



Chapter 10: Decision Models with Uncertainty and Risk

Statistics, Data Analysis, and
Decision Modeling, Fifth Edition
James R. Evans



Risk Analysis

- **Risk** is the probability of occurrence of an undesirable outcome.
- **Risk analysis** is an approach for developing an understanding of risk in making decisions
 - Examines the impacts of uncertainty in estimates of inputs and their potential interaction with one another on the output variable of interest



Monte Carlo Simulation

- The process of generating random values for uncertain inputs in a model, computing the output variables of interest, and repeating this process for many trials in order to understand the distribution of the output results.

Outsourcing Model

	A	B	C	D	E	F	G
1	Outsourcing Decision Model				Demand	Difference	Decision
2				Trial	1090	\$ (4,500)	Manufacture
3	Data			1	952	\$ 2,400	Outsource
4				2	857	\$ 7,150	Outsource
5	Manufactured in-house			3	812	\$ 9,400	Outsource
6	Fixed cost	\$ 50,000		4	874	\$ 6,300	Outsource
7	Unit variable cost	\$ 125		5	860	\$ 7,000	Outsource
8				6	1037	\$ (1,850)	Manufacture
9	Purchased from supplier			7	888	\$ 5,600	Outsource
10	Unit cost	\$ 175		8	1023	\$ (1,150)	Manufacture
11				9	934	\$ 3,300	Outsource
12	Model			10	1054	\$ (2,700)	Manufacture
13				11	1096	\$ (4,800)	Manufacture
14	Demand volume	1090		12	911	\$ 4,450	Outsource
15				13	828	\$ 8,600	Outsource
16	Total manufacturing cost	\$ 186,250		14	1034	\$ (1,700)	Manufacture
17	Total purchased cost	\$ 190,750		15	997	\$ 150	Outsource
18	Difference	\$ (4,500)		16	1137	\$ (6,850)	Manufacture
19				17	904	\$ 4,800	Outsource
20	Decision	Manufacture		18	985	\$ 750	Outsource
21				19	970	\$ 1,500	Outsource
22				20	957	\$ 2,150	Outsource
23					Average	\$ 2,225	
24						% Manufacture	30%
25						% Outsource	70%



Monte-Carlo Simulation Using *Crystal Ball*

1. Build a spreadsheet model for a decision problem
2. Recognize uncertain model variables and identify probability distributions associated with them (**assumptions**)
3. Identify output variables of interest (**forecast cells**)
4. Set the number of trials and other run preferences
5. Run the simulation
6. Interpret the results

Example: Moore Pharmaceuticals Model

	A	B	C	D	E	F
1	Moore Pharmaceuticals					
2						
3	Data					
4						
5	Market size	2,000,000				
6	Unit (monthly Rx) revenue	\$ 130.00				
7	Unit (monthly Rx) cost	\$ 40.00				
8	Discount rate	9%				
9						
10	Project Costs					
11	R&D	\$ 700,000,000				
12	Clinical Trials	\$ 150,000,000				
13	Total Project Costs	\$ 850,000,000				
14						
15	Model					
16						
17	Year	1	2	3	4	5
18	Market growth factor		3.00%	3.00%	3.00%	3.00%
19	Market size	2,000,000	2,060,000	2,121,800	2,185,454	2,251,018
20	Market share growth rate		20.00%	20.00%	20.00%	20.00%
21	Market share	8.00%	9.60%	11.52%	13.82%	16.59%
22	Sales	160,000	197,760	244,431	302,117	373,417
23						
24	Annual Revenue	\$ 249,600,000	\$ 308,505,600	\$ 381,312,922	\$ 471,302,771	\$ 582,530,225
25	Annual Costs	\$ 76,800,000	\$ 94,924,800	\$ 117,327,053	\$ 145,016,237	\$ 179,240,069
26	Profit	\$ 172,800,000	\$ 213,580,800	\$ 263,985,869	\$ 326,286,534	\$ 403,290,156
27	Cumulative Net Profit	\$(677,200,000)	\$(463,619,200)	\$(199,633,331)	\$ 126,653,203	\$ 529,943,358
28						
29	Net Present Value	\$ 185,404,860				



Typical Risk Analysis Questions

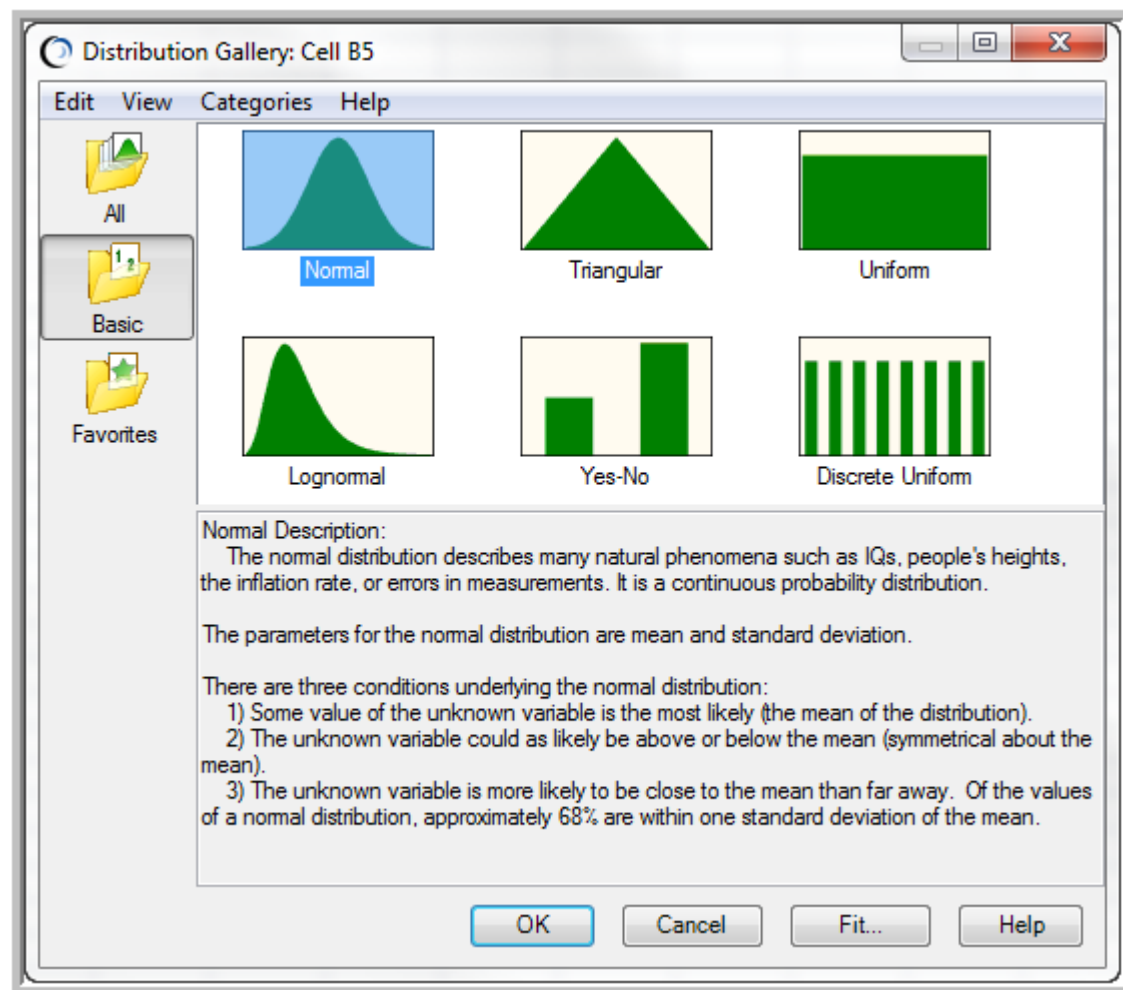
- What is the risk that the NPV over the five years will not be positive?
- What are the chances that the product will show a cumulative net profit in the third year?
- What cumulative profit in the fifth year are we likely to realize with a probability of at least 0.90?



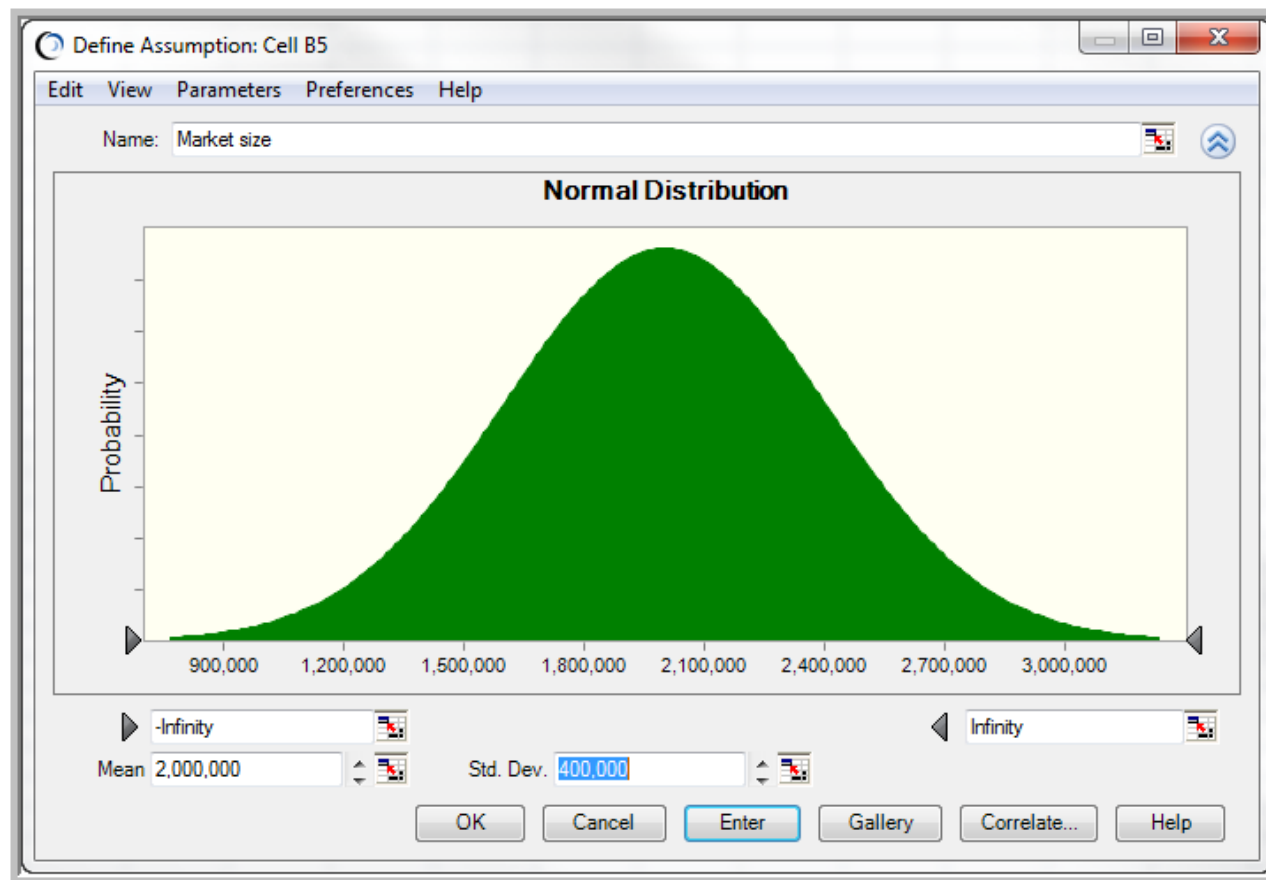
Define Assumptions

- Market size: normal with a mean of 2,000,000 units and a standard deviation of 400,000 units
- R&D costs: uniform between \$600,000,000 and \$800,000,000
- Clinical trial costs: lognormal with mean of \$150,000,000 and standard deviation \$30,000,000
- Annual market growth factor: triangular with minimum = 2%, maximum = 6%, and most likely = 3%
- Annual market share growth rate: triangular with minimum = 15%, maximum = 25%, and most likely = 20%

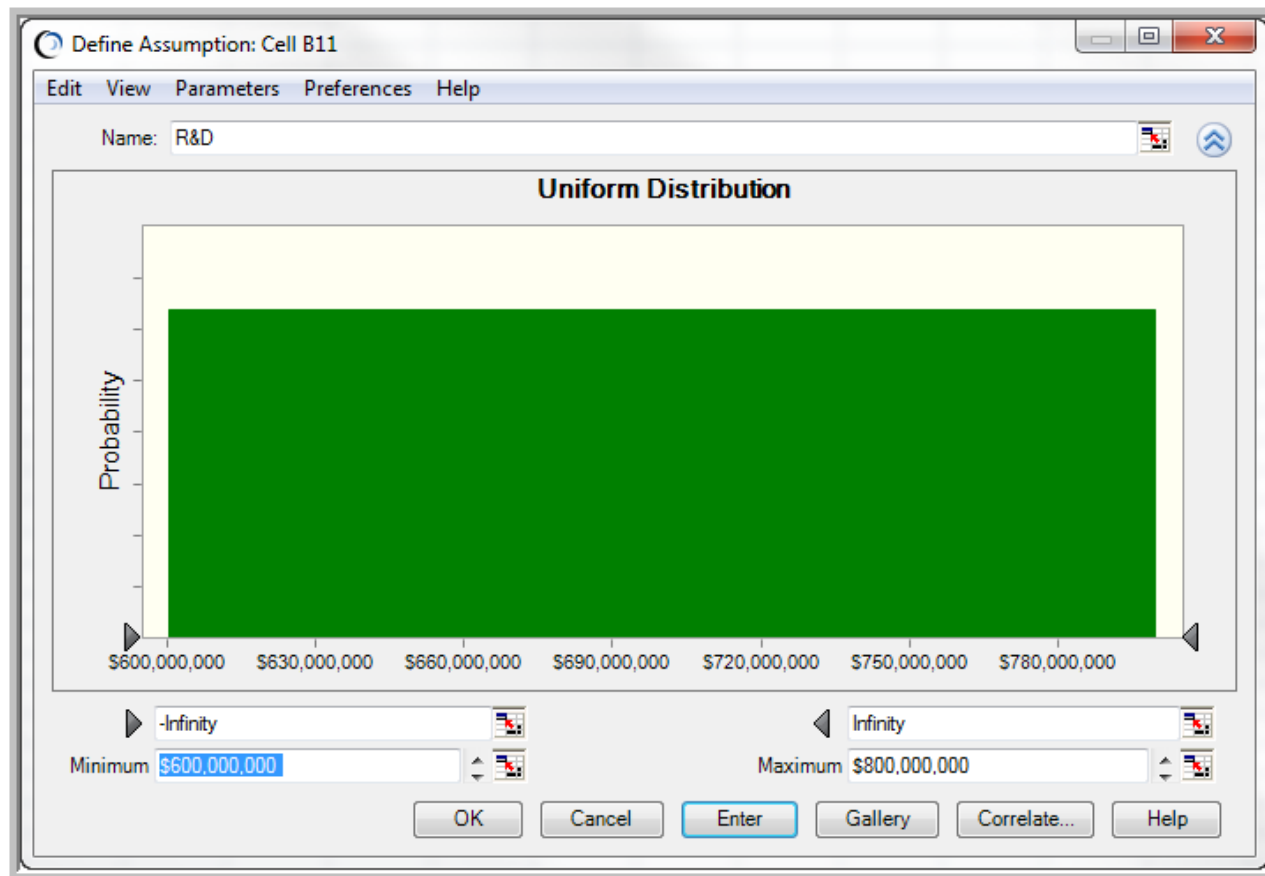
Crystal Ball Distribution Gallery



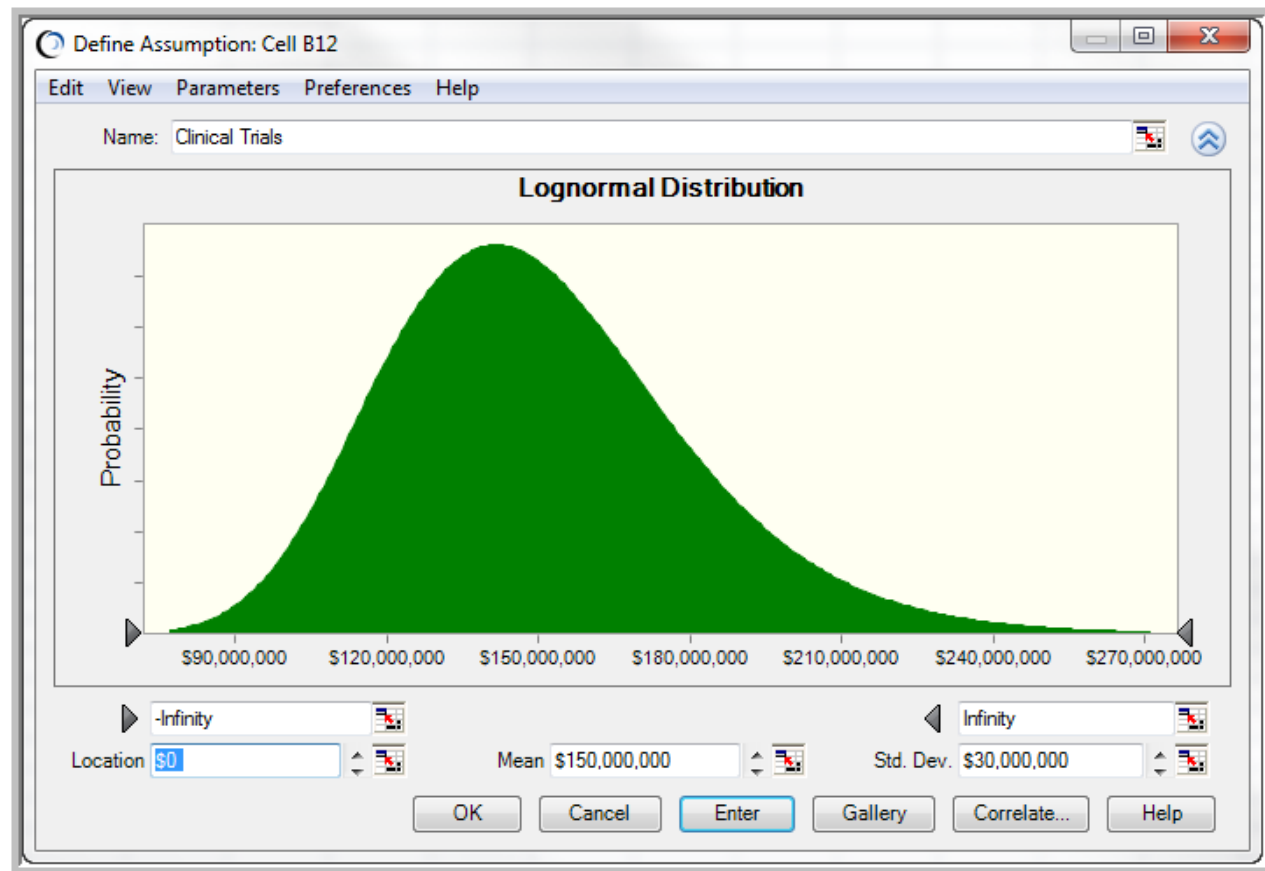
Market Size Normal Distribution Assumption



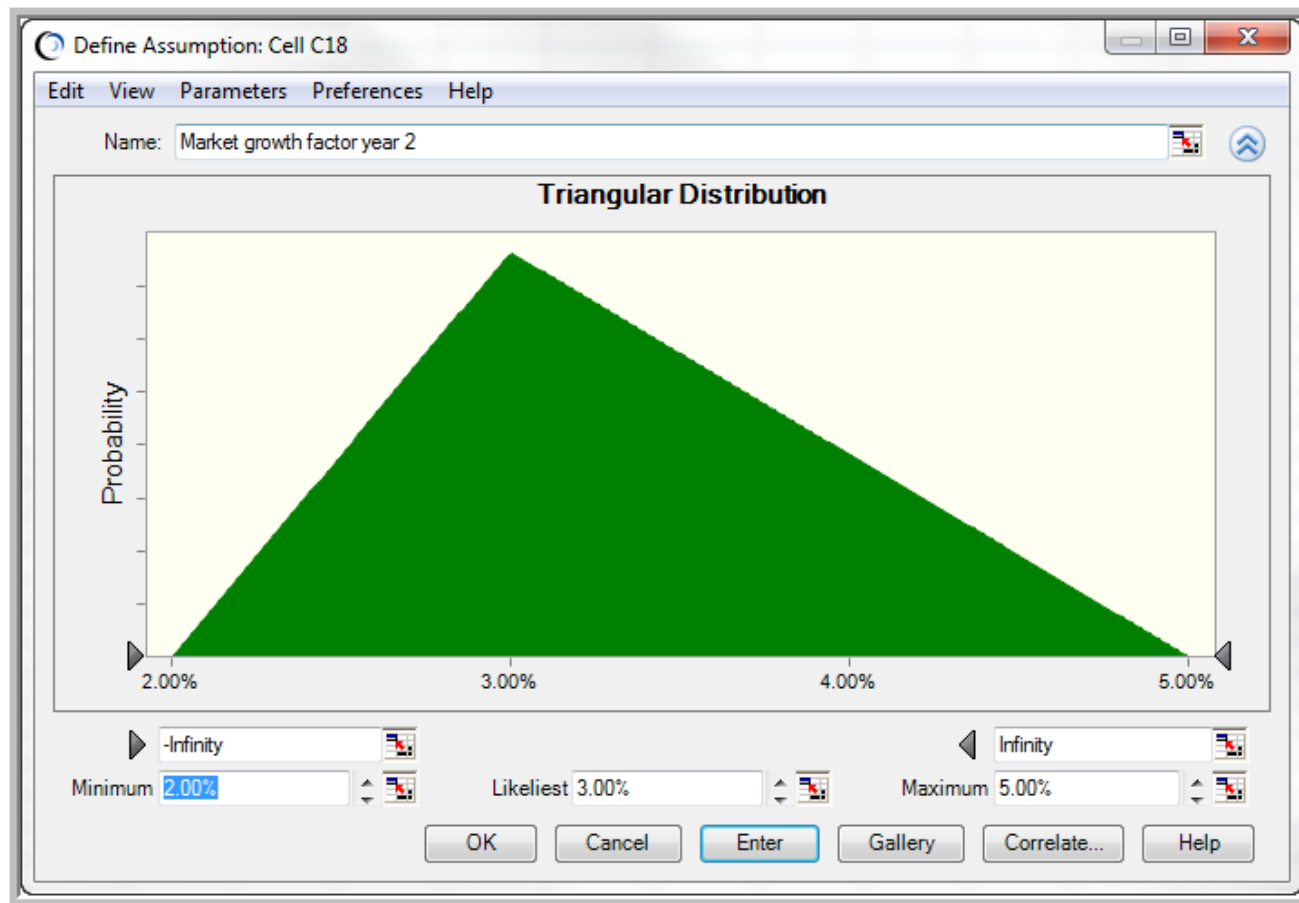
R&D Cost Assumption



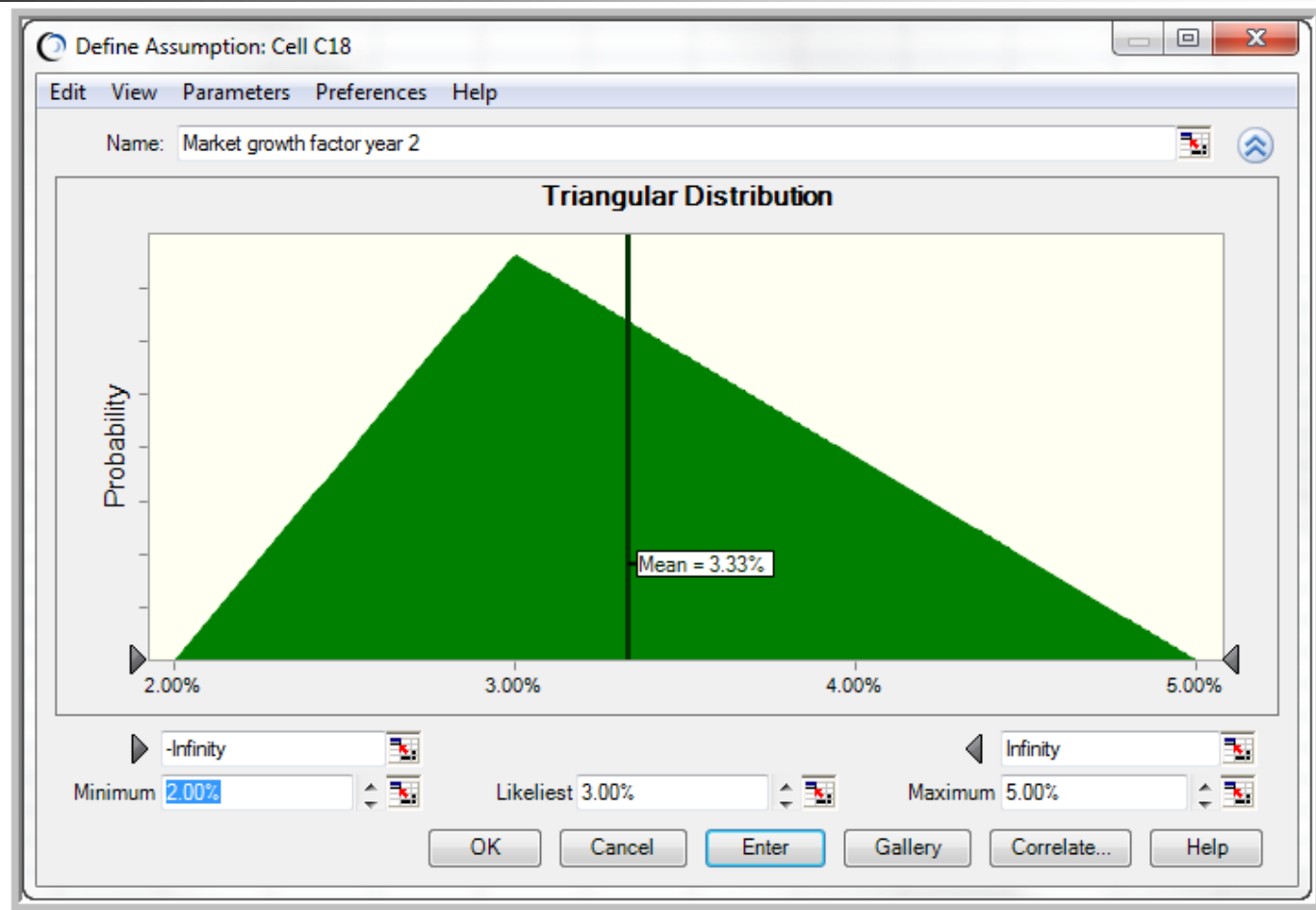
Clinical Trials Cost Assumption



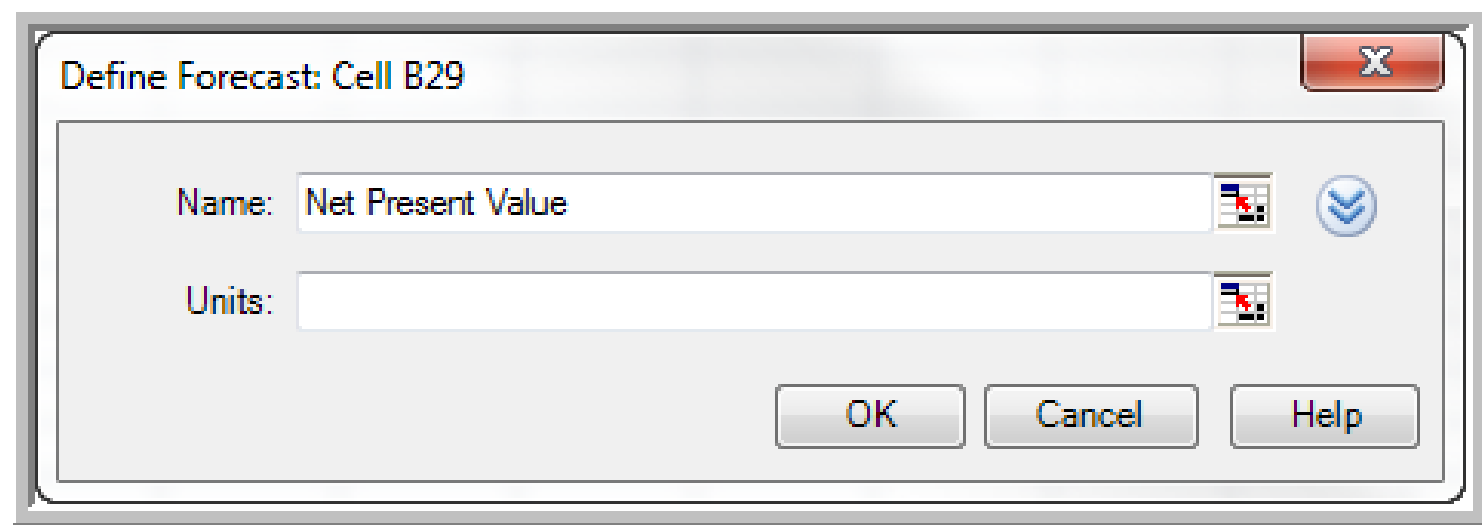
Year 2 Market Growth Factor Assumption



Marker Lines in *Crystal Ball*



Define Forecast Dialog



The image shows a 'Define Forecast' dialog box for cell B29. It has a title bar with a close button (X). The main area contains two input fields: 'Name' with the text 'Net Present Value' and 'Units' which is empty. Both fields have a small icon to their right. To the right of the 'Name' field is a blue button with a downward arrow. At the bottom are three buttons: 'OK', 'Cancel', and 'Help'.

Define Forecast: Cell B29

Name: Net Present Value

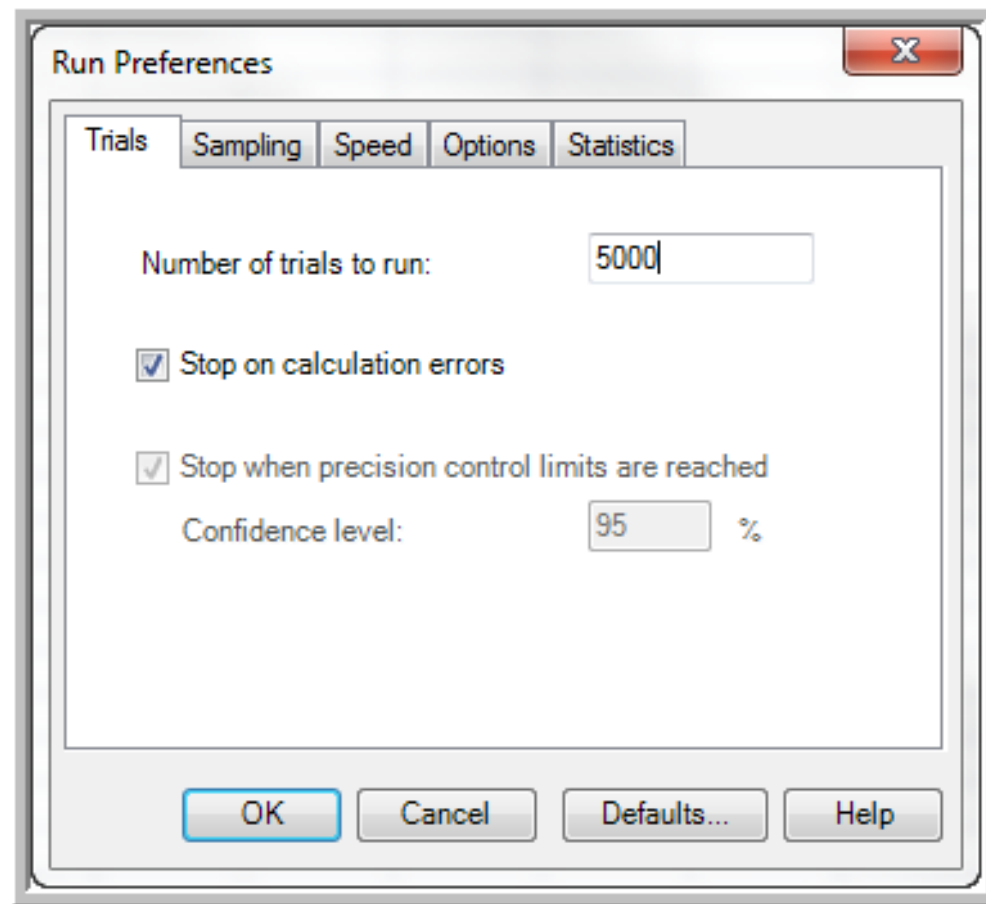
Units:

OK Cancel Help

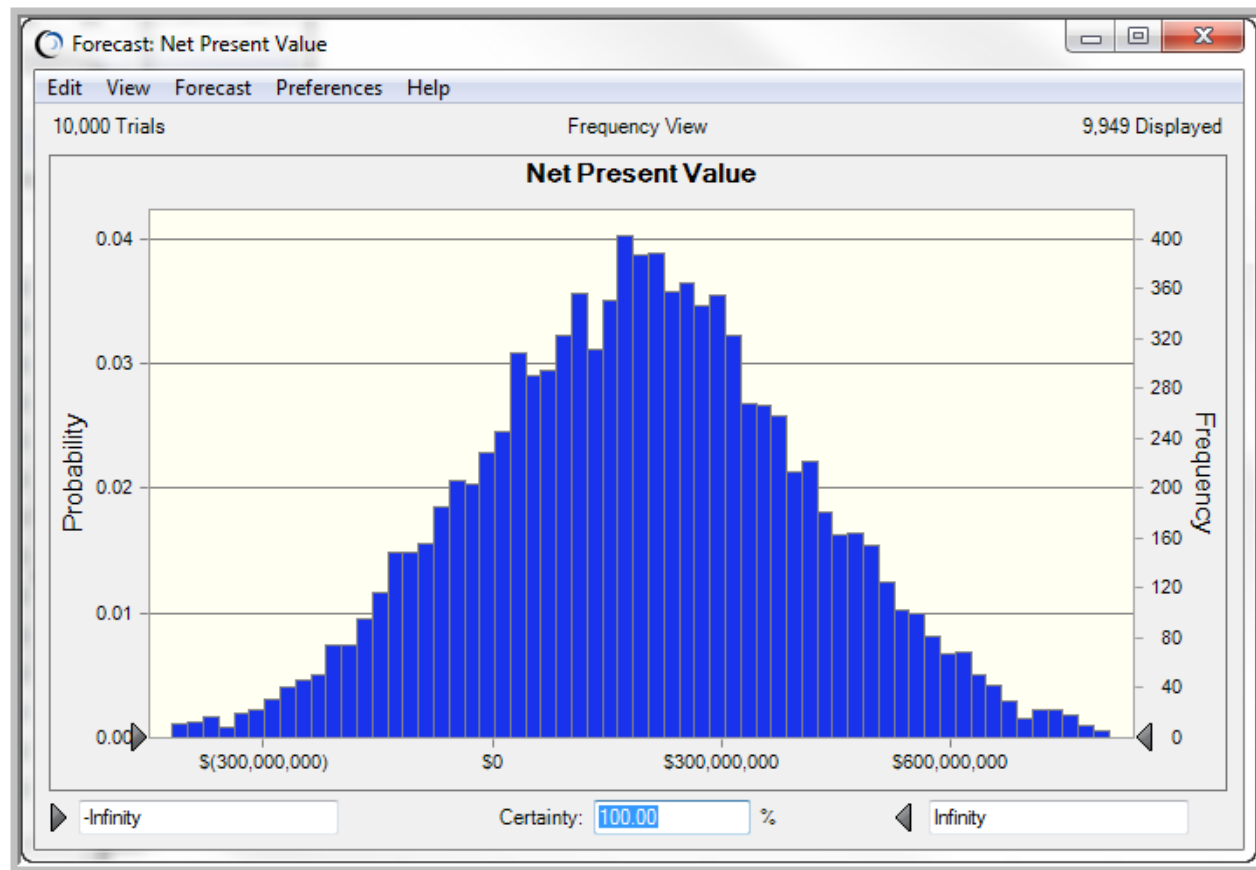
Model With Assumptions and Forecasts

	A	B	C	D	E	F
1	Moore Pharmaceuticals					
2						
3	Data					
4						
5	Market size	2,000,000				
6	Unit (monthly Rx) revenue	\$ 130.00				
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9						
10	Project Costs					
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28						
29	Net Present Value	\$ 185,404,860				

Run Preferences Dialog



Crystal Ball Forecast Chart



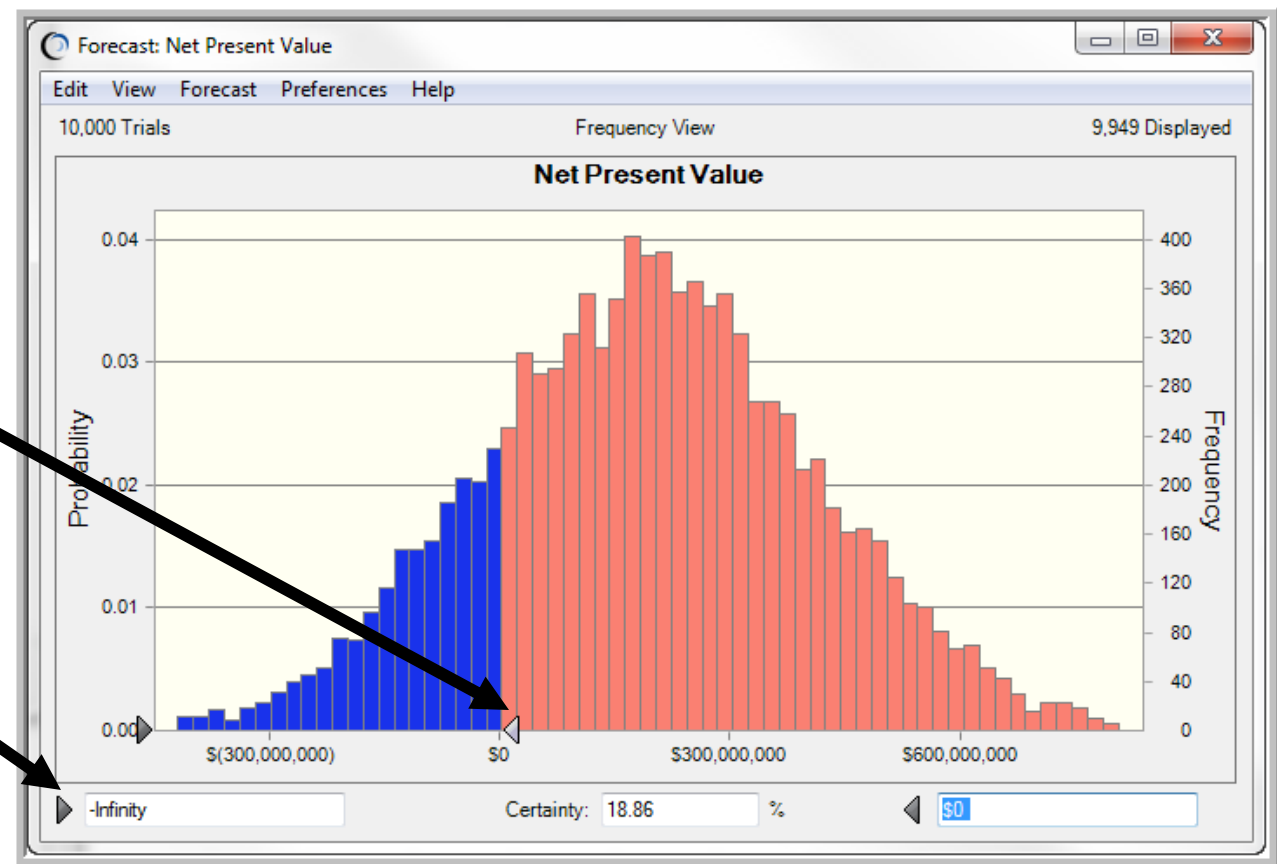


Analyzing Forecast Charts

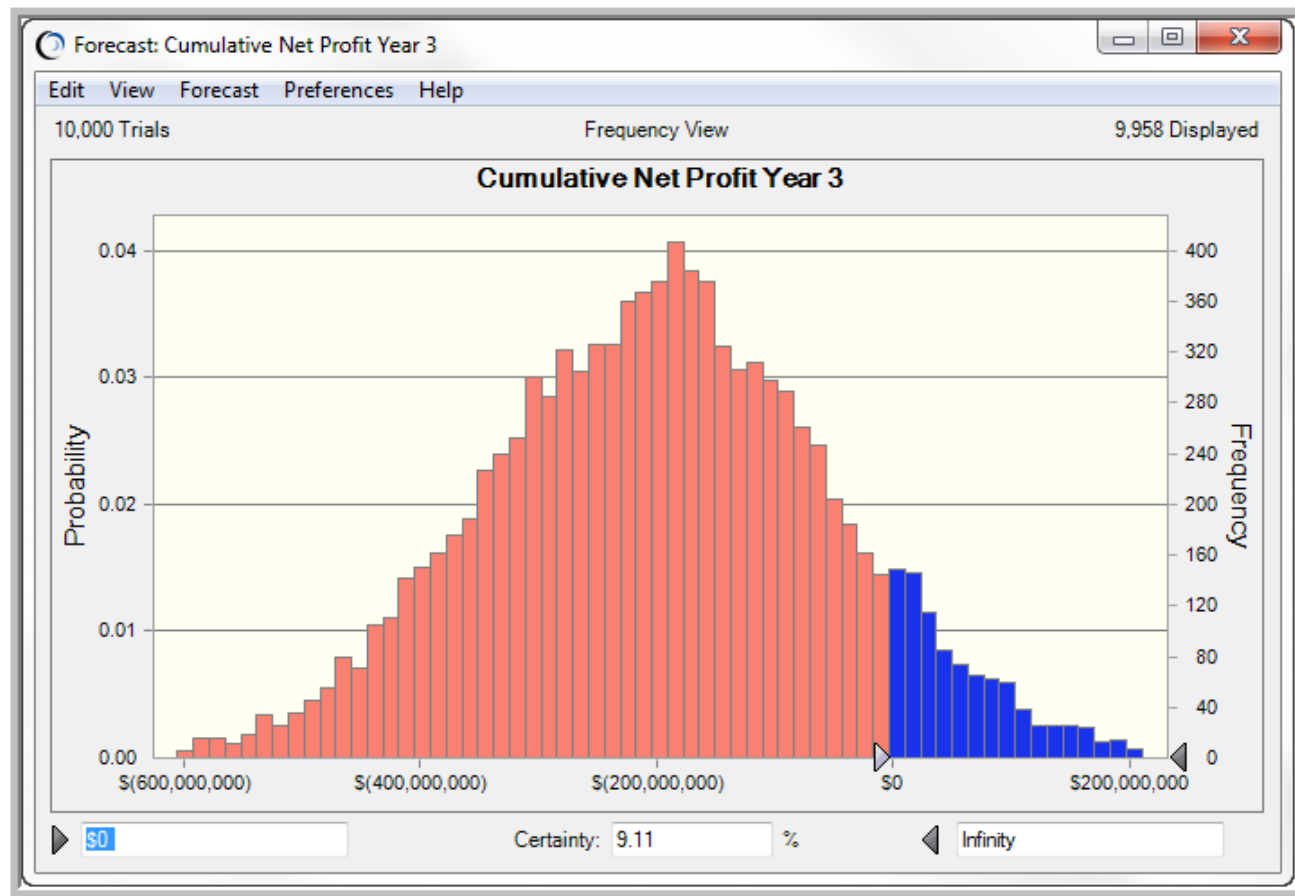
- You may move an endpoint grabber by clicking on the grabber and dragging it along the axis.
- You may type in specific values in the range boxes.
- You may specify a certainty level.

Probability of Nonpositive NPV

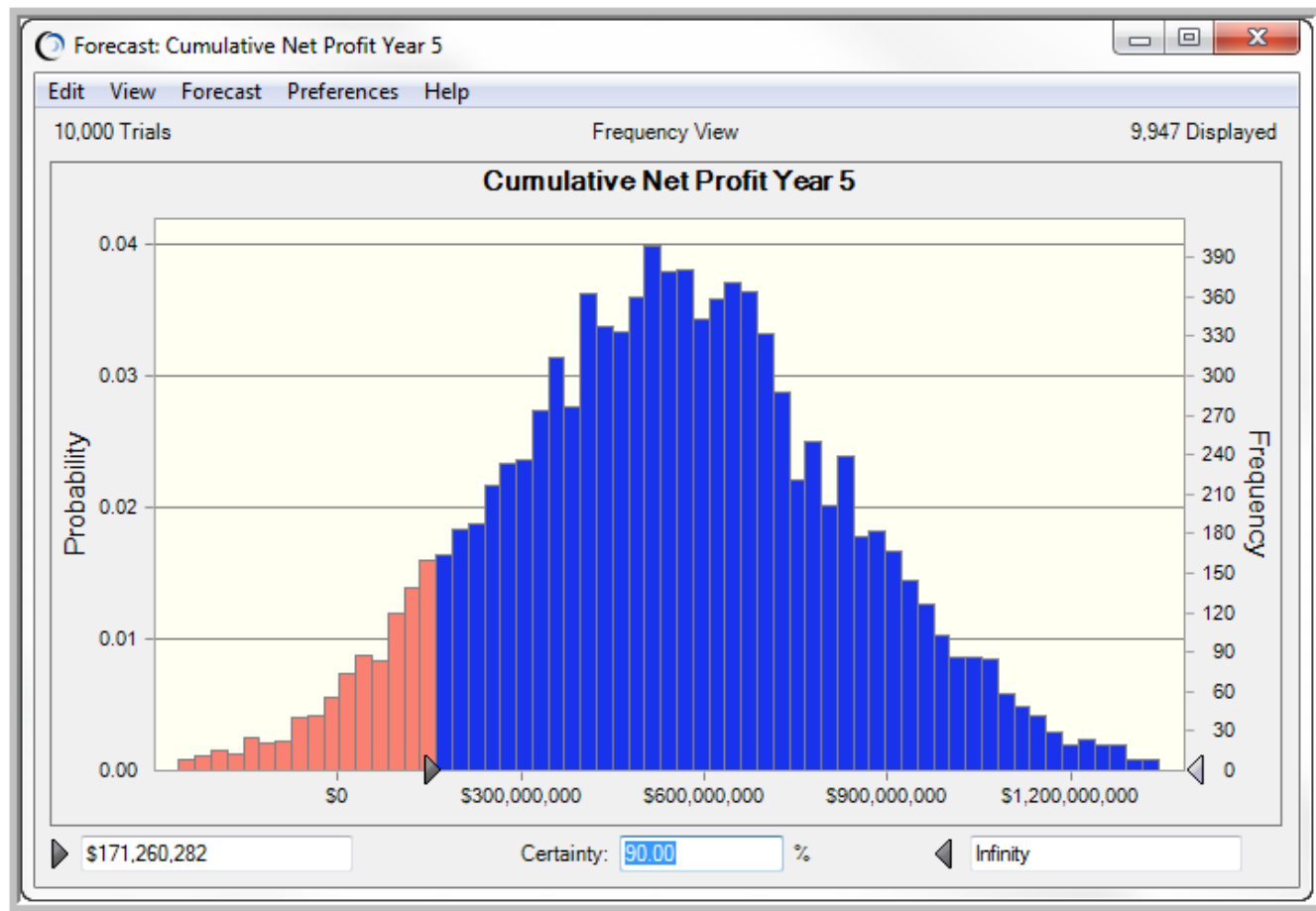
Drag grabber
or enter
values in box



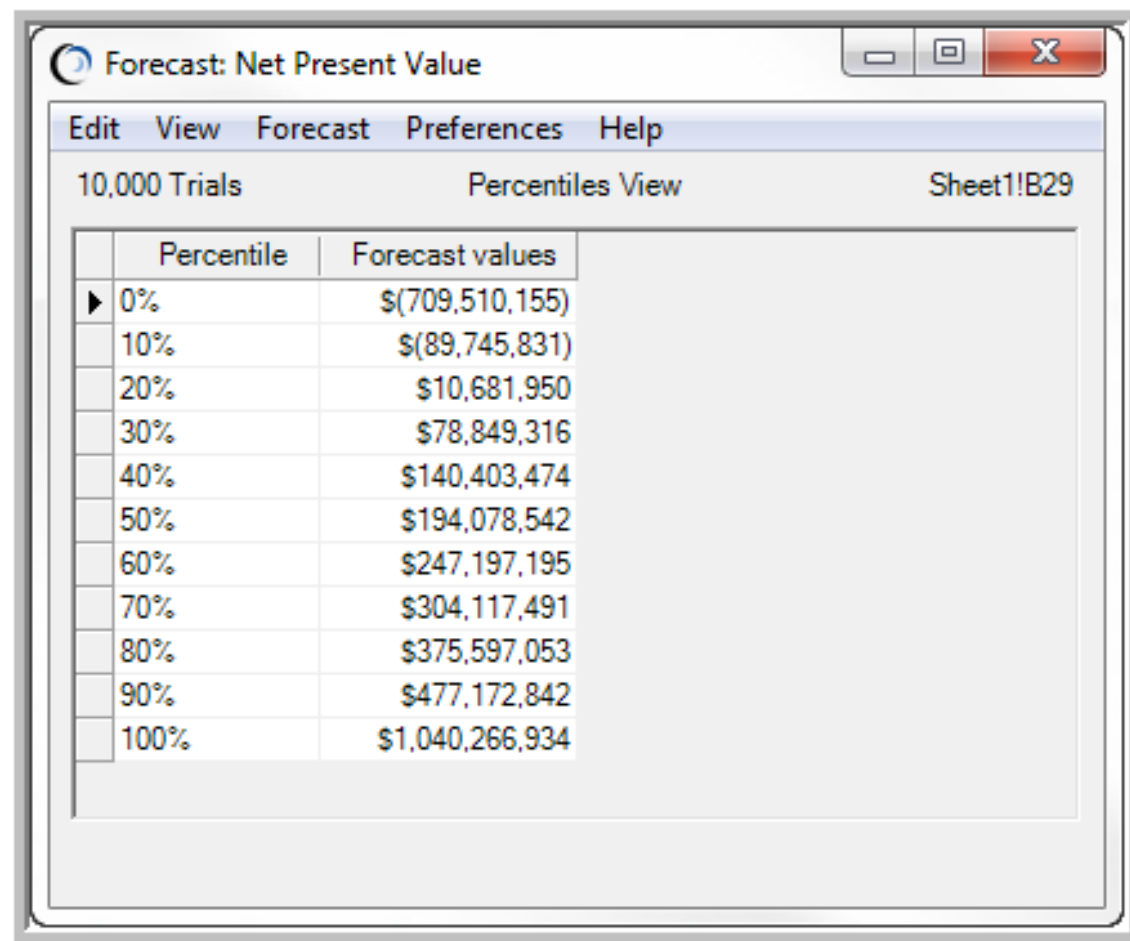
Cumulative Net Profit, Year 3



Cumulative Net Profit, Year 5



Percentiles View



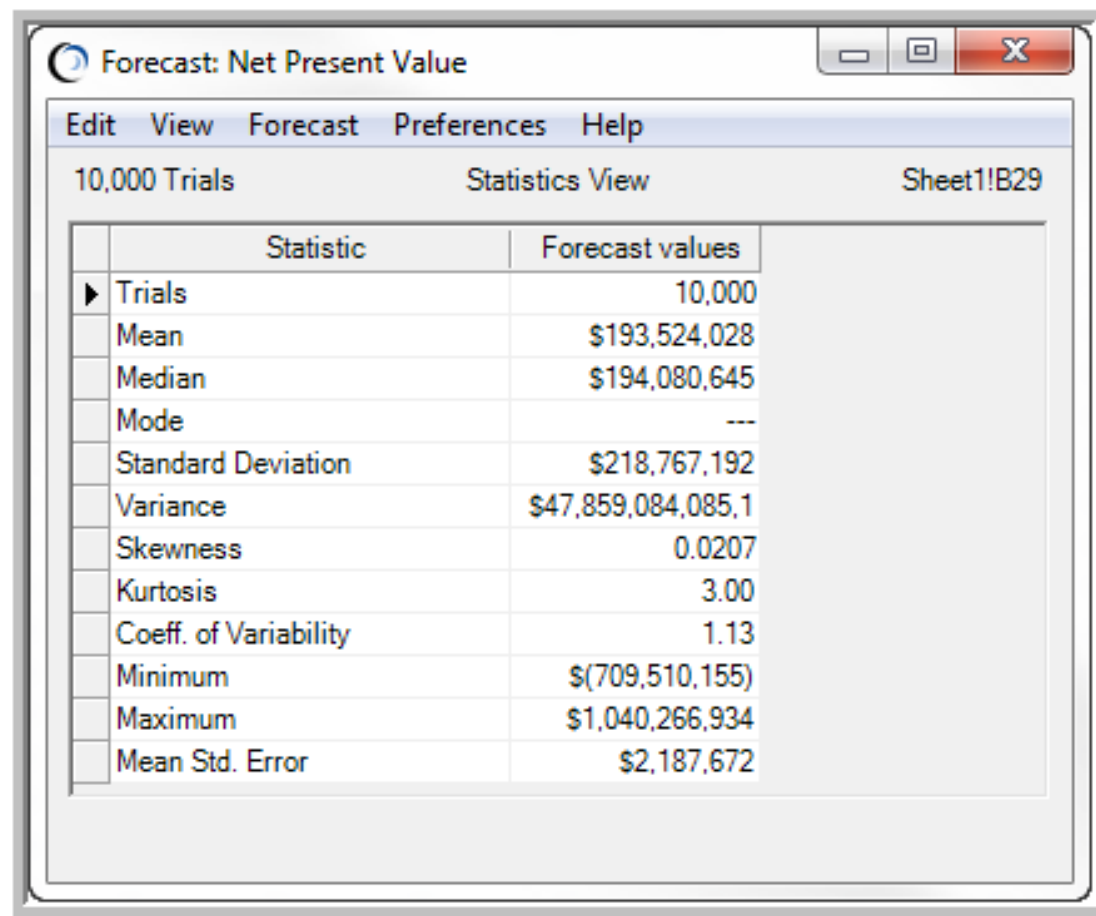
Forecast: Net Present Value

Edit View Forecast Preferences Help

10,000 Trials Percentiles View Sheet1!B29

Percentile	Forecast values
0%	\$(709,510,155)
10%	\$(89,745,831)
20%	\$10,681,950
30%	\$78,849,316
40%	\$140,403,474
50%	\$194,078,542
60%	\$247,197,195
70%	\$304,117,491
80%	\$375,597,053
90%	\$477,172,842
100%	\$1,040,266,934

Statistics View



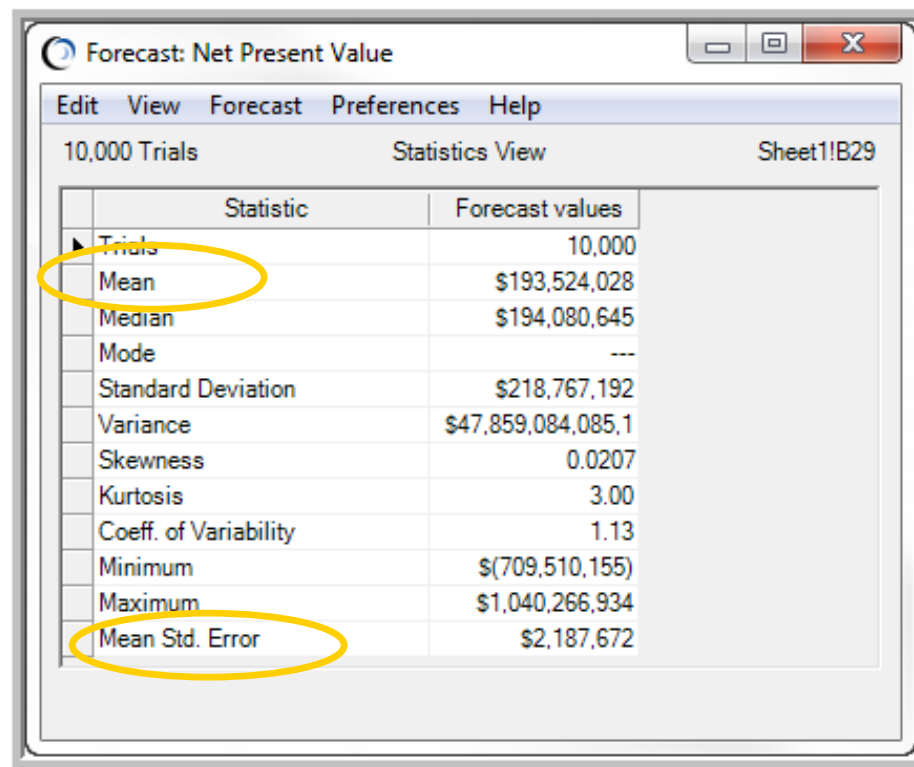
Forecast: Net Present Value

Edit View Forecast Preferences Help

10,000 Trials Statistics View Sheet1!B29

Statistic	Forecast values
► Trials	10,000
Mean	\$193,524,028
Median	\$194,080,645
Mode	---
Standard Deviation	\$218,767,192
Variance	\$47,859,084,085,1
Skewness	0.0207
Kurtosis	3.00
Coeff. of Variability	1.13
Minimum	\$(709,510,155)
Maximum	\$1,040,266,934
Mean Std. Error	\$2,187,672

Computing a CI



Forecast: Net Present Value

10,000 Trials Statistics View Sheet1!B29

Statistic	Forecast values
Trials	10,000
Mean	\$193,524,028
Median	\$194,080,645
Mode	---
Standard Deviation	\$218,767,192
Variance	\$47,859,084,085.1
Skewness	0.0207
Kurtosis	3.00
Coeff. of Variability	1.13
Minimum	\$(709,510,155)
Maximum	\$1,040,266,934
Mean Std. Error	\$2,187,672

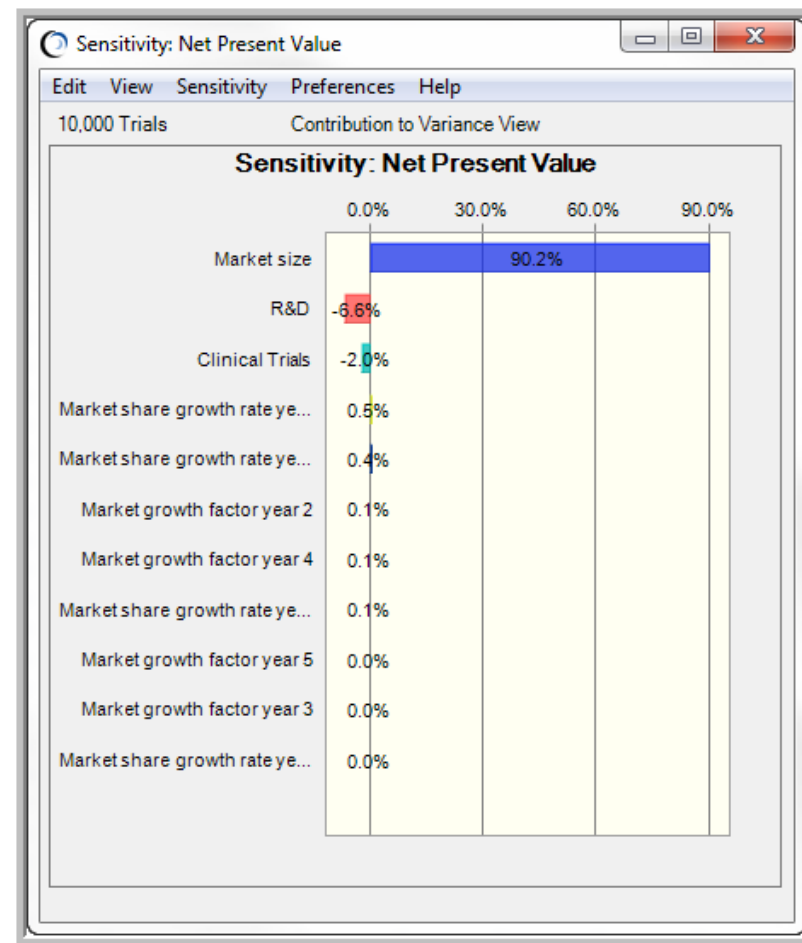
A 95 percent confidence interval for the mean would be
 $\$193,524,028 \pm 1.96(2,187,672)$ or $[\$189,236,191, \$197,811,865]$



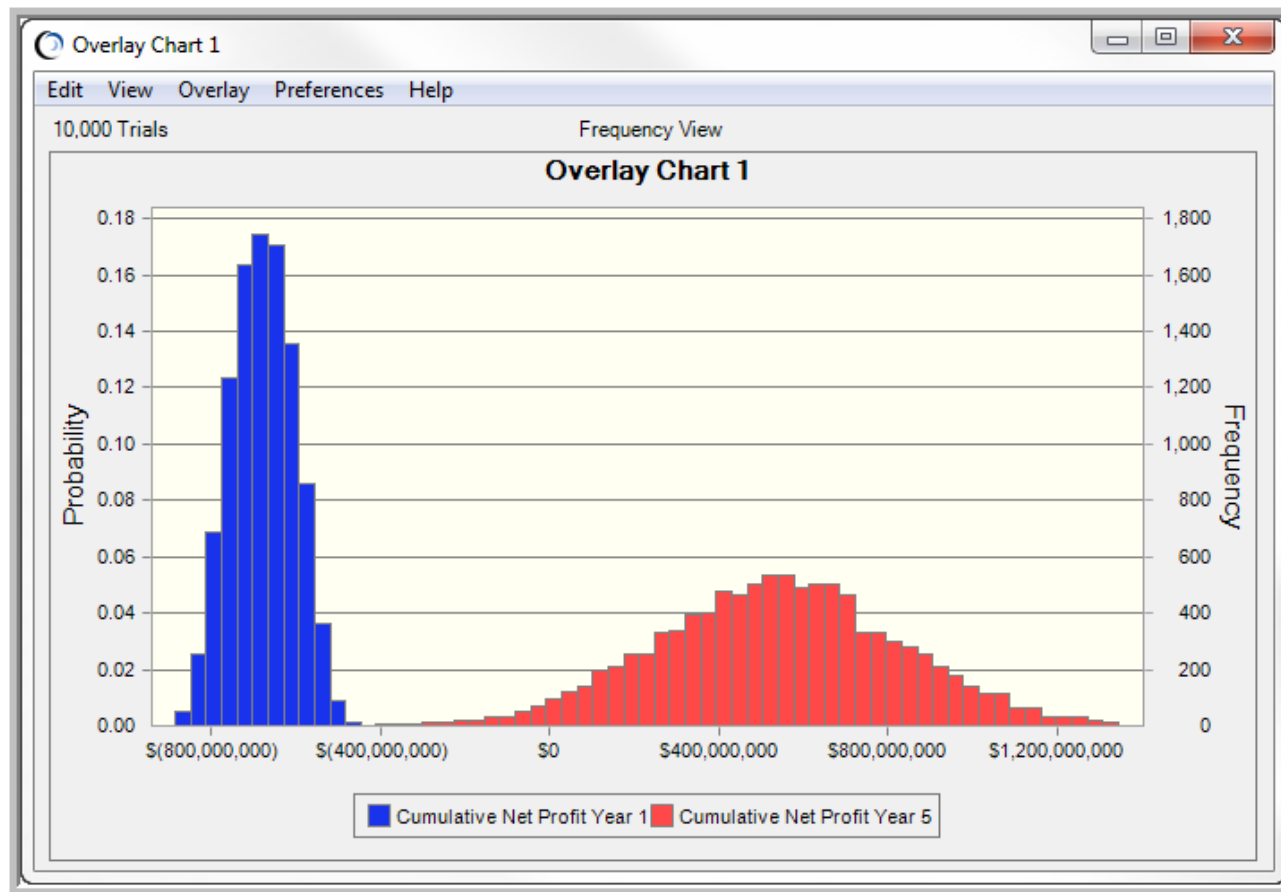
Sensitivity Chart

- It tells which assumptions are influencing forecasts the most and which need better estimates.
- It tells which assumptions are influencing forecasts the least and can be ignored or discarded altogether.
- By understanding how assumptions affect your model, you can develop more realistic spreadsheet models and improve the accuracy of your results.

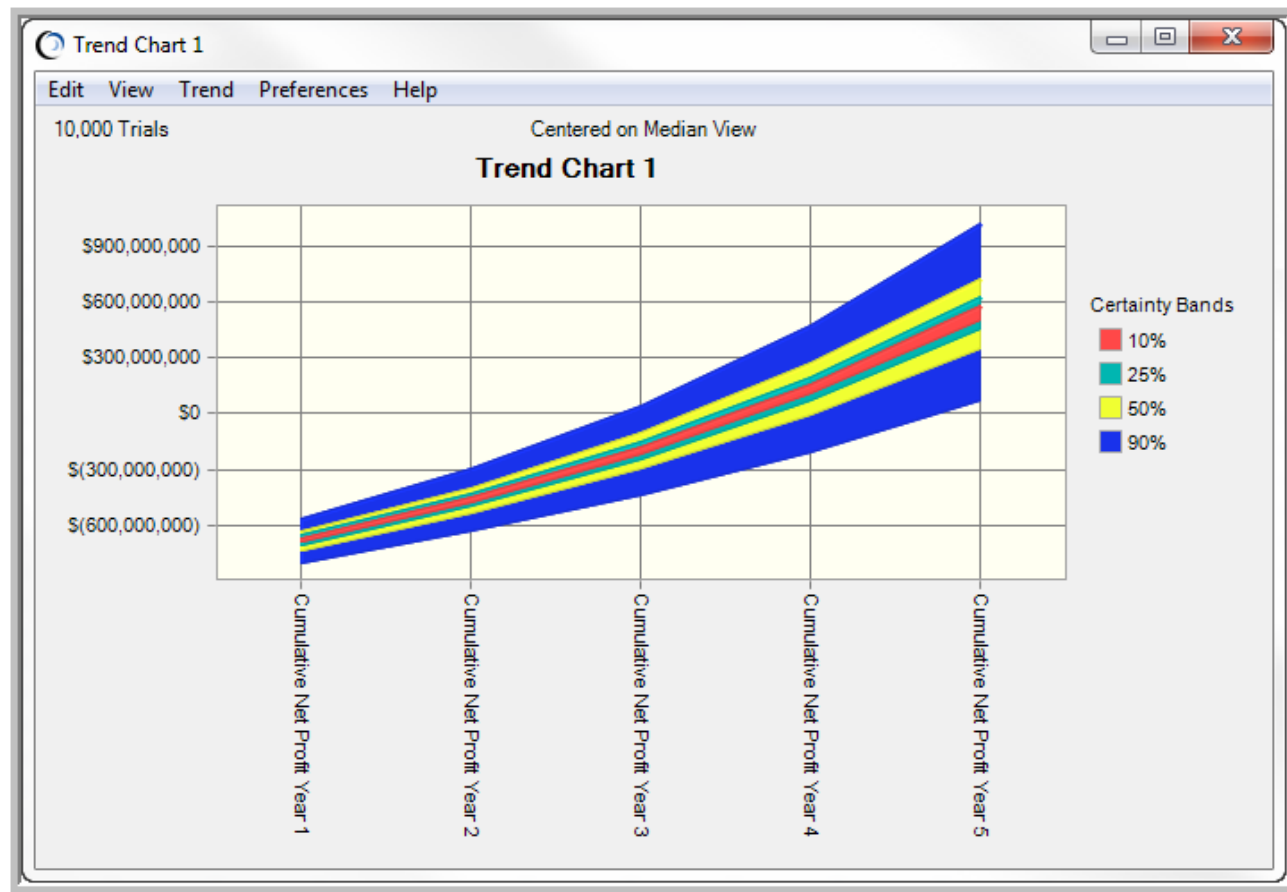
Sensitivity Chart – Contribution to Variance



Overlay Chart



Trend Chart





Reports and Data Extraction

- Create customized reports from the *Analyze* menu
- Extract data into an Excel worksheet
 - Statistics
 - Percentiles
 - Chart Bins – the intervals in the forecast chart along with their probability and frequency of occurrences.
 - Sensitivities – sensitivity data for all pairs of assumptions and forecasts
 - Trial Values – the generated assumption and forecast values for each simulation trial.



Crystal Ball Functions

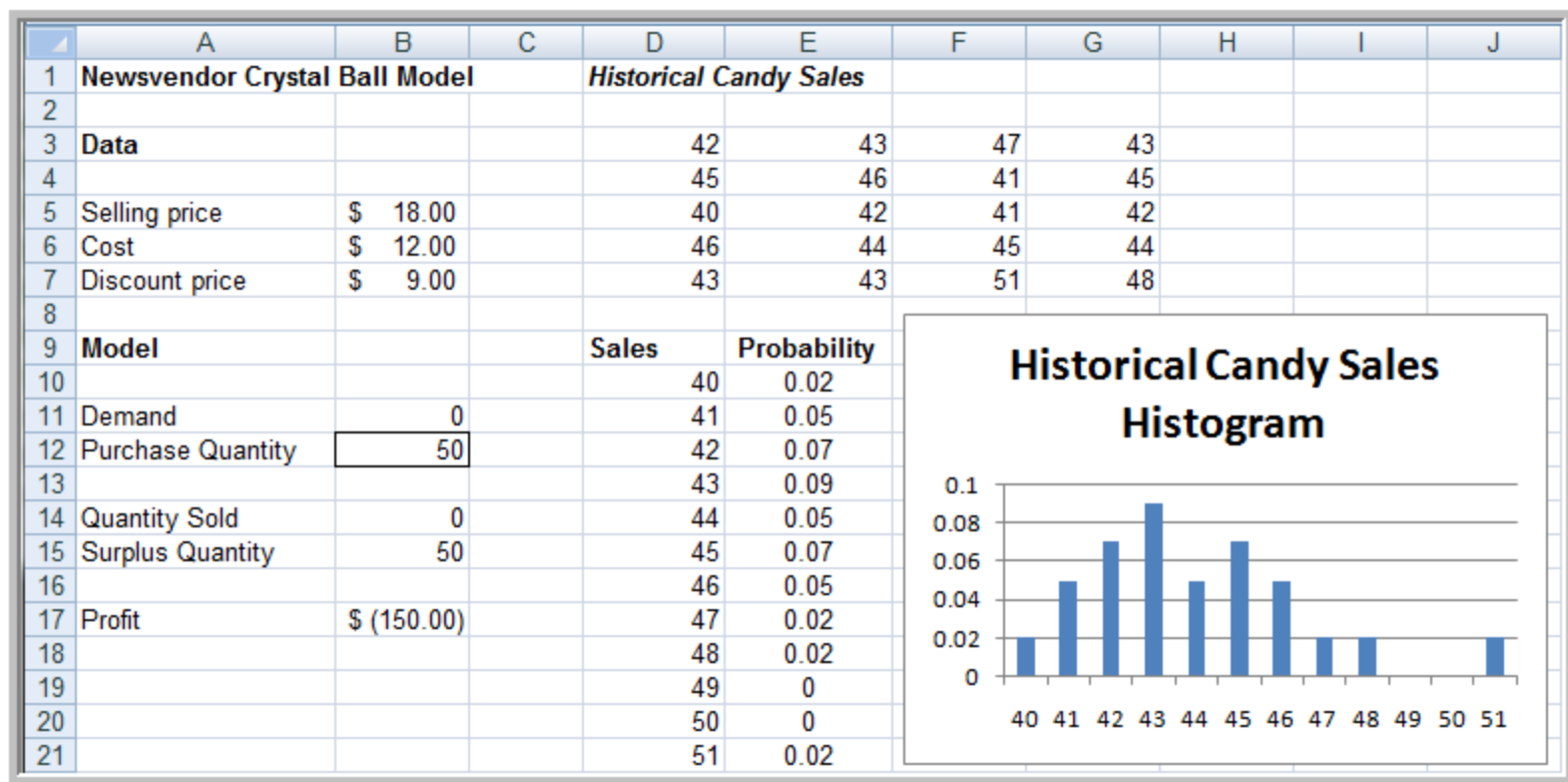
- Click on the *Insert Function* button [f_x] in Excel and select *Crystal Ball* category for a complete list.
- *Crystal Ball* functions may be used like any other Excel function



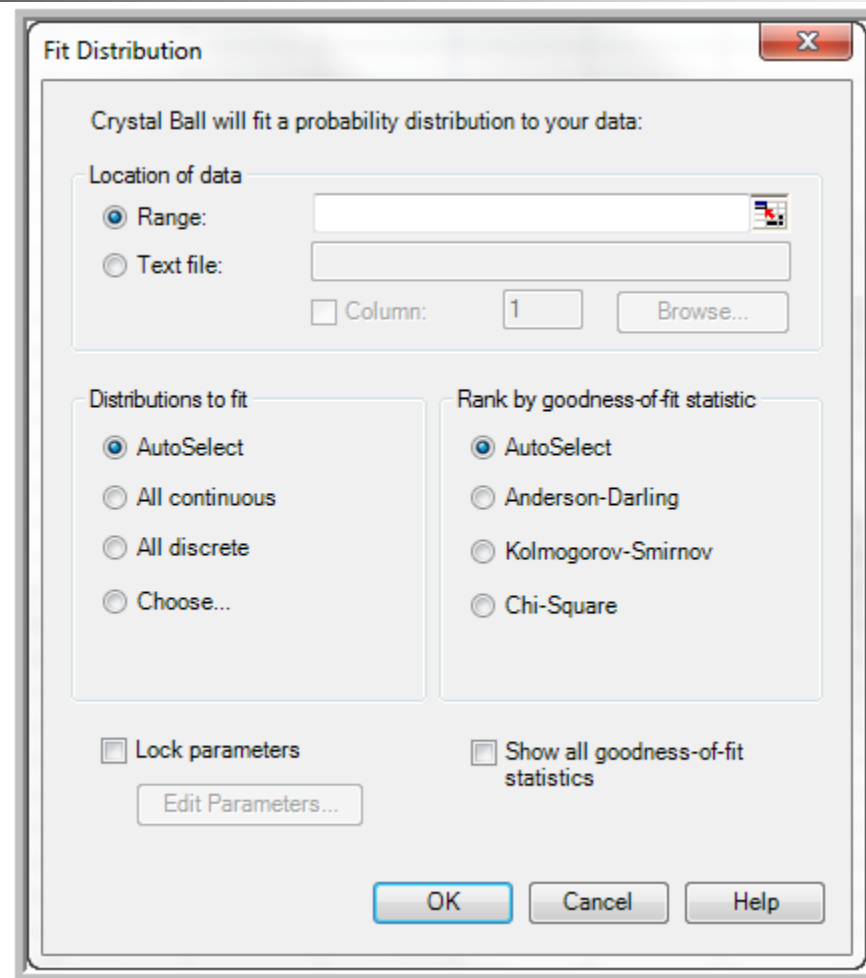
Other *Crystal Ball* Tools

- Batch Fit
- Correlation Matrix
- Tornado Chart
- Bootstrap Tool
- Decision Table
- Scenario Analysis
- Two-Dimensional Simulation

Newsvendor Model



Fit Distribution Dialog




The image shows a 'Fit Distribution' dialog box from a software application. The dialog has a title bar with a close button (X). Inside, it says 'Crystal Ball will fit a probability distribution to your data:'. Under 'Location of data', there are radio buttons for 'Range:' (selected) and 'Text file:', with a 'Column:' dropdown set to '1' and a 'Browse...' button. Below this are two groups of radio buttons: 'Distributions to fit' with 'AutoSelect' (selected), 'All continuous', 'All discrete', and 'Choose...'; and 'Rank by goodness-of-fit statistic' with 'AutoSelect' (selected), 'Anderson-Darling', 'Kolmogorov-Smirnov', and 'Chi-Square'. At the bottom, there are checkboxes for 'Lock parameters' and 'Show all goodness-of-fit statistics', an 'Edit Parameters...' button, and 'OK', 'Cancel', and 'Help' buttons.

Fit Distribution

Crystal Ball will fit a probability distribution to your data:

Location of data

☒ Range: 

☐ Text file:

☐ Column:

Distributions to fit

☒ AutoSelect

☐ All continuous

☐ All discrete

☐ Choose...

Rank by goodness-of-fit statistic

☒ AutoSelect

☐ Anderson-Darling

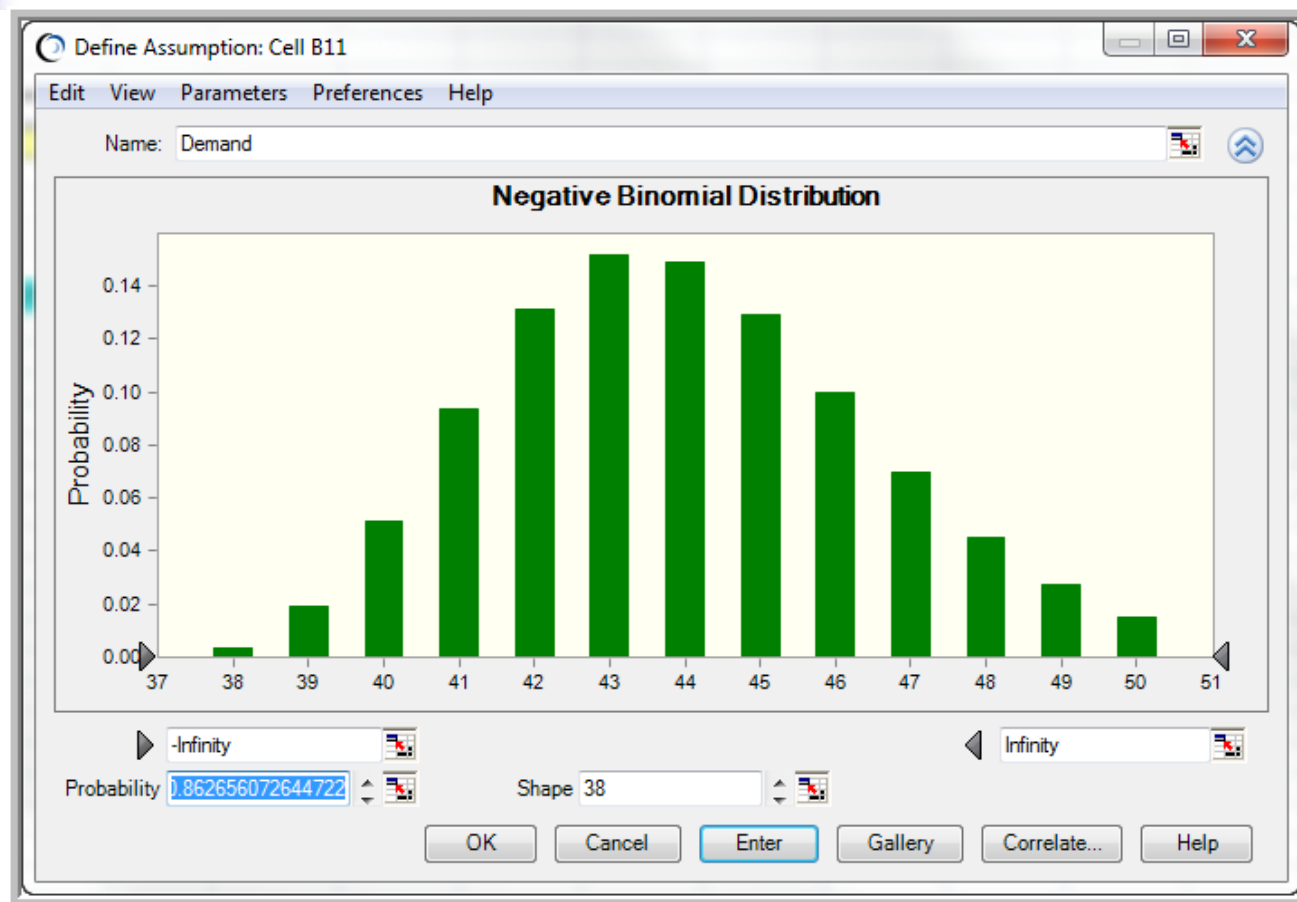
☐ Kolmogorov-Smirnov

☐ Chi-Square

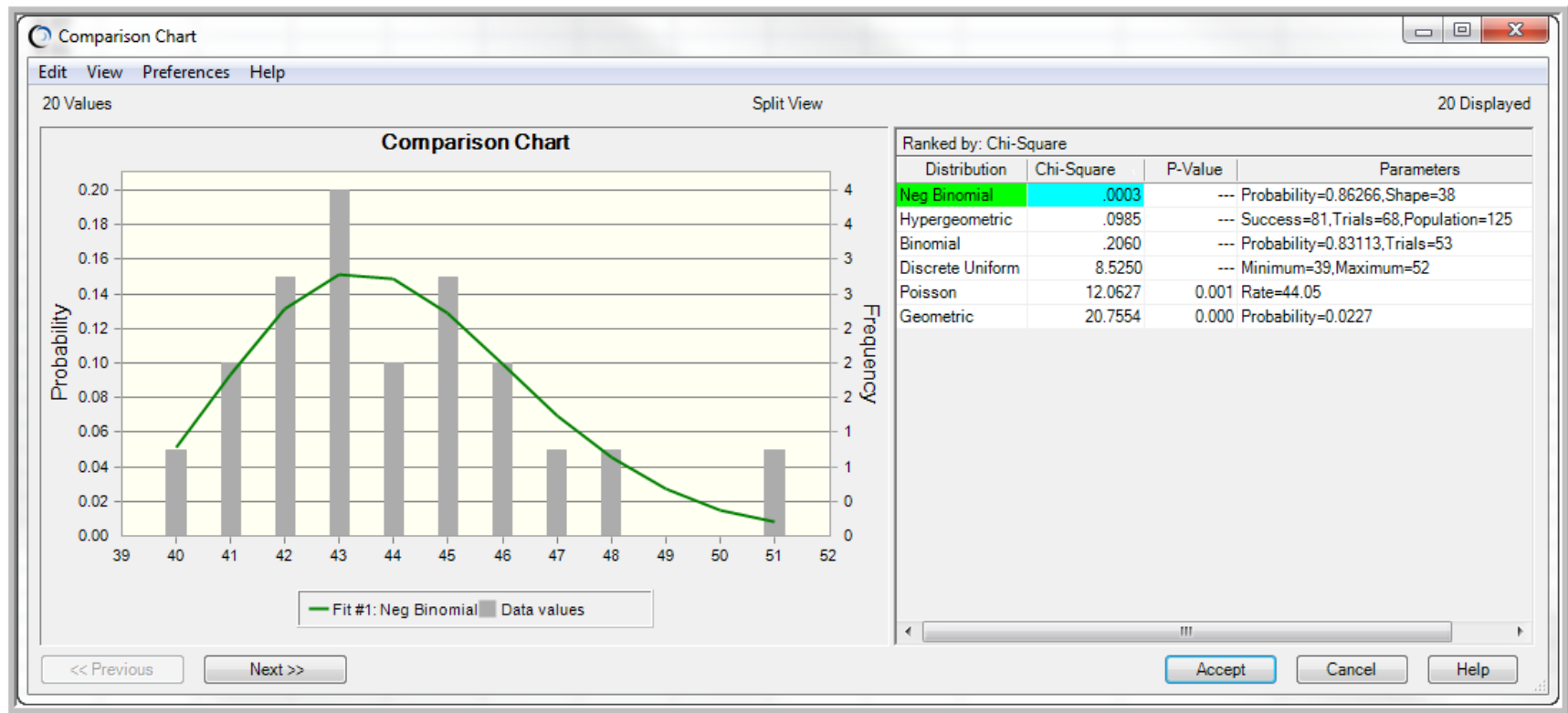
☐ Lock parameters

☐ Show all goodness-of-fit statistics

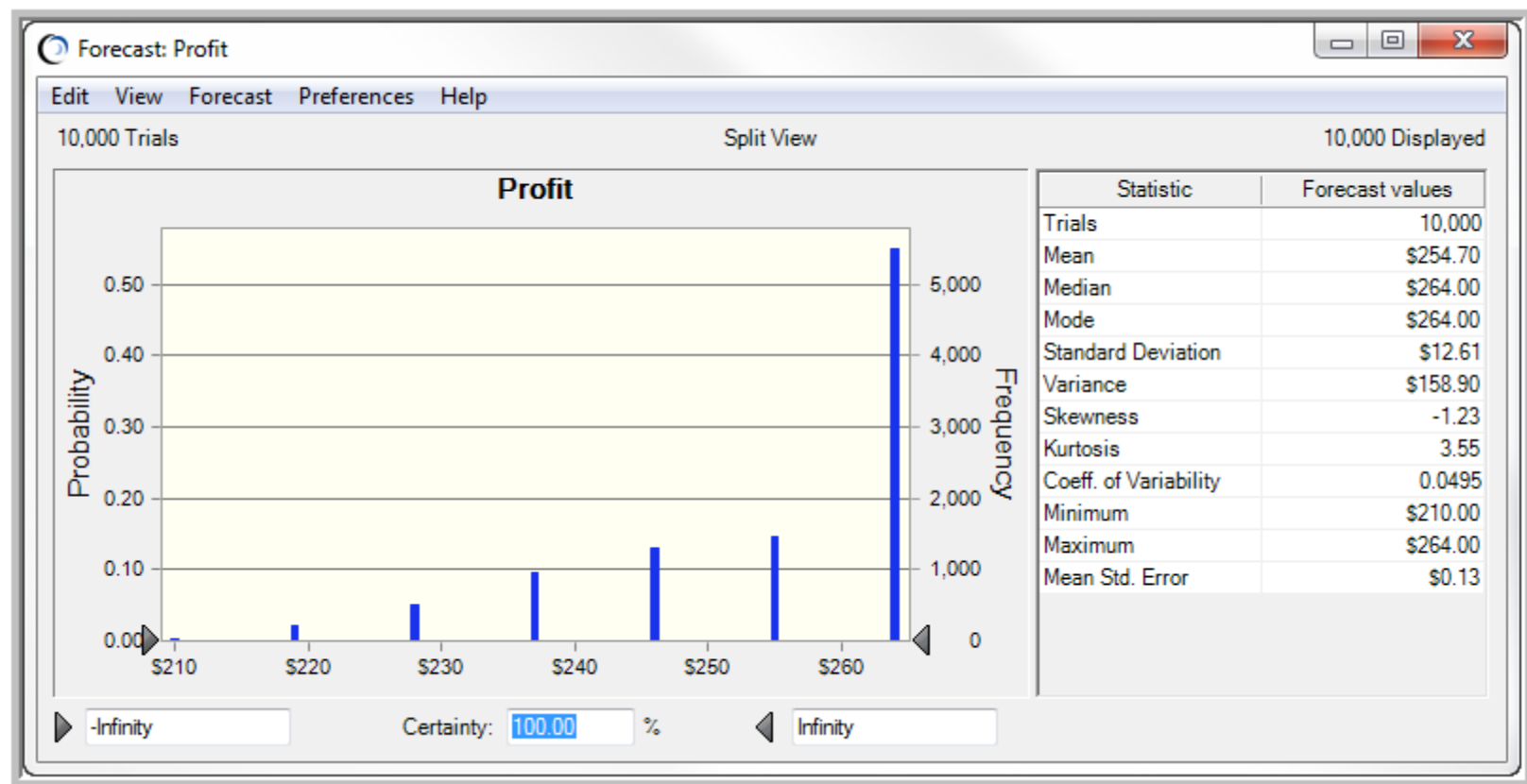
Best Fitting Distribution for Candy Sales



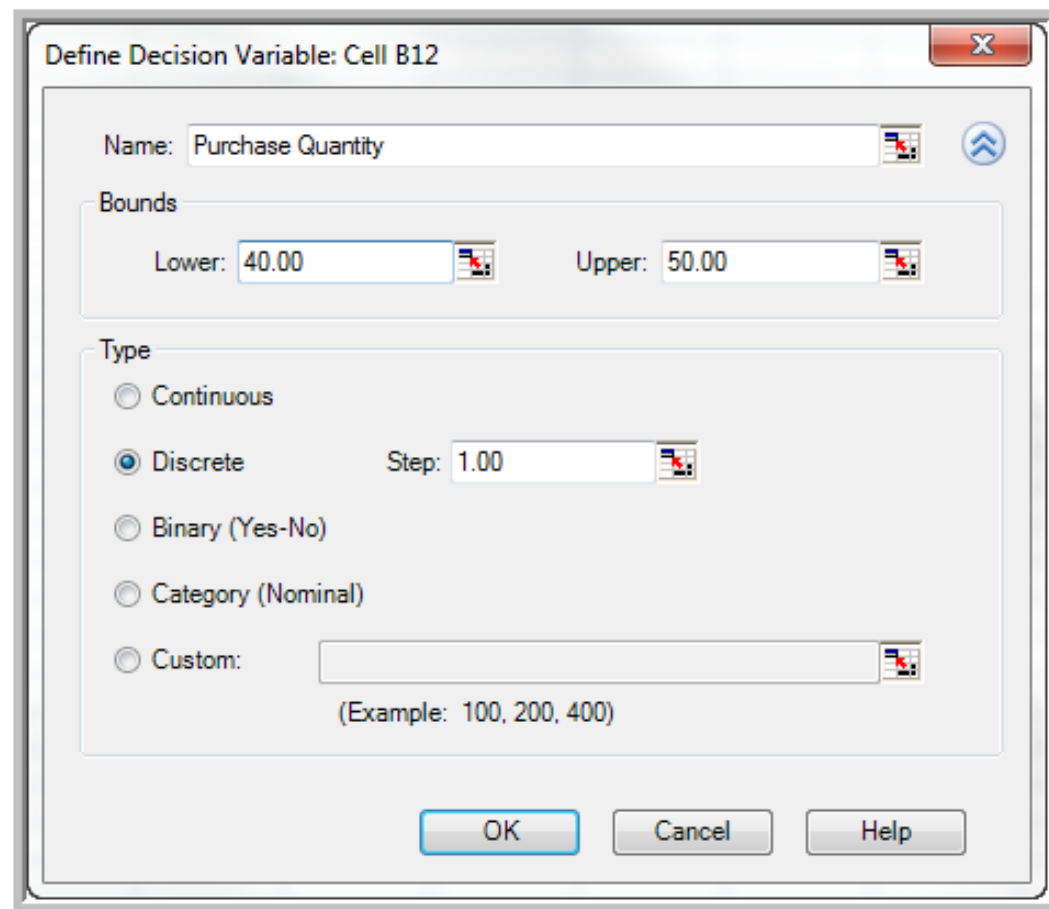
Fit Distribution Comparison Chart



Illustrative Newsvendor Result (Purchase Quantity = 44)



Define Decision Variable Dialog



The dialog box is titled "Define Decision Variable: Cell B12". It contains the following fields and options:

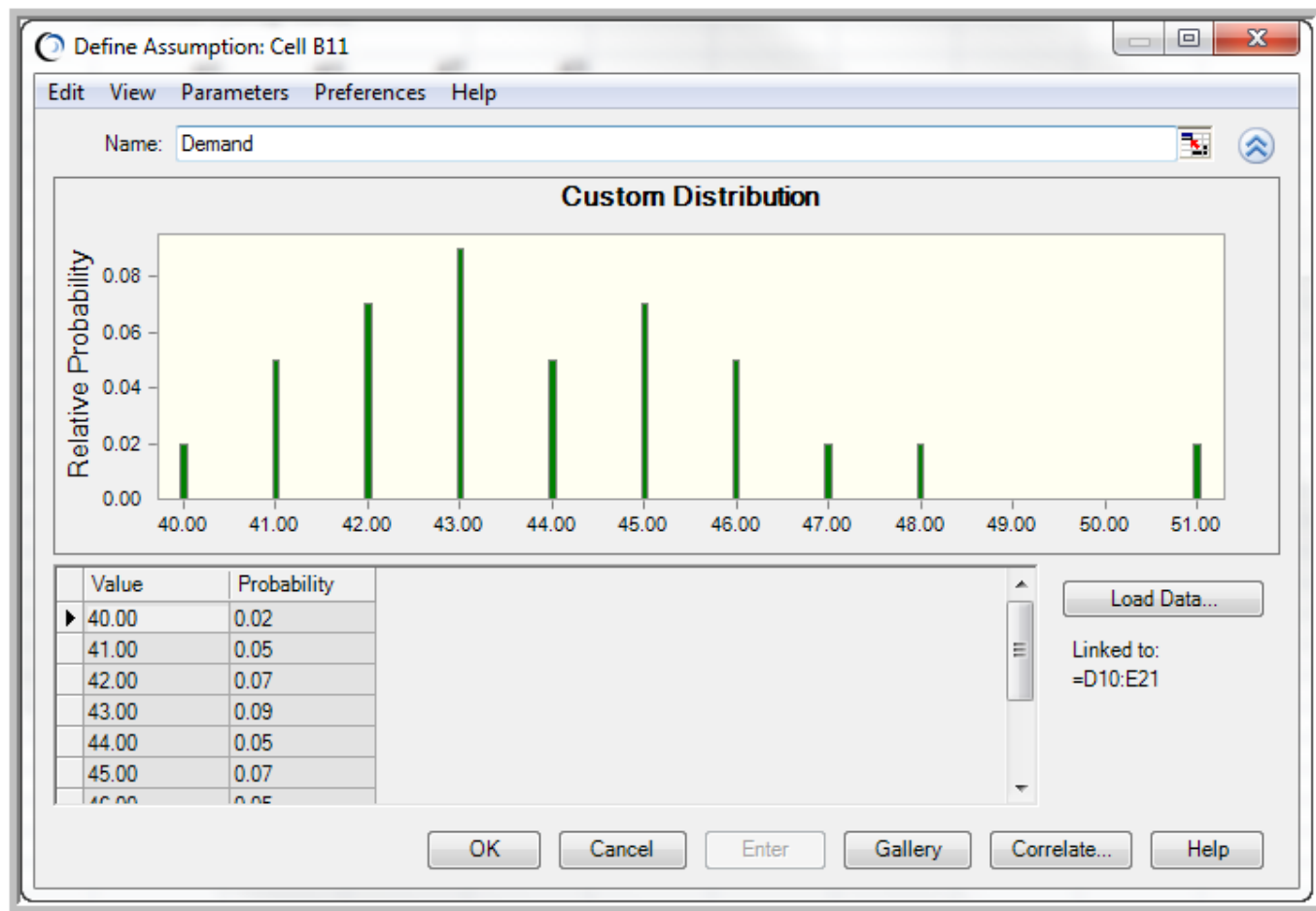
- Name:** Purchase Quantity
- Bounds:**
 - Lower:** 40.00
 - Upper:** 50.00
- Type:**
 - ☐ Continuous
 - ☒ Discrete **Step:** 1.00
 - ☐ Binary (Yes-No)
 - ☐ Category (Nominal)
 - ☐ Custom: (Example: 100, 200, 400)

Buttons at the bottom: OK, Cancel, Help.

Decision Table Tool Results

	A	B	C	D	E	F	G	H	I	J	K	L
	<div>Trend Chart</div> <div>Overlay Chart</div> <div>Forecast Chart</div>	Purchase Quantity (40.00)	Purchase Quantity (41.00)	Purchase Quantity (42.00)	Purchase Quantity (43.00)	Purchase Quantity (44.00)	Purchase Quantity (45.00)	Purchase Quantity (46.00)	Purchase Quantity (47.00)	Purchase Quantity (48.00)	Purchase Quantity (49.00)	Purchase Quantity (50.00)
1												
2		\$239.76	\$245.06	\$249.58	\$252.95	\$254.97	\$255.67	\$255.21	\$253.86	\$251.75	\$249.23	\$246.49
3		1	2	3	4	5	6	7	8	9	10	11

Custom Distribution

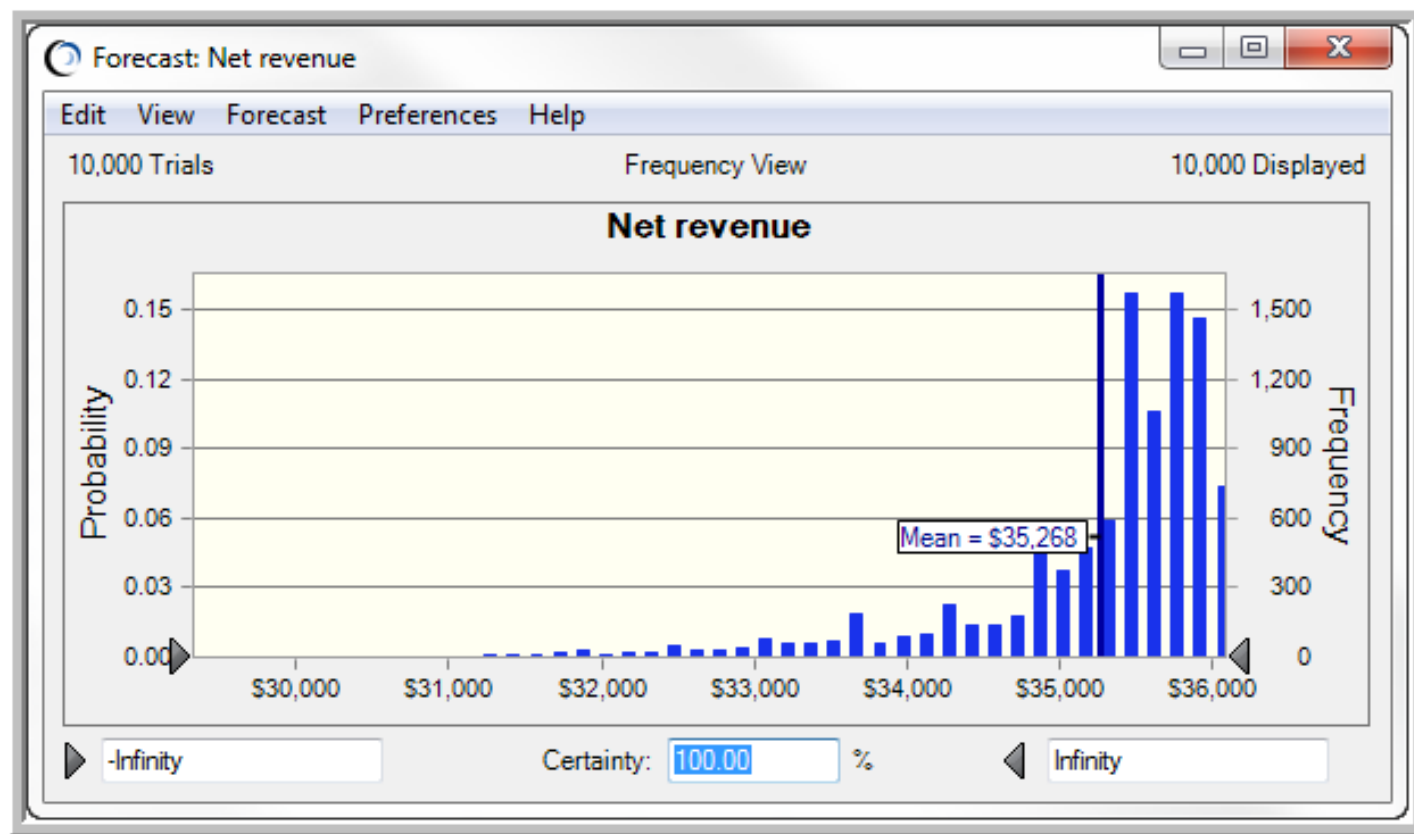


Overbooking Model

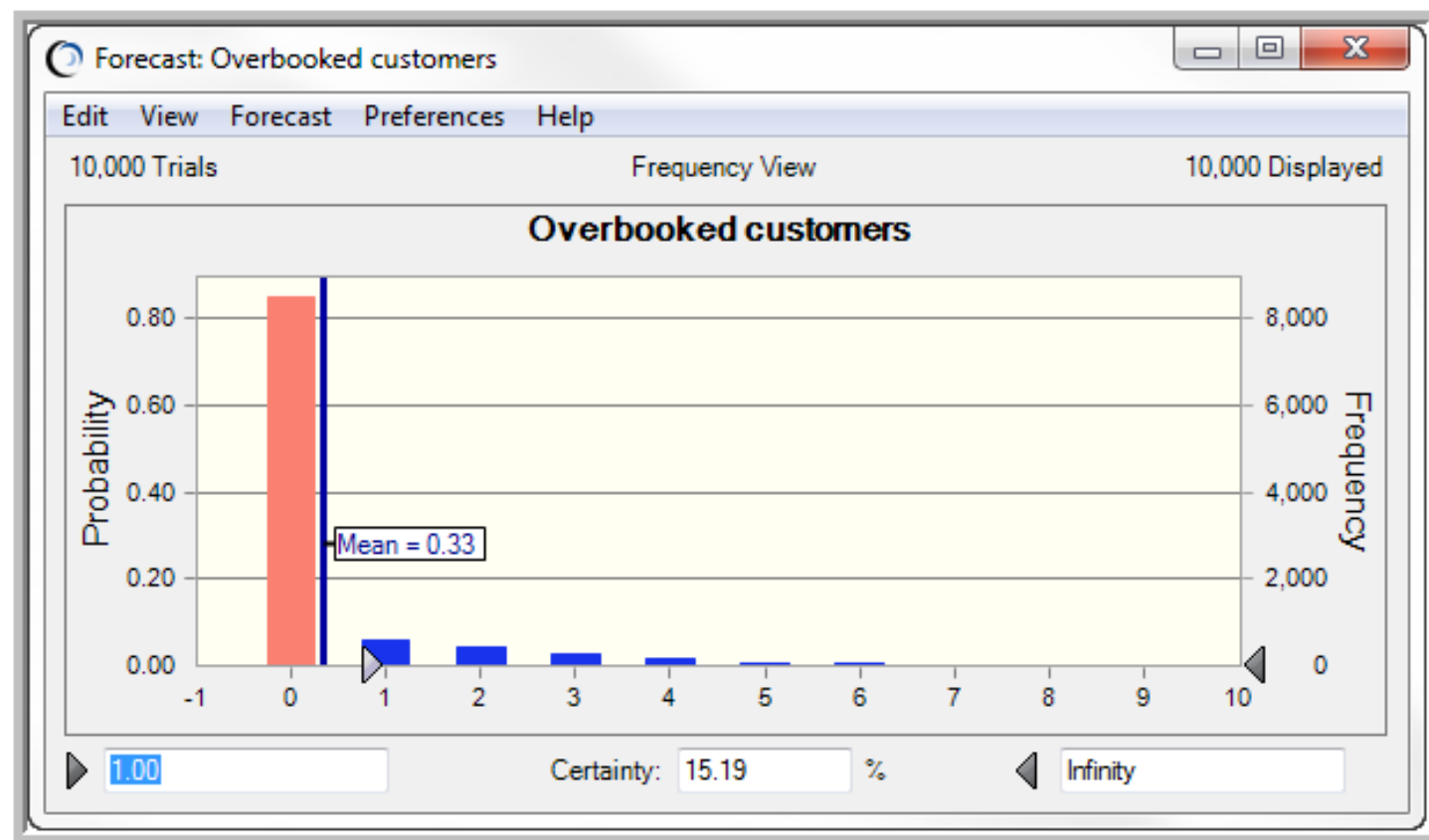
	A	B
1	Hotel Overbooking Model	
2		
3	Data	
4		
5	Rooms available	300
6	Price	\$120
7	Overbooking cost	\$100
8		
9	Model	
10		
11	Reservation limit	310
12	Customer demand	330
13	Reservations made	310
14	Cancellations	6
15	Customer arrivals	304
16	Overbooked customers	4
17		
18	Net revenue	\$35,600

	A	B
1	Hotel Overbooking Model	
2		
3	Data	
4		
5	Rooms available	300
6	Price	120
7	Overbooking cost	100
8		
9	Model	
10		
11	Reservation limit	310
12	Customer demand	=CB.Poisson(320)
13	Reservations made	=MIN(B11,B12)
14	Cancellations	=CB.Binomial(0.04,B13)
15	Customer arrivals	=B13-B14
16	Overbooked customers	=MAX(0,B15-B5)
17		
18	Net revenue	=MIN(B15,B5)*B6-B16*B7

Overbooking Model Results – Net Revenue (310 Reservations)



Overbooking Model Results – Overbooked Customers (310 Reservations)



Cash Budgeting Model

	A	B	C	D	E	F	G	H	I	J	K
1	Cash Budgeting										
2	Desired Minimum Balance	\$ 100,000									
3			February	March	April	May	June	July	August	September	October
4	Sales		\$ 400,000	\$ 500,000	\$ 600,000	\$ 700,000	\$ 800,000	\$ 800,000	\$ 700,000	\$ 600,000	\$ 500,000
5	<i>Cash Receipts</i>										
6	Collections (current)	20%			\$ 120,000	\$ 140,000	\$ 160,000	\$ 160,000	\$ 140,000	\$ 120,000	
7	Collections (previous month)	50%			\$ 250,000	\$ 300,000	\$ 350,000	\$ 400,000	\$ 400,000	\$ 350,000	
8	Collections (2nd month previous)	30%			\$ 120,000	\$ 150,000	\$ 180,000	\$ 210,000	\$ 240,000	\$ 240,000	
9	Total Cash Receipts				\$ 490,000	\$ 590,000	\$ 690,000	\$ 770,000	\$ 780,000	\$ 710,000	
10											
11	<i>Cash Disbursements</i>										
12	Purchases				\$ 420,000	\$ 480,000	\$ 480,000	\$ 420,000	\$ 360,000	\$ 300,000	
13	Wages and Salaries				\$ 72,000	\$ 84,000	\$ 96,000	\$ 96,000	\$ 84,000	\$ 72,000	
14	Rent				\$ 10,000	\$ 10,000	\$ 10,000	\$ 10,000	\$ 10,000	\$ 10,000	
15	Cash Operating Expenses				\$ 30,000	\$ 30,000	\$ 30,000	\$ 30,000	\$ 25,000	\$ 25,000	
16	Tax Installments				\$ 20,000			\$ 30,000			
17	Capital Expenditure						\$ 150,000				
18	Mortgage Payment					\$ 60,000					
19	Total Cash Disbursements				\$ 552,000	\$ 664,000	\$ 766,000	\$ 586,000	\$ 479,000	\$ 407,000	
20											
21	<i>Ending Cash Balance</i>										
22	Net Cash Flow				\$ (62,000)	\$ (74,000)	\$ (76,000)	\$ 184,000	\$ 301,000	\$ 303,000	
23	Beginning Cash Balance				\$ 150,000	\$ 100,000	\$ 100,000	\$ 100,000	\$ 122,000	\$ 423,000	
24	Available Balance				\$ 88,000	\$ 26,000	\$ 24,000	\$ 284,000	\$ 423,000	\$ 726,000	
25	Monthly Borrowing				\$ 12,000	\$ 74,000	\$ 76,000	\$ -	\$ -	\$ -	
26	Monthly Repayment				\$ -	\$ -	\$ -	\$ 162,000	\$ -	\$ -	
27	Ending Cash Balance			\$ 150,000	\$ 100,000	\$ 100,000	\$ 100,000	\$ 122,000	\$ 423,000	\$ 726,000	
28	Cumulative Loan Balance			\$ -	\$ 12,000	\$ 86,000	\$ 162,000	\$ -	\$ -	\$ -	

Correlation Matrix Tool

Select assumptions (step 1 of 2)

Correlation Matrix

View or edit the full correlation matrix for a selected set of assumptions

Available Assumptions

- Collections (current) (Sheet1)
- Collections (previous month) (Sheet1)

Selected Assumptions

- Sales April (Sheet1)
- Sales May (Sheet1)
- Sales June (Sheet1)
- Sales July (Sheet1)
- Sales August (Sheet1)
- Sales September (Sheet1)
- October (Sheet1)

Top Up Down Bottom

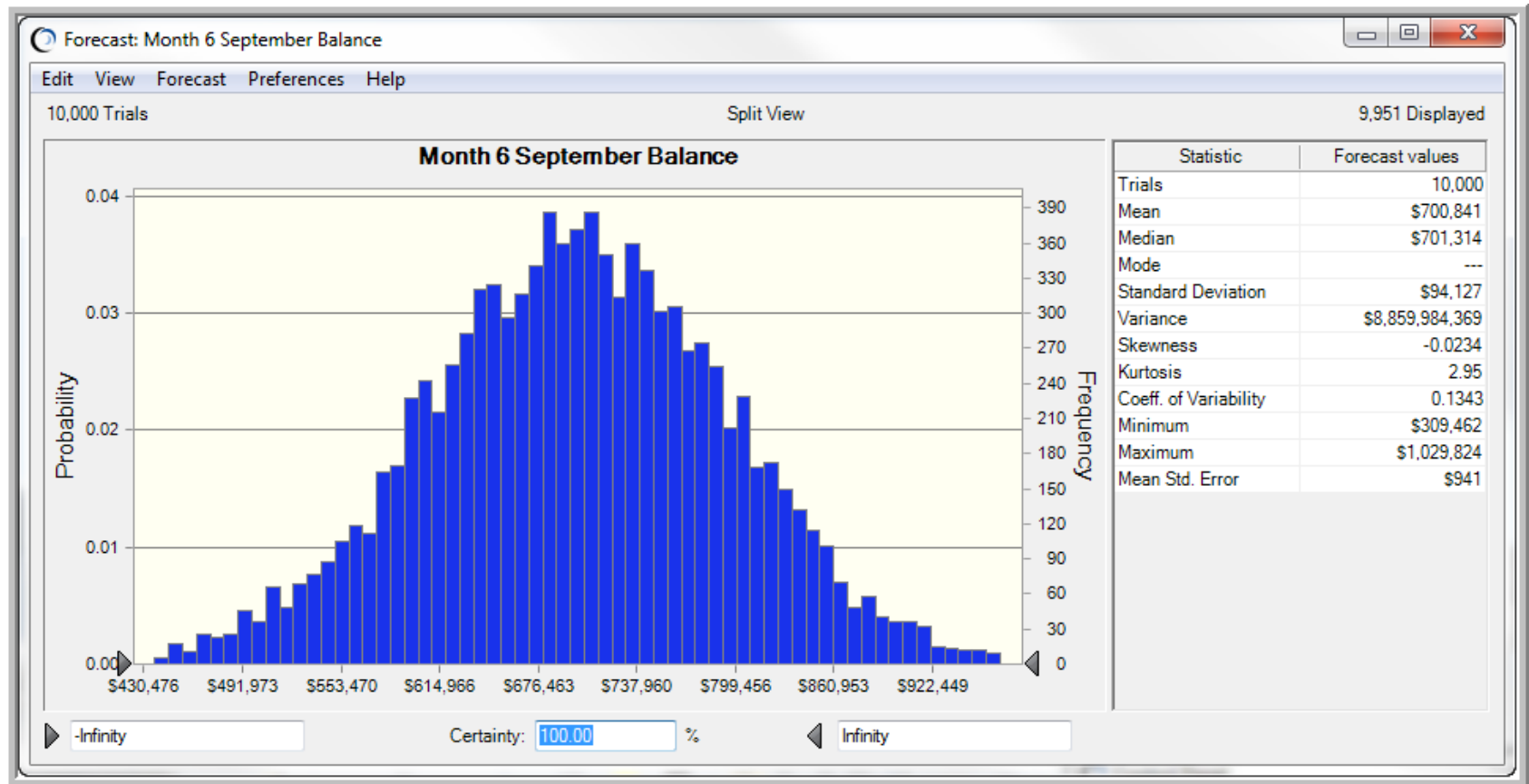
Back Next >

Cancel Help

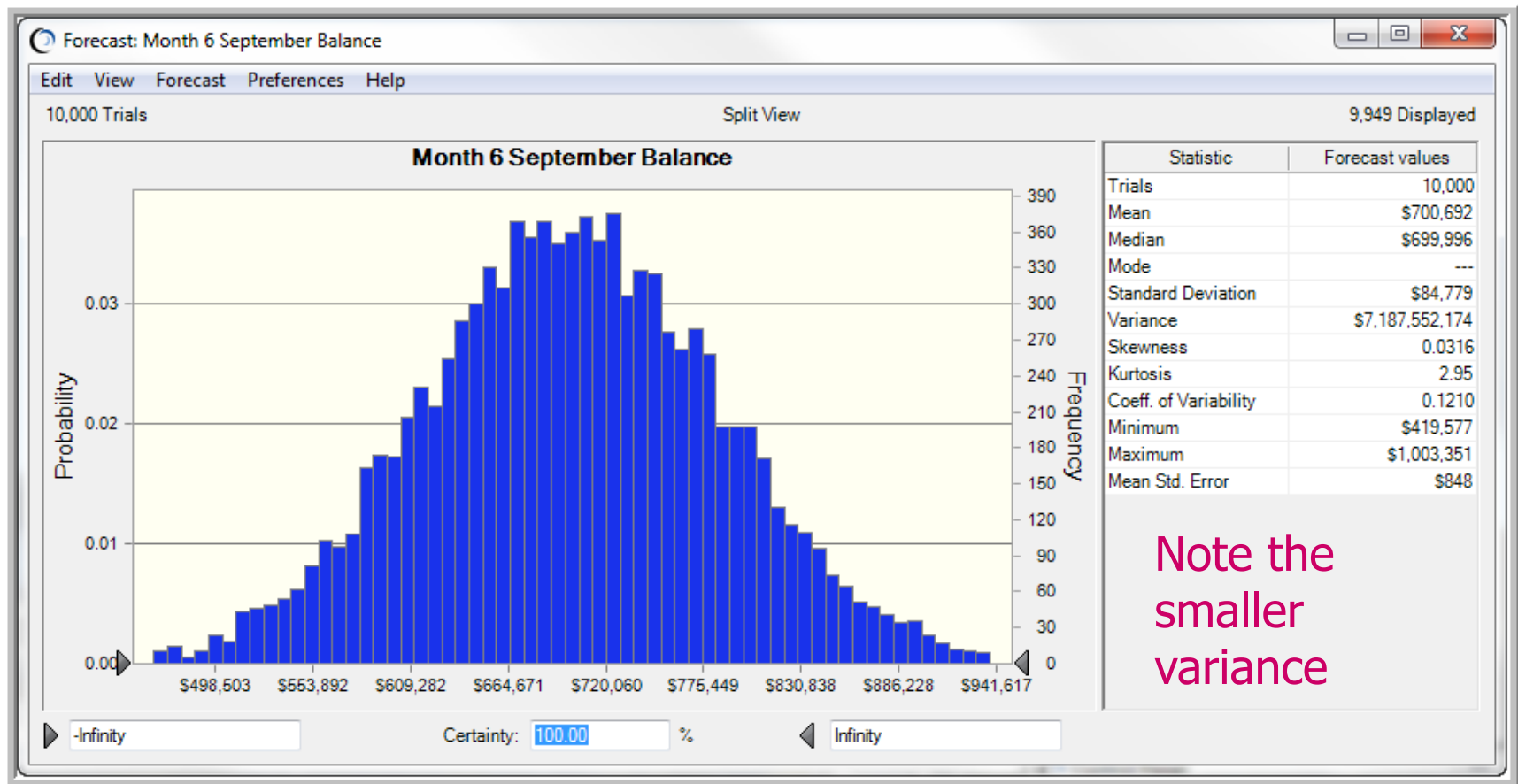
Wire Channel, In.	1.00	0.05	0.23	-0.14	0.20	0.14	-0.77	0.30
Cut Channel, In.	1.00	0.00	0.10	-0.76	0.05	-0.80	0.11	
Material 1 Strength	1.00	-0.00	0.24	-0.20	0.12	0.44		
Material 2 Strength	1.00	-0.00	0.19	0.70	-0.17			
Clamping Method	1.00	0.04	0.40	-0.30				
Number of Cables	1.00	-0.72	0.31					
Spring Deflection, In.	1.00	0.88						
Material 2 Strength	1.00							

	A	C	D	E	F	G	H	I
1	Load the matrix	Sales April (Sheet1)	Sales May (Sheet1)	Sales June (Sheet1)	Sales July (Sheet1)	Sales August (Sheet1)	Sales September (Sheet1)	October (Sheet1)
2	Sales April (Sheet1)	1.000	0.600					
3	Sales May (Sheet1)		1.000	0.600				
4	Sales June (Sheet1)			1.000	0.600			
5	Sales July (Sheet1)				1.000	0.600		
6	Sales August (Sheet1)					1.000	0.600	
7	Sales September (Sheet1)						1.000	0.600
8	October (Sheet1)							1.000

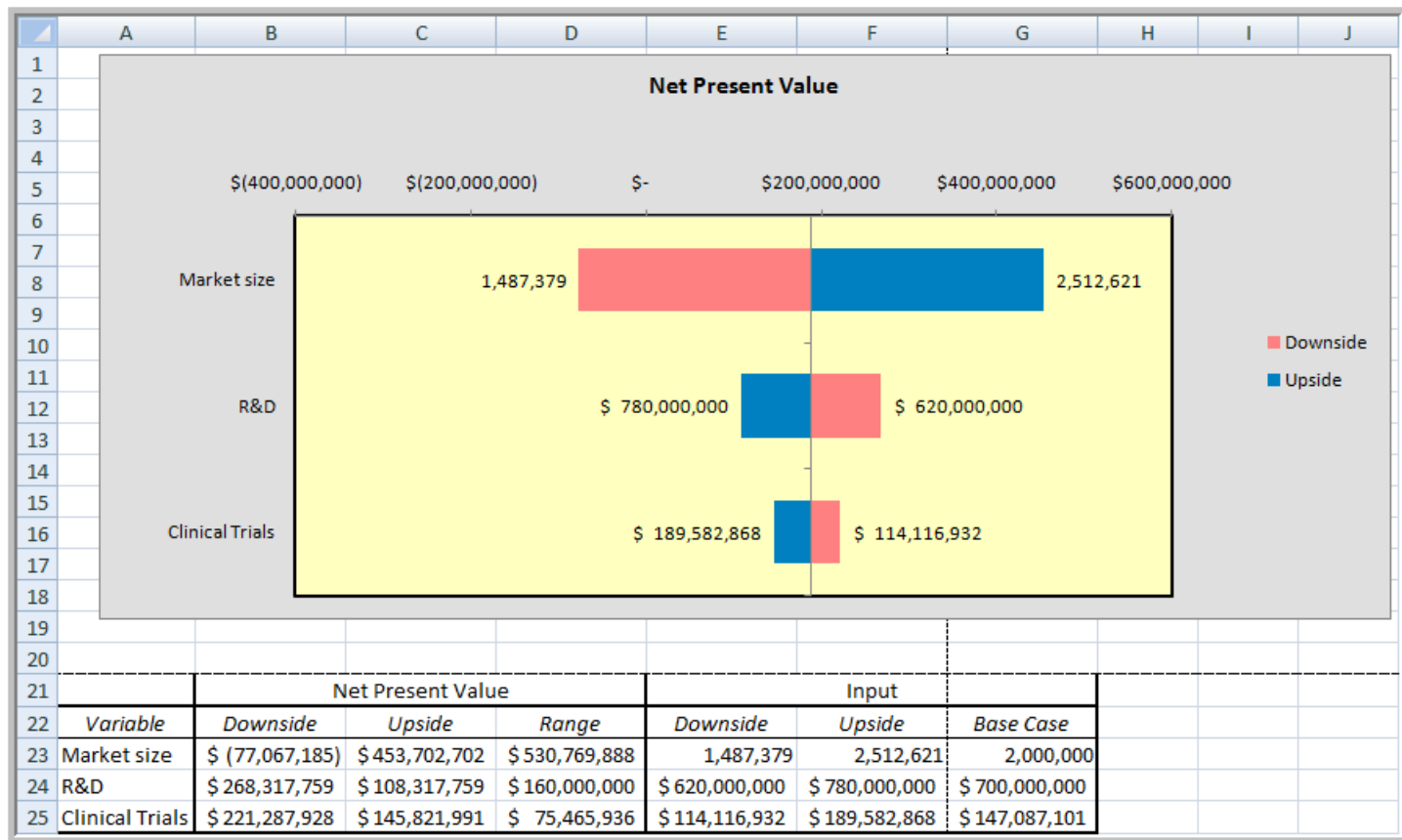
Uncorrelated Assumptions



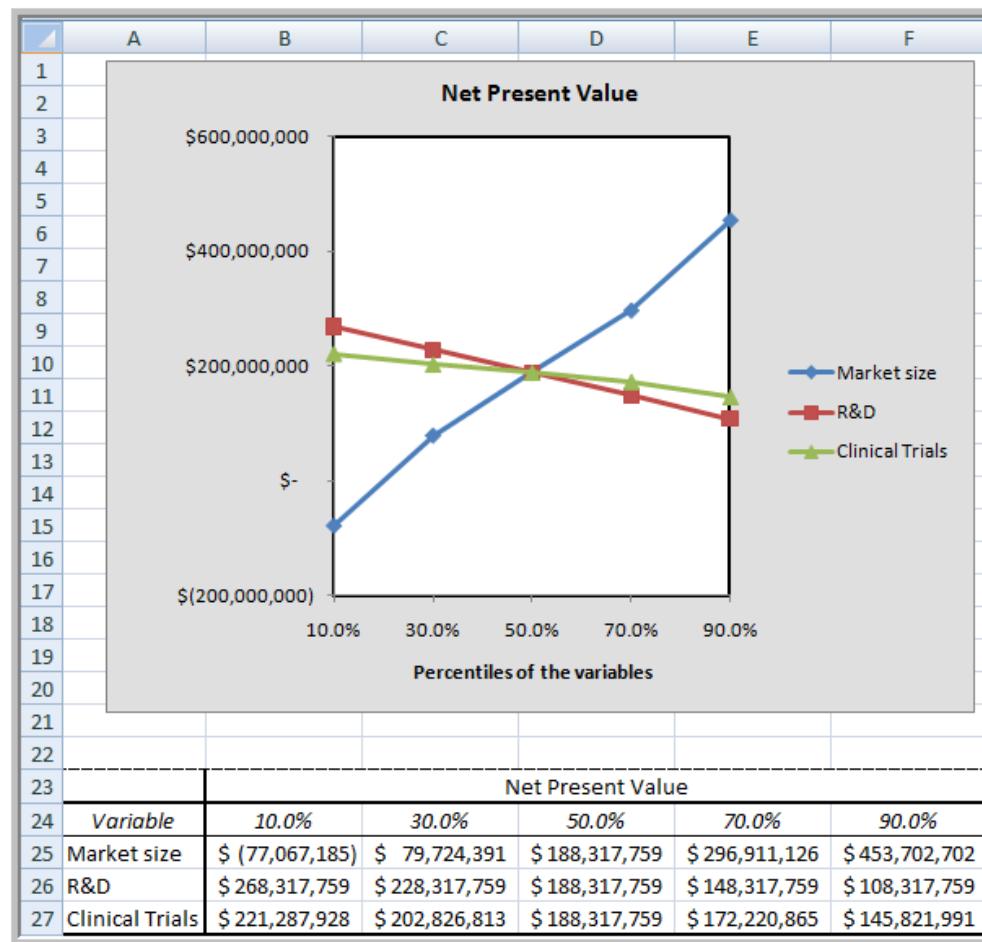
Correlated Assumptions



Tornado Chart



Spider Chart



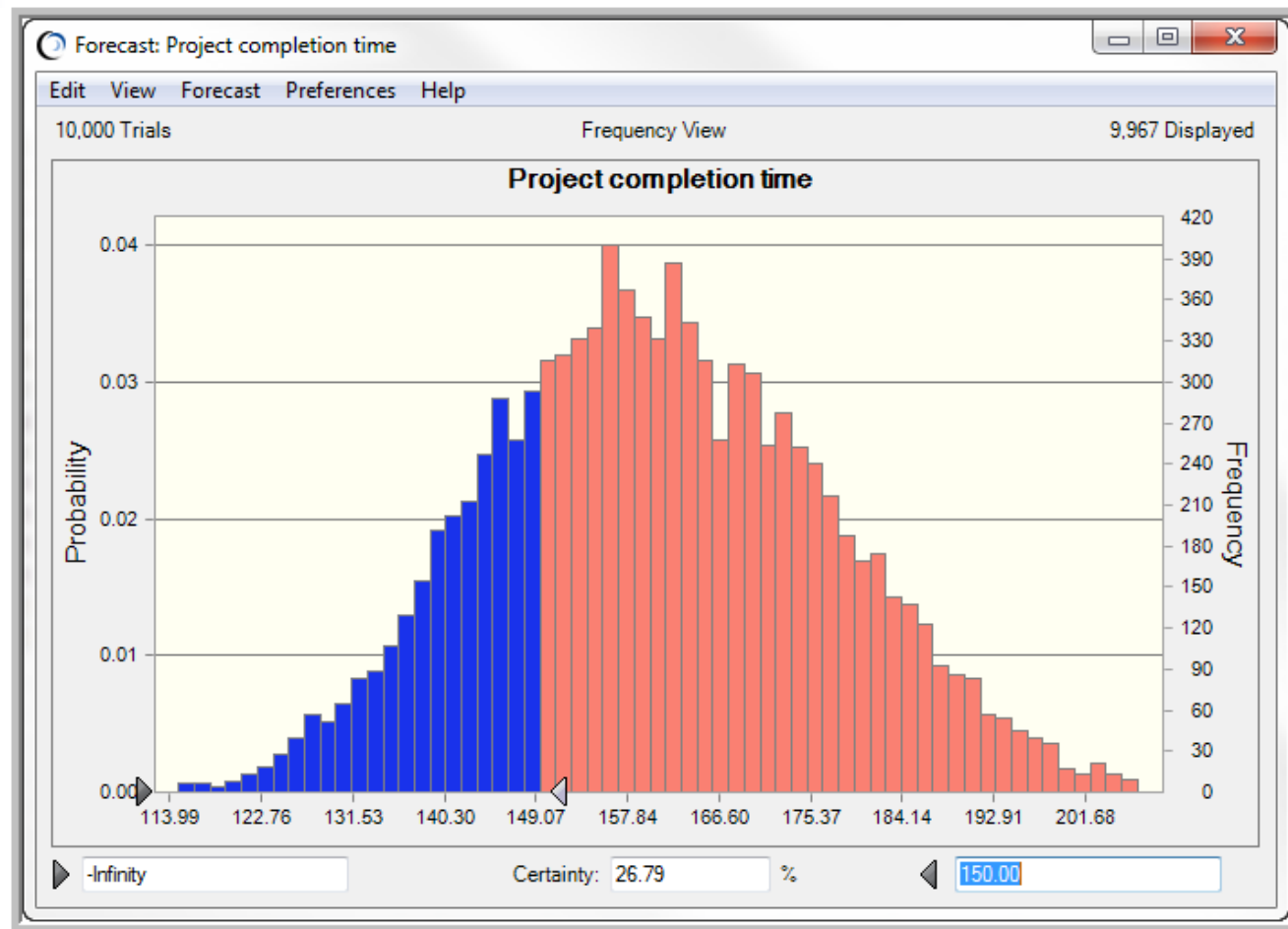
Project Management

	A	B	C	D	E	F	G	H	I	J	K
1	Becker Consulting Project Management Simulation Model										
2											
3		10th	Most	90th	Activity	Early	Early	Latest	Latest		On Critical
4	Activity	Percentile	Likely	Percentile	Time	Start	Finish	Start	Finish	Slack	Path?
5	A	15	15	15	15.00	0.00	15.00	27.32	42.32	27.32	0
6	B	40	45	60	49.32	0.00	49.32	0.00	49.32	0.00	1
7	C	10	14	30	19.19	0.00	19.19	30.12	49.32	30.12	0
8	D	2	3	5	3.43	0.00	3.43	45.88	49.32	45.88	0
9	E	5	7	9	7.00	15.00	22.00	42.32	49.32	27.32	0
10	F	4	5	8	5.86	49.32	55.18	49.32	55.18	0.00	1
11	G	1	1	1	1.00	55.18	56.18	55.18	56.18	0.00	1
12	H	25	30	50	36.49	56.18	92.67	56.18	92.67	0.00	1
13	I	3	5	10	6.29	92.67	98.96	92.67	98.96	0.00	1
14	J	3	7	10	6.57	98.96	105.53	124.54	131.11	25.58	0
15	K	20	30	45	32.15	98.96	131.11	98.96	131.11	0.00	1
16	L	3	4	5	4.00	98.96	102.96	127.11	131.11	28.15	0
17	M	3	3	3	3.00	131.11	134.11	131.11	134.11	0.00	1
18	N	10	13	20	14.72	134.11	148.83	137.71	152.43	3.60	0
19	O	10	14	28	18.32	134.11	152.43	134.11	152.43	0.00	1
20	P	2	2	2	2.00	152.43	154.43	152.43	154.43	0.00	1
21	Q	5	5	5	5.00	154.43	159.43	154.43	159.43	0.00	1
22											
23			Project completion time			159.43					

Analytical Critical Path Calculations

<i>Critical Path Calculations</i>				
<i>a</i>	<i>m</i>	<i>b</i>	<i>mean</i>	<i>variance</i>
15	15	15	15.00	0.00
33.63	45	69.31	49.31	55.37
4.07	14	39.51	19.19	55.70
0.95	3	6.34	3.43	1.23
3.38	7	10.62	7.00	2.18
2.73	5	9.89	5.87	2.23
1	1	1	1.00	0.00
17.58	30	61.89	36.49	87.07
0.67	5	13.21	6.29	6.76
0.03	7	12.68	6.57	6.69
10.66	30	55.79	32.15	85.44
2.19	4	5.81	4.00	0.55
3	3	3	3.00	0.00
6.62	13	24.55	14.72	13.77
4.48	14	36.48	18.32	45.00
2	2	2	2.00	0.00
5	5	5	5.00	0.00
On critical path:			159.44	281.88
standard deviation				16.79

Probability of On-Time Project Completion



Bootstrap Tool – Sampling Distribution of Maximum Project Completion Time

