results, Table 11.31 shows the two portfolio combinations side by side. Of course, the results here are only for a specific set of input assumptions, constraints, and so forth. You may choose to change any of the input assumptions to obtain different variants of optimal portfolio allocations.

Many observations can be made from Table 11.31's summary of results. While both optimal portfolios are constrained at under a $3,500M budget and $9,500,000 FTE total cost, P3 uses the budget more effectively as it generates a higher NPV for the entire portfolio but has a higher level of risk (wider range for NPV and risk, higher volatility risk coefficient, requires more projects making it riskier, and higher total cost to implement). For the budget used and the NPV obtained, the lowest risk level required is 218 percent, which is about a 20 percent greater risk compared to P2. In contrast, P2 costs less and has lower risk but comes at the cost of a slightly less NPV and IRR level—these values are obtained from the forecast charts from Risk Simulator (not shown). It is at this point that the decision maker has to decide which risk–return profile to undertake. All other combinations of projects in a portfolio are by definition suboptimal to these two, given the same constraints, and should not be entertained. Hence, from a possible portfolio combination of 20! or 2×10^{18} possible outcomes, we have now isolated the decision down to these two best portfolios. Finally, we can again employ a high-level portfolio real option on the decision. That is, because both portfolios require the implementation of projects D, E, F, H, J, M, do these first! Then, leave the option open to execute the remaining projects (I, K, T) if management decides to pursue P3 later.

CASE 7: BIOPHARMACEUTICAL INDUSTRY—VALUING STRATEGIC MANUFACTURING FLEXIBILITY

This case study was contributed by Uriel Kusiatin, principal and cofounder of 2Value Consulting Group (urielk@twovalue.com), a New York–based management consulting firm that applies advanced financial evaluation and decision analysis techniques to help biopharmaceutical companies significantly improve the way they make and execute strategic decisions. Specifically, 2Value utilizes real options, Monte Carlo simulation, and optimization techniques to evaluate R&D portfolio decisions, licensing opportunities, and major capital investments. 2Value is a strategic partner of the author's firm, Real Options Valuation, Inc. Mr. Kusiatin holds an MBA from the Wharton School and a BSc in industrial engineering from The Engineering Academy of Denmark.

Making decisions on significant investments in manufacturing capacity is a challenging proposition. Biopharmaceutical manufacturing and operations executives are often required to make difficult decisions—decisions that may have significant impact on their company's ability to successfully compete in a complex and highly uncertain business environment.

One of the biggest challenges facing these executives is securing manufacturing capacity for products that are under development and years away from launch. They face a choice between multiple alternatives that include building internal capabilities, outsourcing these to a Contract Manufacturing Organization (CMO), or a combination of the two.

These decisions involve significant capital investments as well as the opportunity cost of allocating funds away from other important initiatives. An internal solution may take four to six years and cost up to $500 million to implement, while there is no guarantee that an outsourced solution will be available when needed, or be sufficiently cost-effective and flexible to meet the needs of the company.

Sizing capacity needs is also challenging. Technology risk associated with biopharmaceutical drug development efforts is high. The probability of a drug candidate in preclinical trials reaching the market is on average less than 20 percent. Market assumptions regarding price, demand, and competition may change dramatically during the lengthy development process and require different capacity than initially anticipated. Build too much and the company