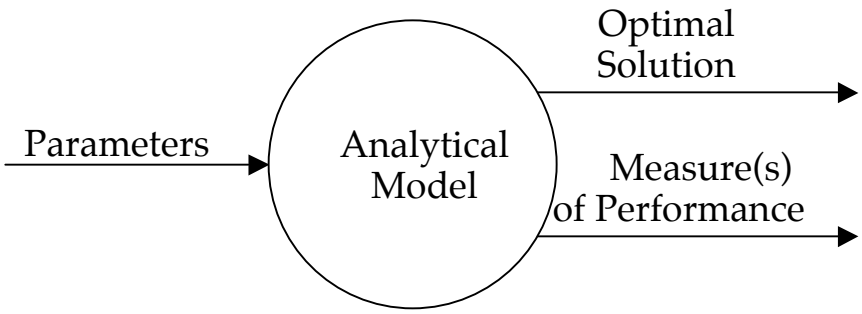
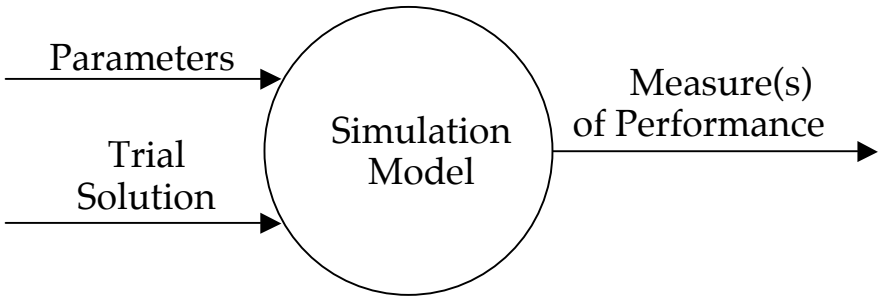
Introduction to Simulation

Analytical Models:



Simulation Models:



Advantages:

Disadvantages:

Monte-Carlo Simulation with Crystal Ball®

To run a simulation using Crystal Ball®:

1. Setup Spreadsheet

Build a spreadsheet that will calculate the performance measure (e.g., profit) in terms of the inputs (random or not). For random inputs, just enter any number.

2. Define Assumptions—i.e., random variables

Define which cells are random, and what distribution they should follow.

3. Define Forecast—i.e., output or performance measure

Define which cell(s) you are interested in forecasting (typically the performance measure, e.g., profit).

4. Choose Number of Trials

Select the number of trials. If you would later like to generate the Sensitivity Analysis chart, choose "Sensitivity Analysis" under Options in Run Preferences.

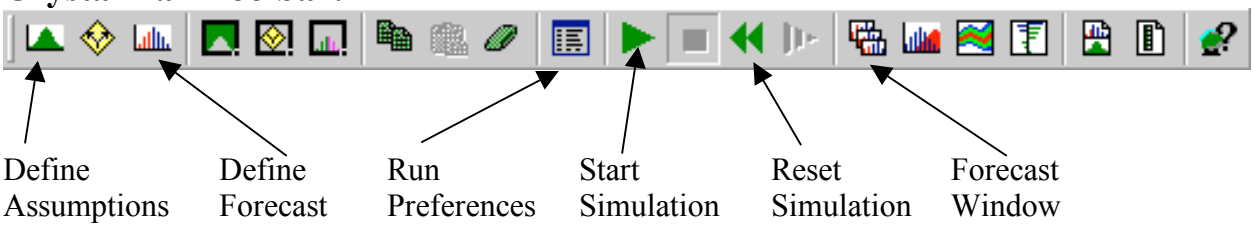
5. Run Simulation

Run the simulation. If you would like to change parameters and re-run the simulation, you should "reset" the simulation (click on the "Reset Simulation" button on the toolbar or in the Run menu) first.

6. View Results

The forecast window showing the results of the simulation appears automatically after (or during) the simulation. Many different results are available (frequency chart, cumulative chart, statistics, percentiles, sensitivity analysis, and trend chart). The results can be copied into the worksheet.

Crystal Ball Toolbar:



Walton Bookstore Simulation with Crystal Ball®

In August, Walton Bookstore must decide how many of next year's nature calendars to order. Each calendar costs the bookstore $7.50 and is sold for $10. After February, all unsold calendars are returned to the publisher for a refund of $2.50 per calendar. Suppose Walton predicts demand will be somewhere between 100 and 300.

Demand = d ~ Uniform[100, 300]
Order Quantity = Q (decision variable)

Revenue =

Cost =

Refund =

Profit =

Step #1 (Setup Spreadsheet)

	B	C	D	E	F
3		**Data**			
4	Unit Cost	$7.50			
5	Unit Price	$10.00			
6	Unit Refund	$2.50			
7					
8	**Demand Distribution (Uniform)**				
9	Minimum	100			
10	Maximum	300			
11					
12		**Decision Variable**			
13	Order Quantity	200			
14					
15	**Simulation**				
16	Demand	Revenue	Cost	Refund	Profit
17	200	$2,000.00	$1,500.00	$0.00	$500.00

	B	C	D	E	F
16	Demand	Revenue	Cost	Refund	Profit
17	200	=$C$5*MIN($C$13,B17)	=$C$4*$C$13	=$C$6*MAX($C$13-B17,0)	=C17-D17+E17

For random inputs, just enter any number (e.g., 200 in B17).

Calculate performance measure (Profit) as a function of the random input(s) (Demand).

Walton Bookstore Simulation with Crystal Ball®

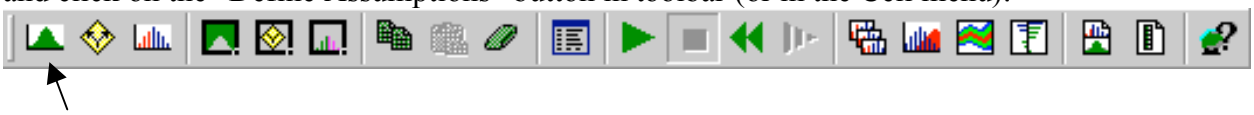
Step #2 (Define Assumptions—i.e., random variables)

Select the cell that contains the random variable (B17):

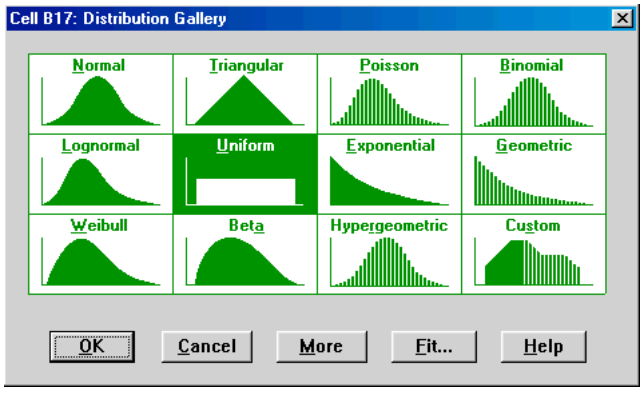
	B
16	Demand
17	200

(Note: The cell *must* contain a value before choosing Define Assumption)

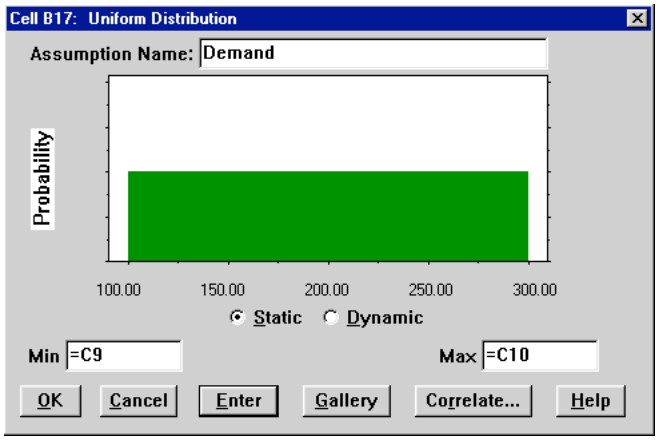
and click on the "Define Assumptions" button in toolbar (or in the Cell menu):



Select type of distribution:



Provide parameters of distributions:



	B	C
8	Demand Distribution	(Uniform)
9	Minimum =	100
10	Maximum =	300

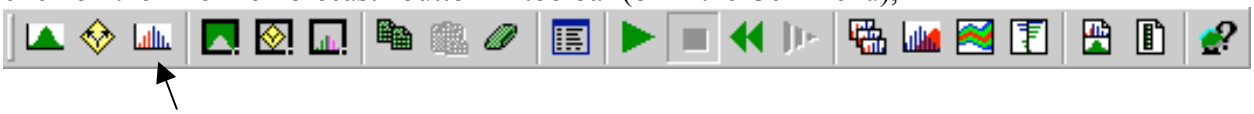
Walton Bookstore Simulation with Crystal Ball®

Step #3 (Define Forecast—i.e., output)

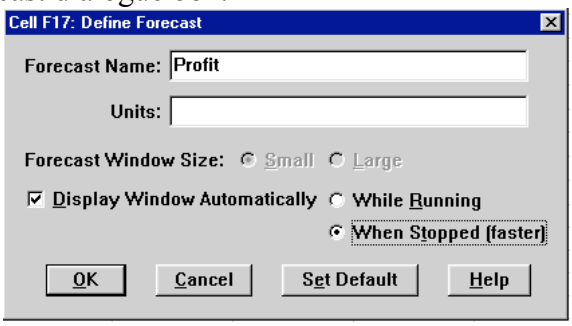
Select the cell that contains the output variable to forecast (F17):

	F
16	Profit
17	$500.00

click on the "Define Forecast" button in toolbar (or in the Cell menu),



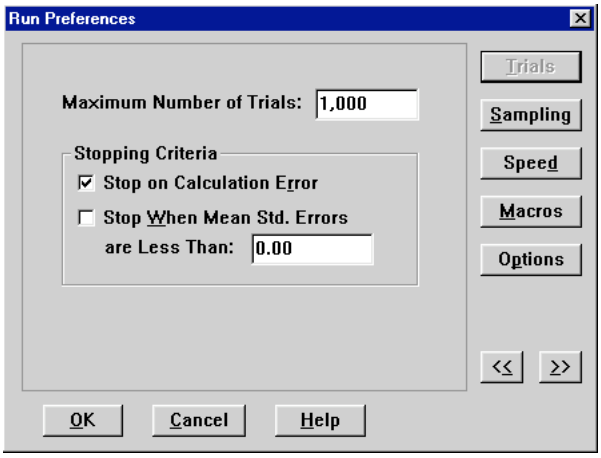
and fill in the Define Forecast dialogue box.



Step #4 (Choose Number of Trials)

Click on the "Run Preferences" button in toolbar (or in the Run menu):

and select the number of trials to run.



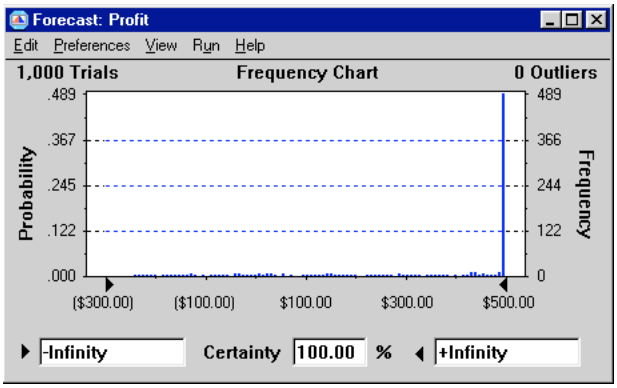
Walton Bookstore Simulation with Crystal Ball®

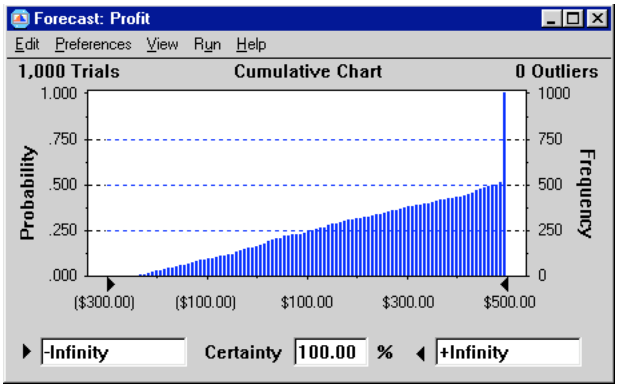
Step #5 (Run Simulation)

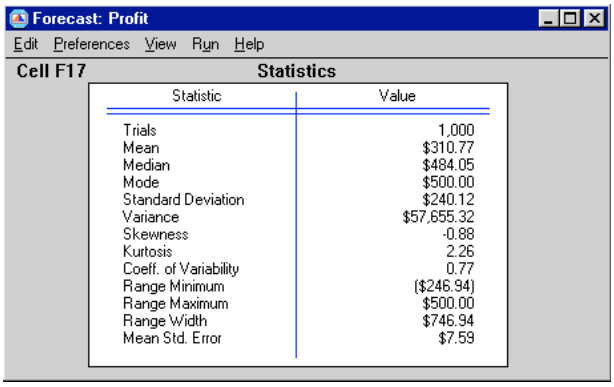
Click on the "Start Simulation" button in toolbar (or Run in the Run menu):

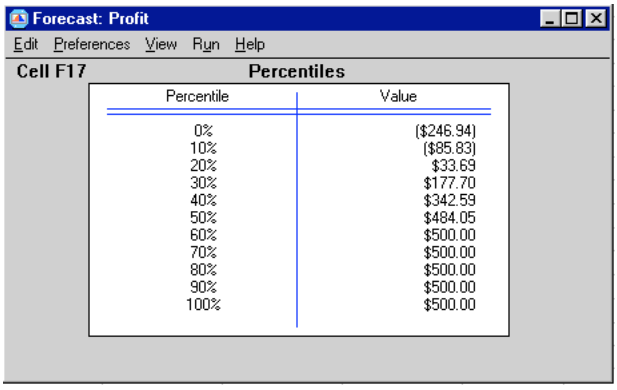
Step #6 (View Results)

The results of the simulation can be viewed in a variety of different ways (frequency chart, cumulative chart, statistics, and percentiles). Choose different options under the View menu in the forecast window.









The results can be copied into a worksheet or Word document (choose Copy under the Edit menu in the simulation output window.

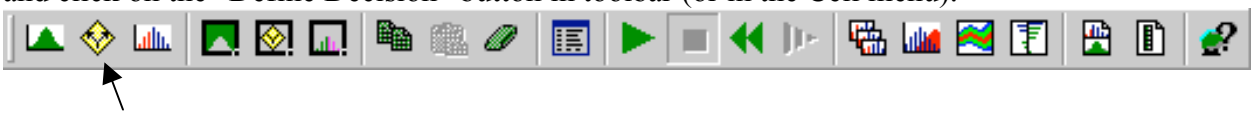
Using Decision Tables

The **Decision Table** tool can be used to quickly run a simulation for many values of a decision variable (e.g., the order quantity).

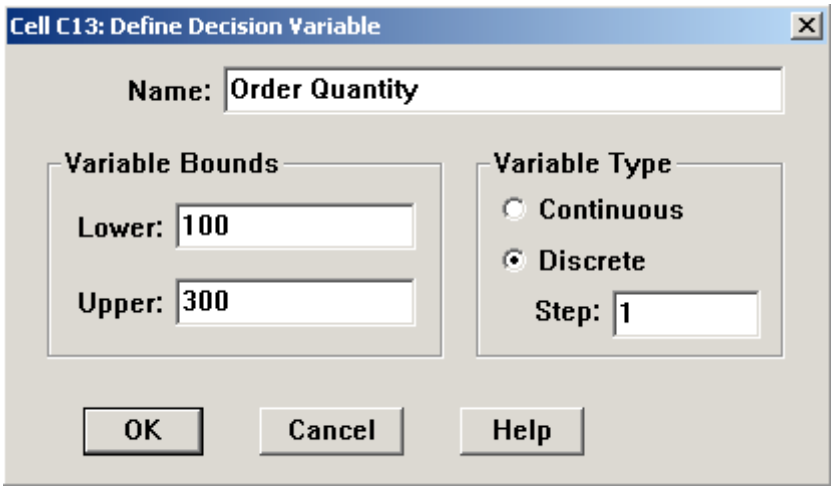
Select the cell that contains the decision variable (C13):

	B	C
12		**Decision Variable**
13	Order Quantity	200

and click on the "Define Decision" button in toolbar (or in the Cell menu):



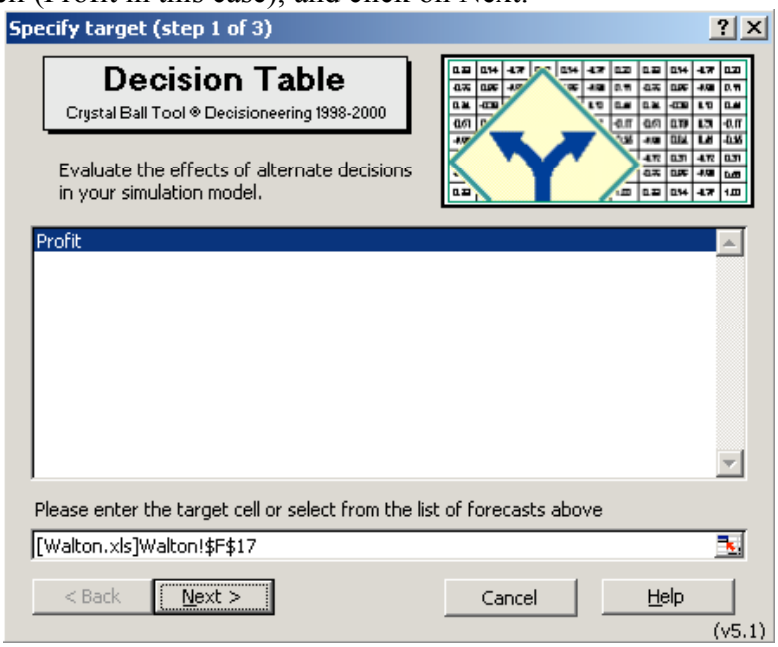
and specify the type of variable (continuous or discrete) and upper and lower bounds:



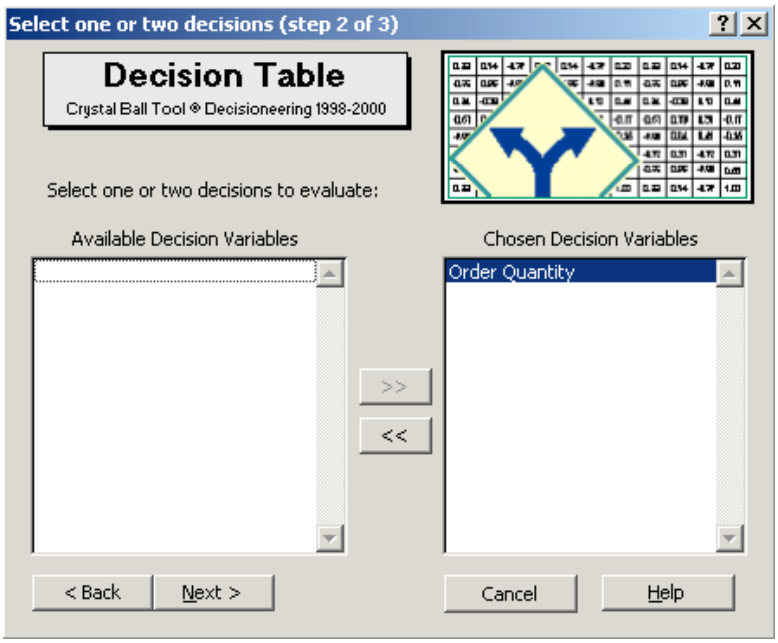
Using Decision Tables

Choose Decision Table from the CB Tools menu, and follow the instructions in the three dialogue boxes:

Choose the target cell (Profit in this case), and click on Next.

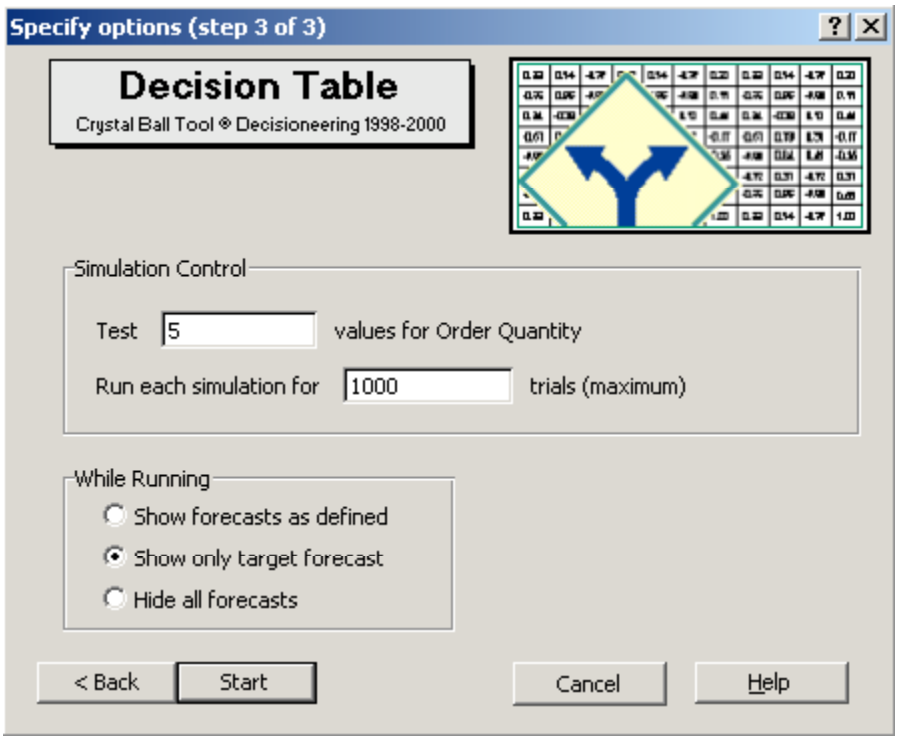


Specify the decision variable(s) to vary (Order Quantity in this case), and click on >> to move it to the "Chosen Decision Variables" column. Then click on Next. Note: a maximum of two decision variables can be varied at a time.

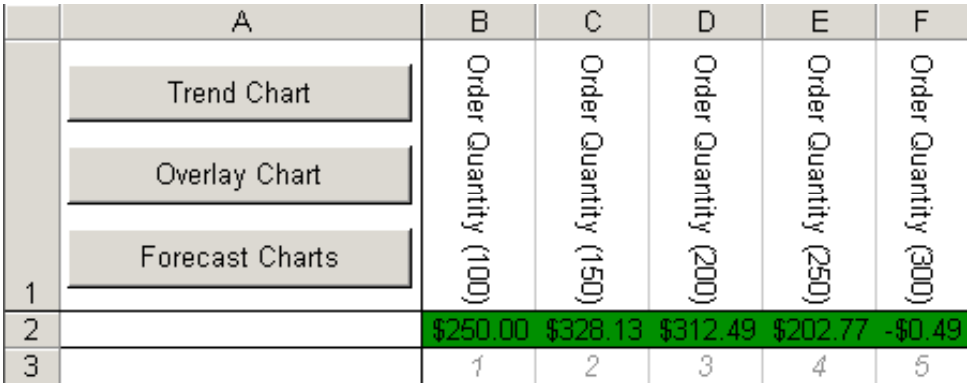


Using Decision Tables

Select the number of different trial values to simulate for the decision variable. The values will be evenly distributed between the lower and upper bound for the decision variable. For example, 5 trial values with a lower bound of 100 and an upper bound of 300 will simulate order quantities of 100, 150, 200, 250, and 300. Also specify the number of trials to run for each simulation run. Then click on Start to run the simulations.



The resulting decision table shows the mean result of the target cell (Profit) for each value of the decision variable (order quantity). To see the complete simulation results for an order quantity, select the appropriate cell (B2, C2, D2, E2, or F2) and click on forecast chart.

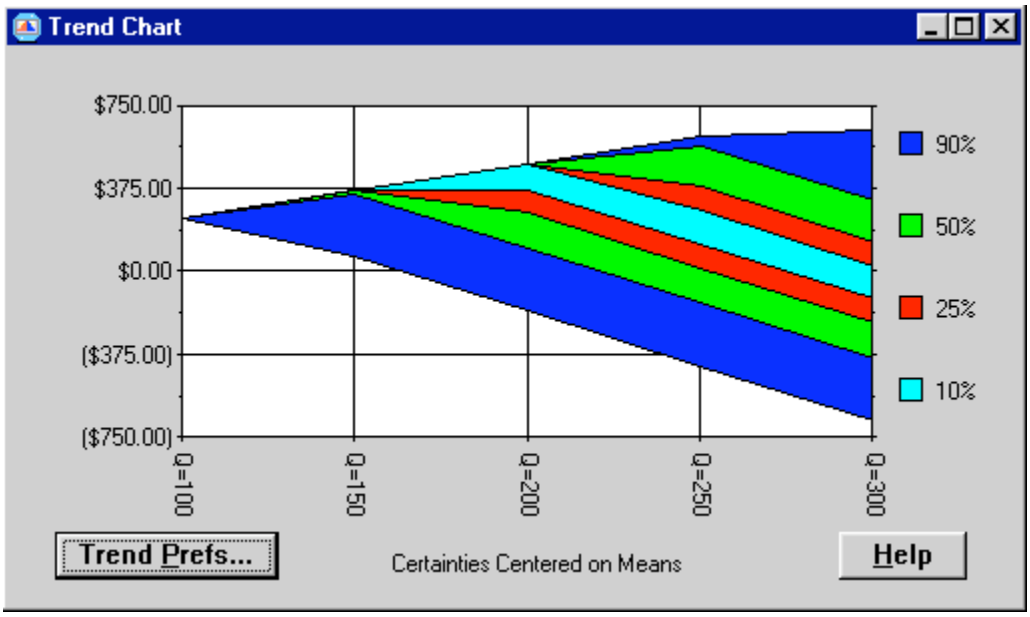


Trend Charts

A trend chart can be used to show trends across a range of values for the decision variable. To generate a trend chart, select the entire set of results for all of the decision variables (B2:F2)

	A	B	C	D	E	F
1	Trend Chart Overlay Chart Forecast Charts	Order Quantity (100)	Order Quantity (150)	Order Quantity (200)	Order Quantity (250)	Order Quantity (300)
2		$250.00	$328.13	$312.49	$202.77	-$0.49
3		1	2	3	4	5

and then click on Trend Chart.



This chart gives "certainty bands" (similar to a confidence interval) for the forecast cells. 10% of the time, the project duration will fall within the inner band (light blue), 25% of the time within the 2nd band (red), 50% of the time within the third band (green), and 90% of the time within the outside band (dark blue).

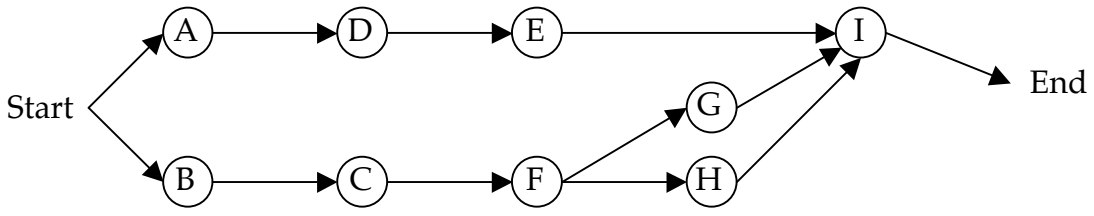
Project Management—Global Oil

Global Oil is planning to move their credit card operation to Des Moines, Iowa from their home office in Dallas. The move involves many different divisions within the company. Real estate must select one of three available office sites. Personnel has to determine which employees from Dallas will move, how many new employees to hire, and who will train them. The systems group and treasurer's office must organize the new operating procedure and make financial arrangements. The architects will have to design the interior space, and oversee needed structural improvements. Each site is an existing building with sufficient open space, but office partitions, computer facilities, furnishings, and so on, must all be provided.

A complicating factor is that there is an interdependence of activities. In other words, some parts of the project cannot be started until other parts are completed. For example, Global cannot construct the interior of an office before it has been designed. Neither can it hire new employees until it has determined its personnel requirements.

The necessary activities and their necessary predecessors (due to interdependence) are listed below. Three estimates are made for the completion time of each activity—the minimum time, most likely time, and maximum time.

		Immediate	Time Estimates (days)		
Activity	Description	Predecessor	Minimum	Most Likely	Maximum
A	Select Office Site	—	21	21	21
B	Create Org. & Fin. Plan	—	20	25	30
C	Determine Personnel Req.	B	15	20	30
D	Design Facility	A, C	20	28	42
E	Construct Facility	D	40	48	66
F	Select Personnel to Move	C	12	12	12
G	Hire New Employees	F	20	25	32
H	Move Key Employees	F	28	28	28
I	Train New Personnel	E, G, H	10	15	24



Global Oil Simulation with Crystal Ball®

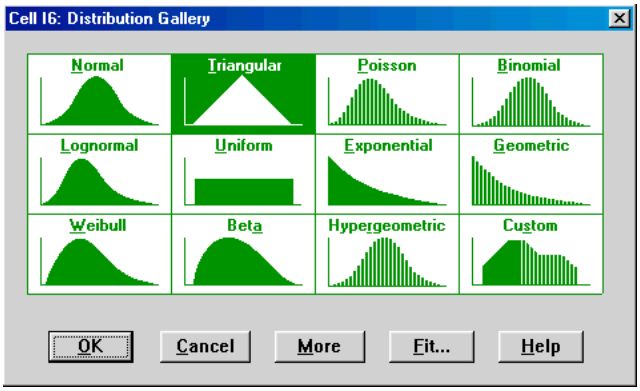
Step #1 (Setup Spreadsheet)

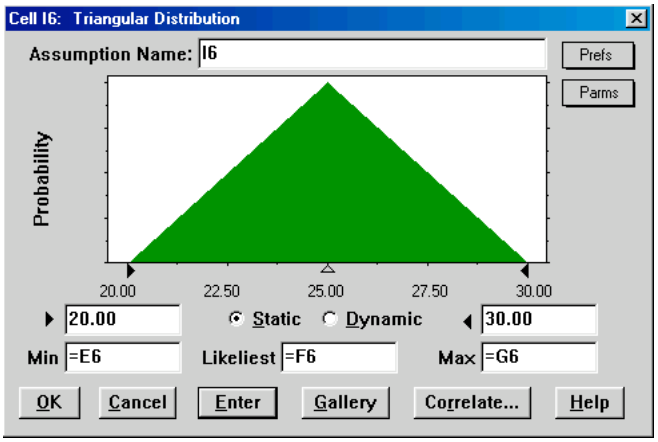
	B	C	D	E	F	G	H	I	J
2				Activity Time (Triangular)					
3			Immediate		Most		Start	Activity	Finish
4	Activity	Description	Predecessors	Minimum	Likely	Maximum	Time	Time	Time
5	A	Select Site	-	21	21	21	0	21	21
6	B	Create Org. & Fin. Plan	-	20	25	30	0	25	25
7	C	Determine Personnel Req.	B	15	20	30	25	20	45
8	D	Design Facility	A, C	20	28	42	45	28	73
9	E	Construct Facility	D	40	48	66	73	48	121
10	F	Select Personnel to Move	C	12	12	12	45	12	57
11	G	Hire New Employees	F	20	25	32	57	25	82
12	H	Move Key Employees	F	28	28	28	57	28	85
13	I	Train New Personnel	E, G, H	10	15	24	121	15	136
14									
15						Project Completion Time			136.00

	H	I	J
3	Start	Activity	Finish
4	Time	Time	Time
5	0	21	=H5+I5
6	0	25	=H6+I6
7	=J6	20	=H7+I7
8	=MAX(J5,J7)	28	=H8+I8
9	=J8	48	=H9+I9
10	=J7	12	=H10+I10
11	=J10	25	=H11+I11
12	=J10	28	=H12+I12
13	=MAX(J9,J11,J12)	15	=H13+I13
14			
15		Project Completion Time	=J13

Step #2 (Define Assumptions—i.e., random variables)

Each of the random activity times (B, C, D, E, G, and I) is assumed to follow the triangular distribution.





Global Oil Simulation with Crystal Ball®

Step #3 (Define Forecast—i.e., output)

Cell J15 is the forecast cell:

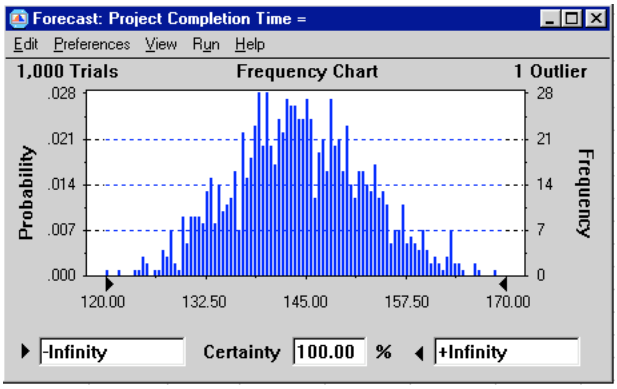
	H	I	J
15	Project Completion Time		136.00

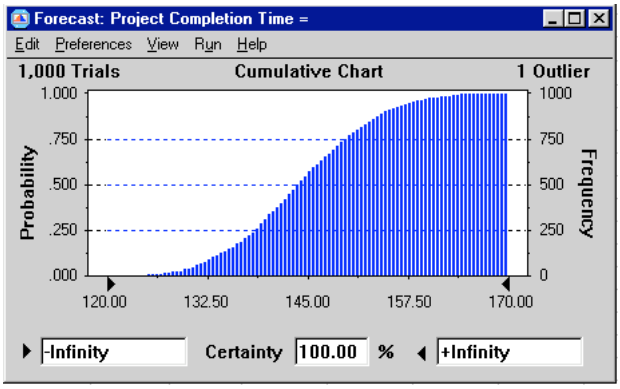
Step #4 (Choose Number of Trials)

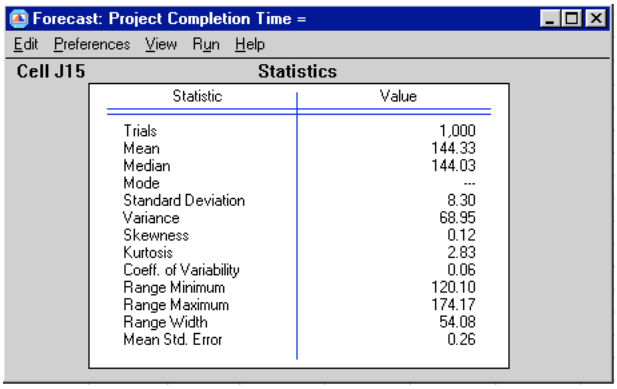
1000 trials were run. In addition, Sensitivity Analysis was enabled in the Options of the Run Preferences dialogue box. This allows for the generation of sensitivity analysis results later.

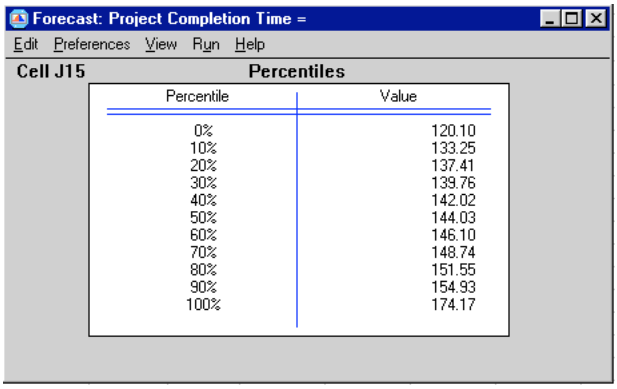
Step #5 (Run Simulation)

Step #6 (View Results)





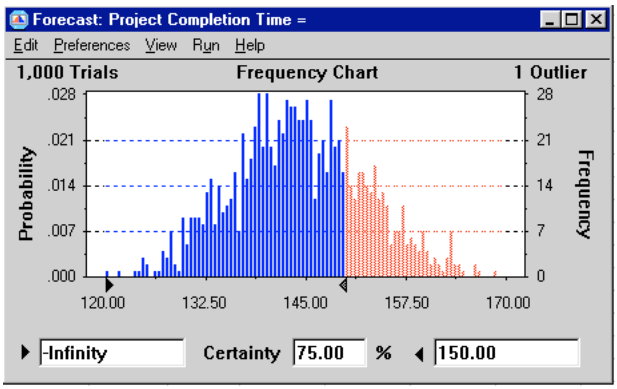


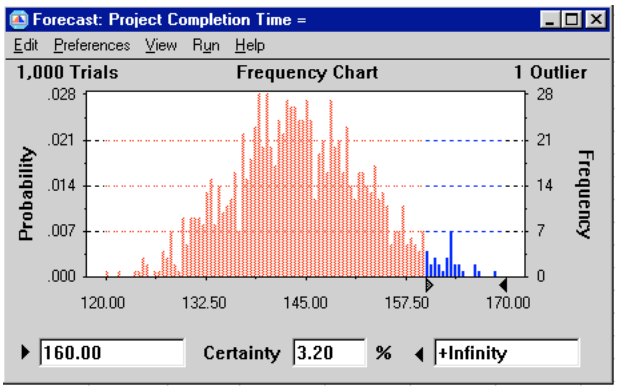


Additional Results Available with Crystal Ball®

Slide the triangles below the histograms to determine the probability that the output (project duration) is less than a certain value (e.g., a deadline), greater than a certain value, or between any two values (by sliding both triangles).

Alternatively, you can type in values for the lower bound or upper bound to determine the probability. You can also type in a probability (in "Certainty"), and it will determine the range that has that probability.

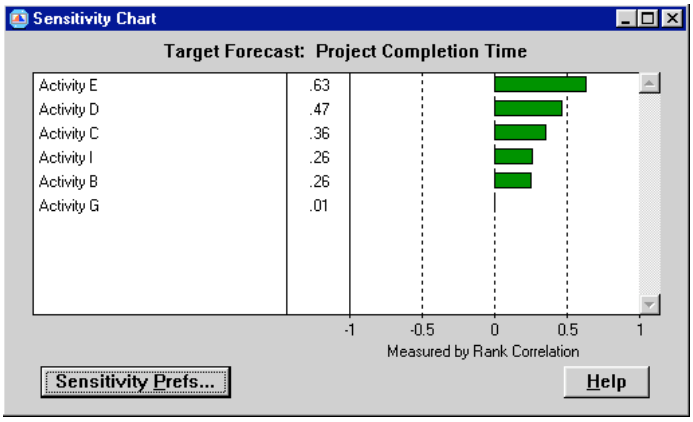




There is a 75% chance the project will be completed within 150 days. There is a 3.2% chance that the project will take more than 160 days.

Sensitivity Chart

Choose "Open Sensitivity Chart" in the Run menu. Note that this chart is only available if you selected the "Sensitivity Analysis" option under Run Preferences. This chart gives an indication as to which random variables (activity times) have the greatest impact on the output cell (project completion time).



Variability in activity E has the greatest impact on overall project duration, followed by activity D, C, I, and B. Variability in activity G has almost no impact.

Fitting a Distribution

Crystal Ball can be used to "fit" a distribution to data.

The following data has been collected for the previous 100 phone calls to a mail-order house:

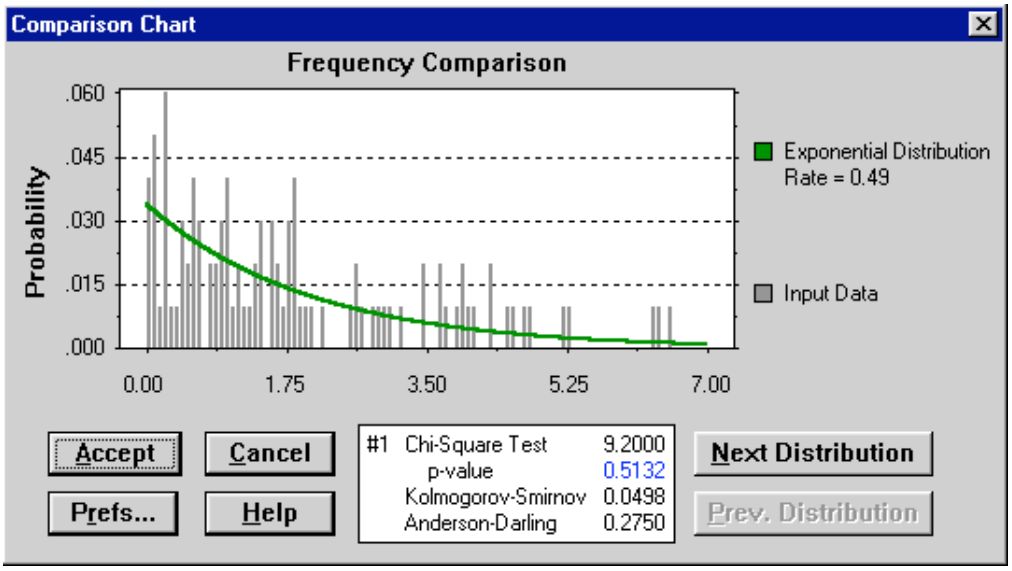
	A	B	C	D	E	F	G	H	I
1	**Phone Data**								
2									
3			Arrival	Interarrival	Length of Call			Interarrival	Length of Call
4		Customer #	(minutes)	Time	(minutes)			Time	(minutes)
5		1	8.22	8.22	3.77		Averages	2.004	4.51
6		2	12.25	4.03	4.53				
7		3	12.27	0.02	4.04				
8		4	16.26	3.98	3.70		Simulation	2	4
9		5	18.06	1.81	5.38				
10		6	18.87	0.81	4.36				
11		7	23.46	4.58	4.41				
12		8	23.53	0.08	5.14				
13		9	28.73	5.20	4.76				
14		10	30.56	1.83	4.68				
15		11	32.36	1.80	5.06				
16		12	36.90	4.54	5.75				
17		13	43.30	6.40	4.06				
18		14	43.88	0.57	3.25				
19		15	45.17	1.29	3.57				
99		95	194.02	0.28	4.26				
100		96	195.48	1.46	3.37				
101		97	195.87	0.38	4.45				
102		98	196.84	0.98	5.06				
103		99	197.81	0.97	5.20				
104		100	200.43	2.61	4.25				

Fitting Data to a Distribution

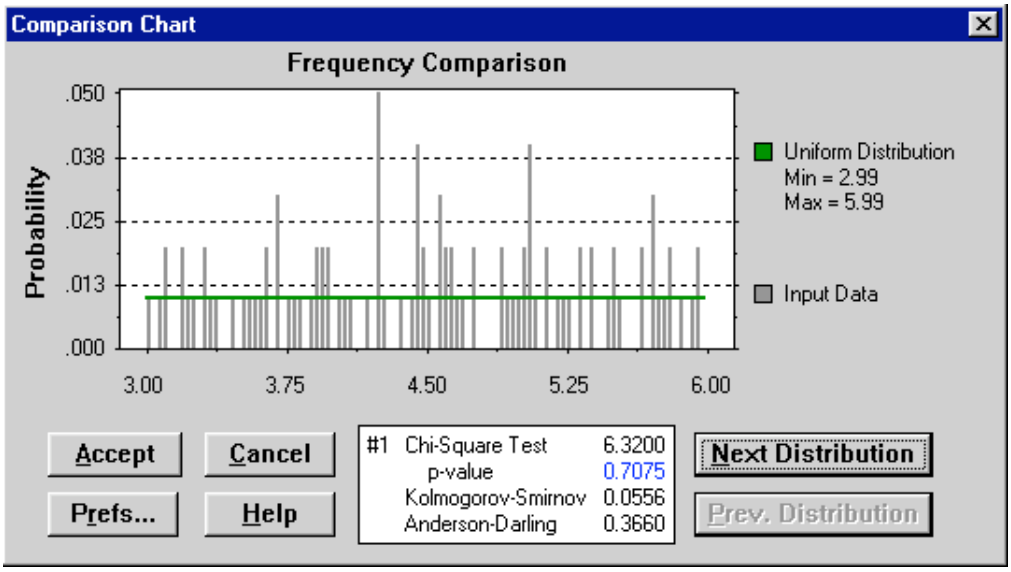
Using Crystal Ball® to fit data to a distribution

1. Select a spreadsheet cell.
2. Choose Define Assumption.
3. Click the Fit button, then select the source of the fitted data.
4. Click the Next button, then select the distributions to try to fit.
5. Click OK.

Interarrival Time



Service Time


Comparison Chart
Frequency Comparison
Probability
.050
.038
.025
.013
.000
3.00
3.75
4.50
5.25
6.00
Uniform Distribution
Min = 2.99
Max = 5.99
Input Data
Accept
Cancel
Prefs...
Help
#1 Chi-Square Test 6.3200
p-value 0.7075
Kolmogorov-Smirnov 0.0556
Anderson-Darling 0.3660
Next Distribution
Prev. Distribution