

Management Science Using Excel

*Harnessing Excel's Advanced Features for
Business Optimization*

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Chapter 12

Monte Carlo Simulations

Introduction

This chapter reveals the Behind the Scenes of Monte Carlo simulations. The chapter will begin by describing the “uses and benefits” of these simulations. Going through the chapter – you will have fun applying simulations of rolling dice on a spreadsheet. Following the basics, you will be simulating a long-term capital investment project hundreds of times - finding out the risk profile of your investment budget. The chapter will also show you how to generate different random numbers of various statistical distributions using The Excel Data Analysis ToolPak.

Objectives

The objective of this chapter is to introduce you to the concept of simulations using Excel. You will find out why simulations are being used and it can help professionals in making wiser decisions in management science.

You will be introduced to random number generators and see how to apply them to simulations. Following the introduction – you will be learning how to apply the concept to a real case. The last part of the chapter will introduce you to generating random numbers for a variety of statistical probability functions.

Excel by itself is not fully a simulations tool, but is great for introductory level instrument. If you wish you can purchase inexpensive Excel add-ins such as CrystalBall or @Risk. There are others - free ones as well.

Structure

Topics to be covered:

- Who is using Monte Carlo Simulation and why?
- What is the concept of random numbers?
- Rolling Dice using Excel
- Case Study: Simulation risk profiles of long-term capital investment.
- Using the Data Analysis for simulating different distributions
- Practice problems and solutions

Who and why is using Monte Carlo Simulation?

The name Monte Carlo is associated with the first modern casino established in Monaco in 1859 and was named Le Grand Casino de Monte Carlo. How has it turn out to be the name of the Monte Carlo simulations? Computer simulations were performed during the 1930s and 1940s to estimate the probability of the chain reaction needed for an atom bomb to detonate successfully. The scientists performing this work were compulsive gamblers, so they decided to use the code name Monte Carlo for these simulations.

“Monte Carlo methods, or Monte Carlo experiments, are a broad class of computational algorithms that rely on repeated random sampling to obtain numerical results. The underlying concept is to use randomness to solve problems that might be deterministic in principle. They are often used in physical and mathematical problems and are most useful when it is difficult or impossible to use other approaches.

Monte Carlo methods are used in corporate finance and mathematical finance to value and analyze (complex) instruments, portfolios and investments by simulating the various sources of uncertainty affecting their value, and then determining the distribution of their value over the range of resultant outcomes.” (Wikipedia.).

Microsoft support site lists several users. Many companies use Monte Carlo simulation as an important part of their decision-making process. Here are some examples:

- General Motors, Proctor and Gamble, Pfizer, Bristol-Myers Squibb, and Eli Lilly use simulation to estimate both the average return on and the risk factor of new product introduction.
- At GM, this information is used by the CEO to determine which products come to market.
- GM uses simulation for activities such as forecasting net income for the corporation, predicting structural and purchasing costs, and determining its susceptibility to different kinds of risk (such as interest rate changes and exchange rate fluctuations).
- Lilly uses simulation to determine the optimal plant capacity for each drug.
- Proctor and Gamble use simulation to model and optimally hedge foreign exchange risk.
- Sears uses simulation to determine how many units of each product line should be ordered from suppliers—for example, the number of pairs of Dockers trousers that should be ordered this year.
- Oil and drug companies use simulation to value “real options,” such as the value of an option to expand, contract, or postpone a project.
- Financial planners use Monte Carlo simulation to determine optimal investment strategies for their clients’ retirement.

What is the concept of random number?

Excel has two functions that are used to generate random numbers **RAND** and **RANDBETWEEN**. We can harness these functions to help generate various random numbers for simulations. The function **=RAND()** generates values between 0 and 1 with equal probabilities as a uniform distribution. The **=RANDBETWEEN(a,b)** generates integers between a and b values with equal probabilities of each.

Rolling dice using Excel

Take, for example the function `=RANDBETWEEN(1,6)` which generates the numbers 1 through 6, simulating rolling a 6-sided dice. *Figure 12.1* displays the probability density function for this function.

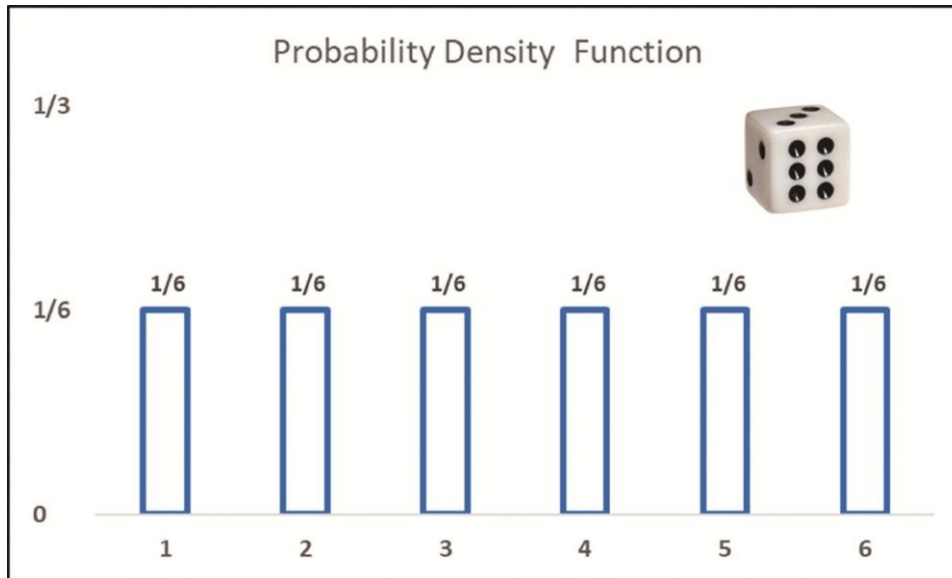


Figure 12.1: The probabilities density function of rolling a six-sided dice

When we use `RAND()` we can create a continuous either uniform distributions or rectangular distributions. If we try `=5+RAND()*10` we get a uniform distribution as displayed in *Figure 12.2*.

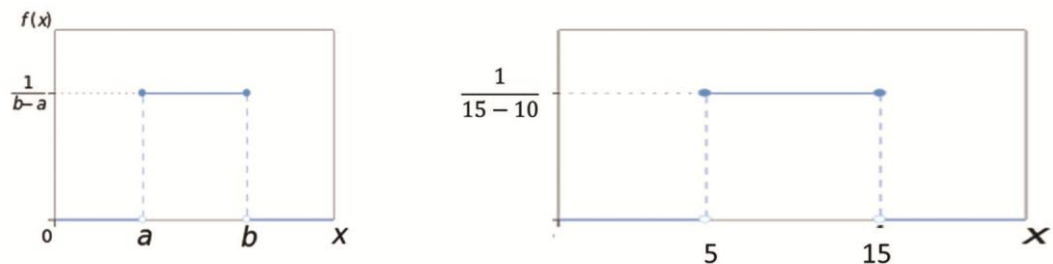


Figure 12.2: Uniform distribution function for $5 < x < 15$

On the Excel file named **Chapter 12 simulations**, tab titled **Demo Dice** for this chapter, we have an example of a rolling a pair of dice. Hit the F9 key to roll them again and again. See *Figure 12.3*.

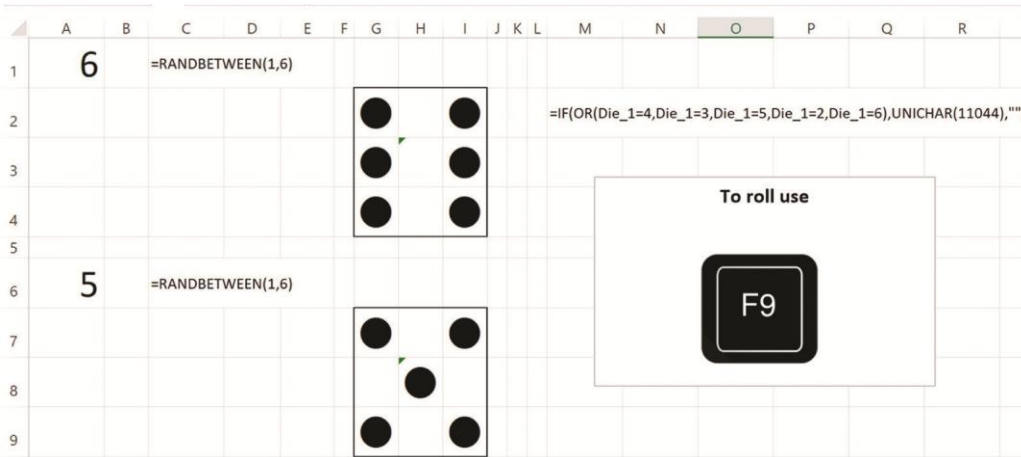


Figure 12.3: Rolling a pair of dice using the RANDBETWEEN(1,6) function

On the **1-Dice** tab of the same Excel chapter 12 workbook – you can see arithmetic results of rolling a single die simultaneously 60,000 times. *Figure 12.4* displays part of the sheet. Cells B2:B60001 contain the function **RANDBETWEEN(1,6)** that is shown in the figure. Cells G3:G9 contain the calculated relative frequency and the associated percentages are shown on column H. We expected a theoretical count 10,000 per value (1 through 6). The results are very close. You are encouraged to open this sheet and use F9 to recalculate.

	A	B	C	D	E	F	G	H	I
1	Number	Die							
2	1	6		60000 dice		F		%	
3	2	5	=RANDBETWEEN(1,6)			1	9974	16.62%	
4	3	2				2	10036	16.73%	
5	4	1				3	9920	16.53%	
6	5	1				4	9974	16.62%	
7	6	3				5	10034	16.72%	
8	7	3				6	10062	16.77%	
9	8	6				SUM	60000		
10	a	c							

Figure 12.4: An example of rolling a single die 60,000 times

On the same Excel file, tab named **Dice** – we are rolling a pair of dice and calculating their sum – repeating it 3,600 times. You can see the calculated sums distribution next to the theoretical values displayed next to it in *Figure 12.5*. We are comparing the theoretical values to the actual simulated values.

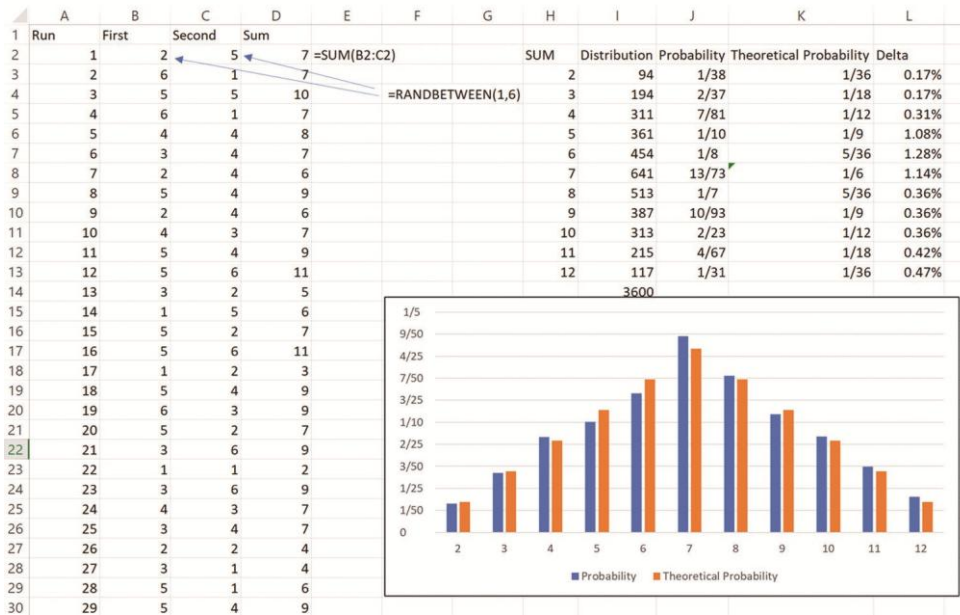


Figure 12.5: A simulation of rolling a pair of dice for 3,600 times

Different distributions of random values

Now we can try a different distribution. The next example is simulating dispersion of 1,000 student IQs from a population normally distributed with an average IQ of 100 and standard deviation of 10. Figure 12.6 displays the simulation and the outcome summary of with 1,000 students. We are using the function `=INT(NORM.INV(RAND(),Average,STD))`:

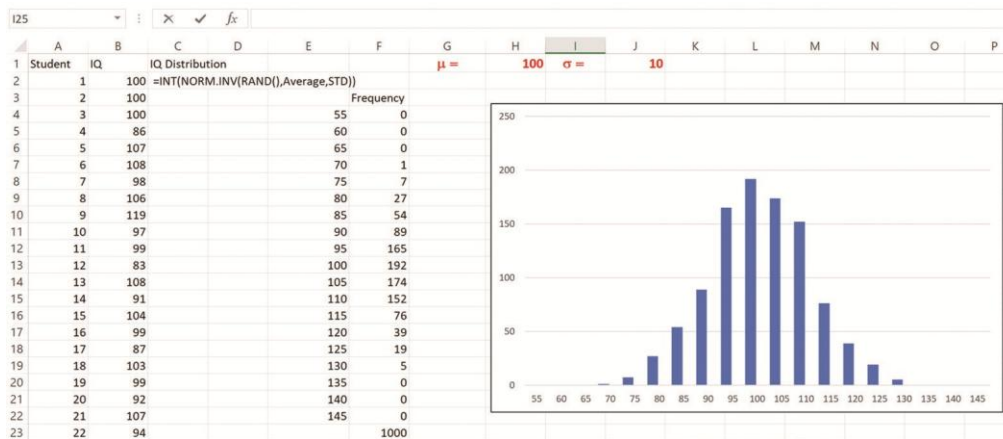


Figure 12.6: Simulating a normal distribution of students' IQs

The preceding example teaches us that by defining the boundaries, we can simulate outcomes. For instance, if we wanted to simulate random demand with an average of 180 units and a standard deviation of 12, we would use the function `=INT(NORM.`

`INV(RAND(),180,12))`. The `INT` part of the function is to generate only whole numbers, avoiding fractions.

Another example is when you have a different distribution of demand. Collecting information of any demand over 100 days, you can predict the future probability distribution of that demand as shown in *Figure 12.7*. On the left side of the figure, we display the demand experienced over the last 100 days. This information is used to create the estimated, future probabilities and the chart.

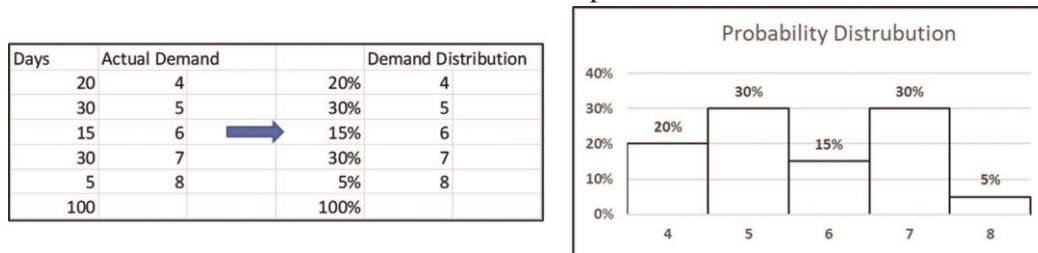


Figure 12.7: A discrete probability distribution and chart based on actual data

The task here is to generate random numbers that will have the same probability distribution of the demand. To do so – we must first create a cumulative probability density function. You can find this example on the same Excel sheet, under the **Discrete Demand** tab.

Figure 12.8 displays the cumulative distribution of the example of *Figure 12.7*. The VLOOKUP function that will generate predicted demand according to previous demand. Since the **RAND()** function generates values between 0 and 0.2, (20% of the time) – the demand will be 4 of this range for 20% of the time. The **RAND()** will generate 30% of the time values in the range of 0.2 and 0.5 – hence the VLOOKUP will generate demand of 5, 30% of the time. The same holds for 6, 7 and 8.

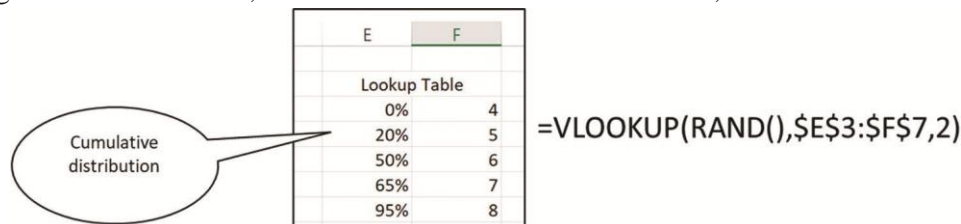


Figure 12.8: The VLOOKUP generates demand according to the cumulative probability distribution function

Case study: simulation risk profiles of long-term capital investments

Now that we know how to generate random numbers according to a given probability distribution, we can apply this technique to real life examples. On the model presented in *Figure 12.9* – we display a long-term capital investment project. The Baron Consulting Firm is planning a new gluten free bakery project.

The initial capital investment is €500,000. You can see the information on the figure. It shows a simplified version of the model. The Excel Tab Budget contains this model. The top of the Budget sheet shows the information of unit selling price and cost. It shows annual fixed cost, capital cost of 8%, used later in our **Net Present Value (NPV)** function and the tax rate. At this initial point our annual demand, (used for setting up the model) is exactly 600,000 units. This demand will be changed further for the simulation.

The three years' calculations functions are displayed in column F. (The three years are the expected lifetime of this project.) Cell B18 has the calculated NPV, of the project investment – when the demand is exactly 600,000 units per year.

	A	B	C	D	E	F	G	H
1	Assumptions							
2	Initial Investment	500,000.00 €		Capital Cost	8%			
3	Selling Price	3.00 €		Tax Rate	41%			
4	Variable Cost/Unit	1.75 €						
5	Annual Fixed cost	325,000.00 €						
6								
7			Annual Demand	600,000 units		=RANDBETWEEN(400000,800000)		
8								
9		Year	1	2	3			
10	Demand		600,000	600,000	600,000	=Annual_Demand		
11	Revenue		1,800,000	1,800,000	1,800,000	=E16*Selling_Price		
12	Fixed Cost		325,000	325,000	325,000	=Annual_Fixed_cost		
13	Variable Cost		1,050,000	1,050,000	1,050,000	=E16*Variable_Cost_Unit		
14	Profit before Tax		425,000	425,000	425,000	=E17-SUM(E18:E19)		
15	Tax		174,250	174,250	174,250	=IF(E20*Tax_Rate<0,E20*Tax_Rate)		
16	Profit after Tax		250,750	250,750	250,750	=E20-E21		
17								
18	Net Present Value	146,207.07 €	=NPV(Capital_Cost,C22:E22)-Initial_Investment					

Figure 12.9: The initial setup of the long-term capital investment model

Baron's consulting is estimating at this moment that the annual demand is uniformly distributed between 400,000 to 800,000 units (integers.) The function which will be used is:

=RANDBETWEEN(400000,800000)

Before we run the simulation, it is a good idea to investigate the range and the limit of the investment without the simulations.

The worst-case scenario is where all the three years' demand is a minimum 400,000 units. Entering 400,000 in cell D7 will yield a negative NPV of -€233,914.74. You can try it yourself.

The best-case scenario or the most optimistic case is when all three years' demands are 800,000 units. Entering 800,000 in cell D7 will yield an NPV of €526,328.88.. Try it again.

The midpoint - scenario is when the demand is 600,000 units a year and the expected profit is €146,207.07. This is the case presented in preceding *Figure 12.9*.

Another important thing is to calculate or find the Break Even Point. To do so we can ask: how many units a year do we have to sell to break even where the profit will be 0?

To answer this question, we must click of cell B18 (the NPV) and use Data>What if analysis>Goal Seek (1). Enter 0 and look for the value in cell D7 (2). See *Figure 12.10*.

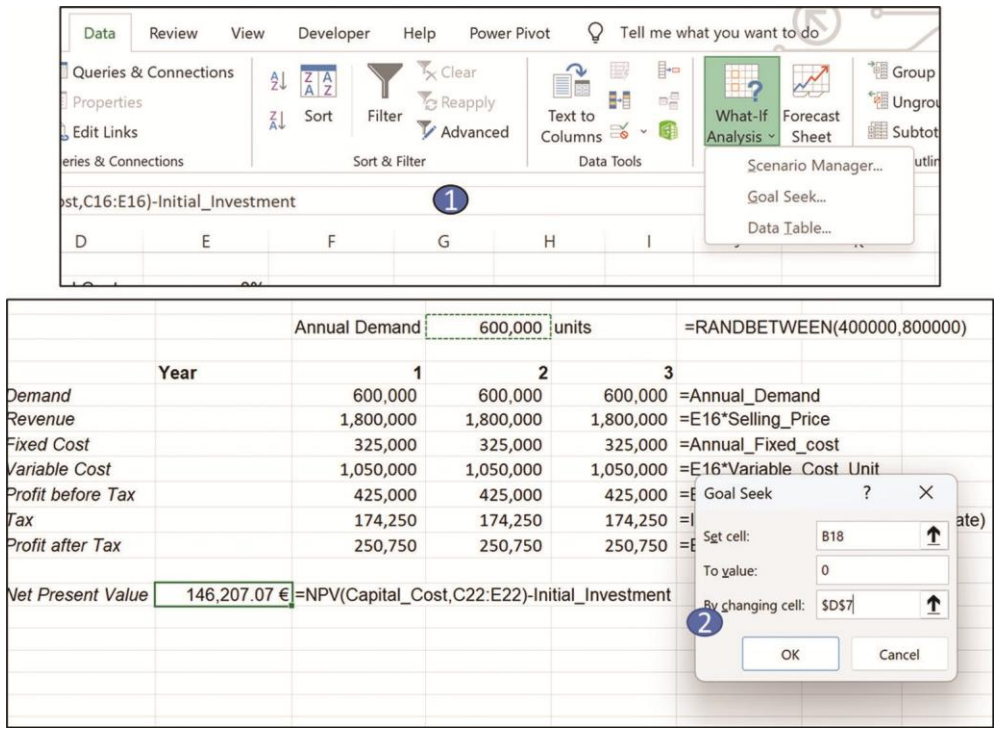


Figure 12.10: Performing the goal seeks to find the break-even point

The break-even point is 523,074 units. Figure 12.11 summarizes our calculated findings.

Deterministic Analysis		
	Annual Demand	NPV
Most Pesimistic	400,000	-233,914.74 €
Break Even	523,074	0.00 €
Most Likely	600,000	146,207.07 €
Most Optimistic	800,000	526,328.88 €

Figure 12.11: Deterministic analysis of the project

To run the simulation, we have to replace the values in cells C10, D10 and E10 with the function =RANDBETWEEN(400000, 800000). Now every time you want to recalculate, click on the F9 key - and the value in cell B18 will change. The objective is to run the simulation many times and collect statistics to determine the risk profile of the investment.

The Simulation: You can find the sheet with the simulated values on the TAB named **Budget rand** on the Excel file of this chapter. We will prepare a sheet to run the simulation multiple times. On the sheet **Simulation setup**, we will run the simulation 200 times. In cell A1 we type the word **Run** to indicate run number. In cell A2 we type the number 1. Next, we use a menu to type the rest of the numbers from 1 to 200 on the cells A2:A201. See Figure 12.12: Go to **Home | Fill | Series (1)**. On the **Series** menu (2) we select columns and type 200 and ok. Now you will have the run numbers in column A.

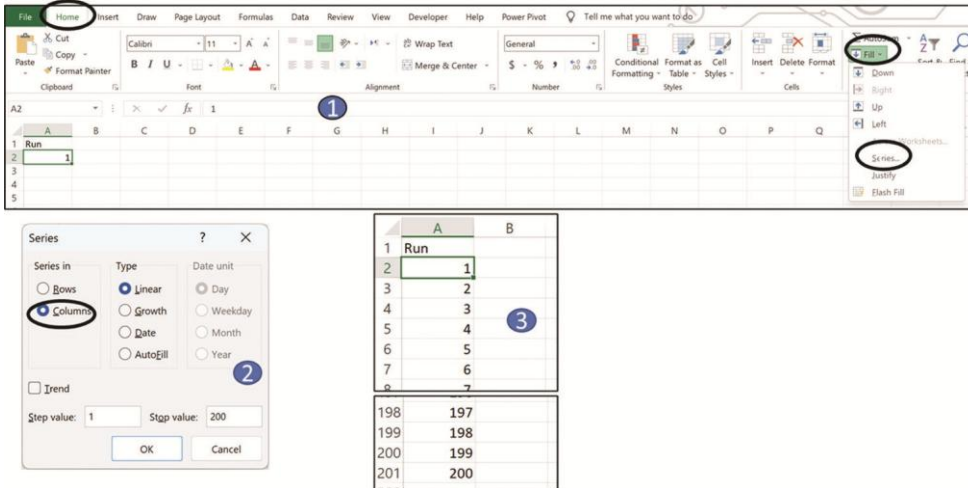


Figure 12.12: Creating the run numbers list in column A

Preparing for the simulations we type the word Simulation in B1. In B2 we type “=” and select cell B18 of the Budget rand sheet. See Figure 12.13.

	A	B	C	D
1	Run	Simulation		
2	1	61464.5	= 'Budget rand'!B18	
3	2			
4	3			

Figure 12.13: Preparing the sheet for the simulation we type in cell B2: = 'Budget rand'!B18

To run the simulation, see Figure 12.14 for the steps:

1. Select the range A2:B201.
2. Go to **Data | What if analysis | Data table**.
3. On the Column input cell, select any empty cell (we used E3) and hit **OK**.

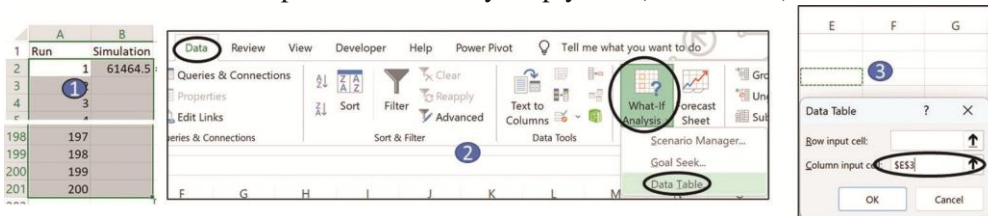


Figure 12.14: Running the simulation 200 times

Figure 12.15 displays a few of the cells with the simulations.

	A	B
1	Run	Simulation
2	1	93,234.44
3	2	-19,892.30
4	3	272,782.08
5	4	157,648.54
6	5	173,850.15
7	6	152,289.71
197	196	299,457.06
198	197	75,433.22
199	198	195,761.05
200	199	101,549.76
201	200	96,702.45

Figure 12.15: Simulation results in cells B2:B210

As we have the results of 200 runs, we can perform a statistical analysis of the results. If we name the range B2:B201 simulations - we can go to (1) **Data | Data Analysis** and use the (2) **Descriptive Statistics**. We enter the range of simulations, ask for all the statistics, and indicate to output it in the cell E2 (3). See Figure 12.16.

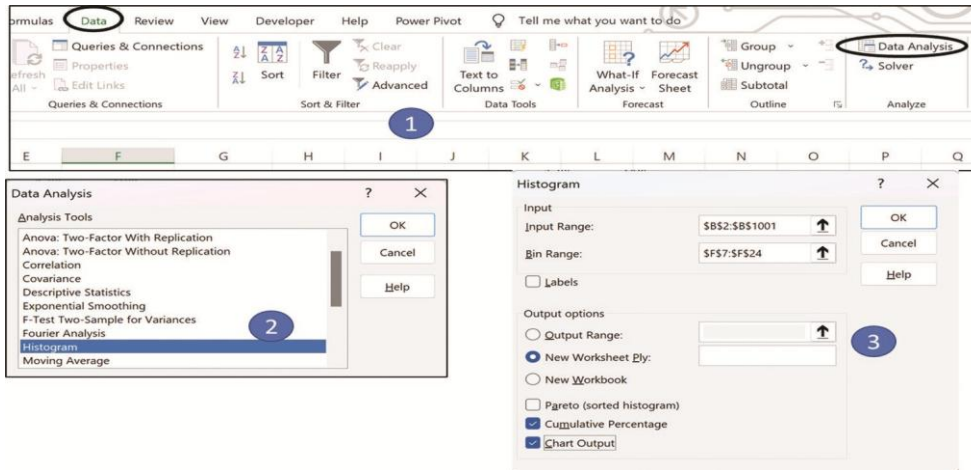


Figure 12.16: Requesting the statistics of the simulations

Figure 12.17 shows the statistics of this run. The mean of the simulation is 143,175 which is almost equal to the value of Figure 12.10 of 146,207. The maximum and the minimum are also close. If we were to randomize (rand) the simulation 1,000 times, it would be even more accurate. The standard deviation of 124,077 is an indication of the spread we expected.

Column1	
Mean	143175.2
Standard Error	8773.633
Median	144600
Mode	#N/A
Standard Deviation	124077.9
Sample Variance	1.54E+10
Kurtosis	0.030212
Skewness	-0.14189
Range	670072.3
Minimum	-208463
Maximum	461609.4
Sum	28635045
Count	200
Largest(1)	461609.4
Smallest(1)	-208463
Confidence Level(95.0%)	17301.22

Figure 12.17: Summary statistics of the simulation

To understand the risk profile of the investment, we have to create a frequency distribution of the results. As shown in *Figure 12.18*: We listed in column I (marked with the number 1), the potential output values, ranging from -250,000 through 550,000. (marked by 2) Using the Excel **FREQUENCY** array function we get the number of occurrences for every range. For an array function use **CTRL + SHIFT + Enter**. (See 3) In addition in column K divide the frequencies by the 200 runs for the percentages. We can create the cumulative calculations in column L.

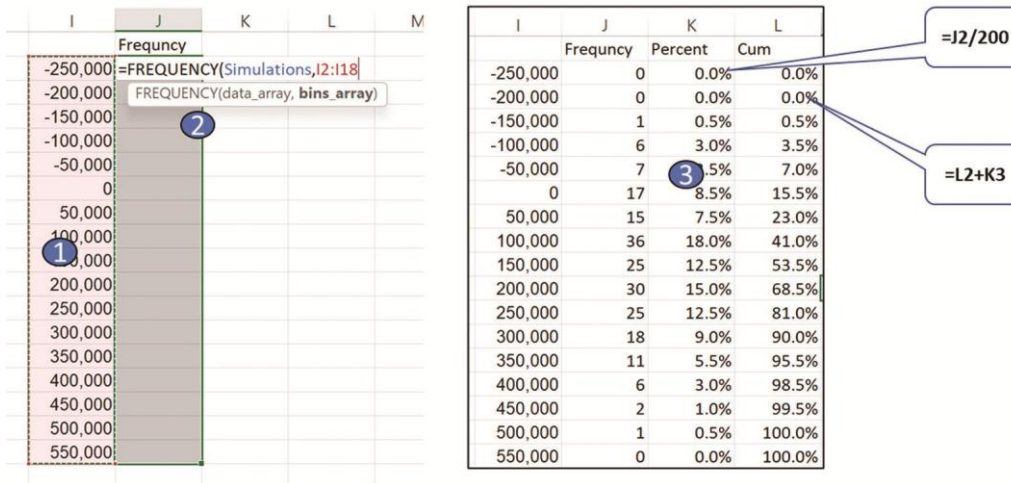


Figure 12.18: Frequency distribution of the simulations results

We can see in column L that 15.5% of the cases that the project is losing funds. These numbers may change slightly as the calculations of the file continue, automatically.

To create a chart: in *Figure 12.19* we select the data of columns I, K and L without the data in column J. Use the selection to create a combination chart of the risk profile.

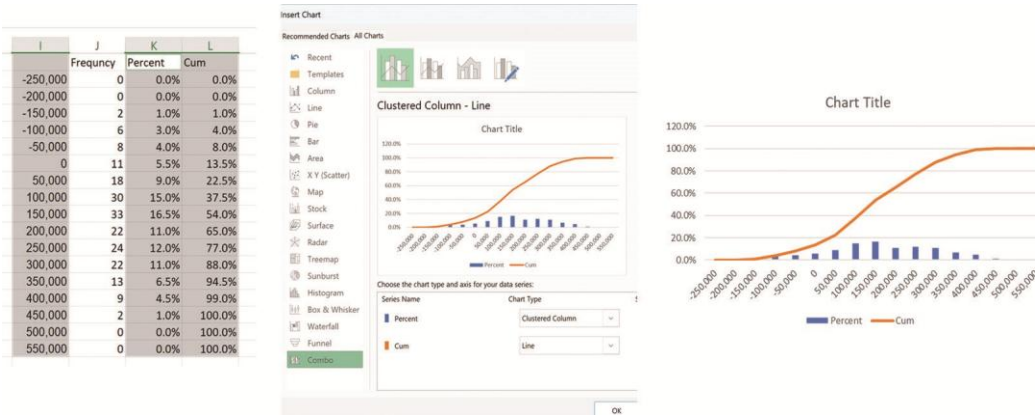


Figure 12.19: Creating the initial combination chart of the simulation results

To format the chart, follow these steps. See Figure 12.20:

1. Delete the header.
2. Right click on the line chart and ask to **Format Data Series**. Check on the secondary axis option.



Figure 12.20: Formatting the combination chart

The next step is to format the columns. Format the column, reduce the gaps and add the value labels. This will give us a chart which will be useful to understand the risk profile of the investment. We formatted the columns with the return values of less than or equal to 0 to be displayed in red. See Figure 12.21.

We can see on the chart that the probability that this investment will not be profitable about 17% of the time. You can also see that the probability of a net present value exceeding 250,000 is 37%.

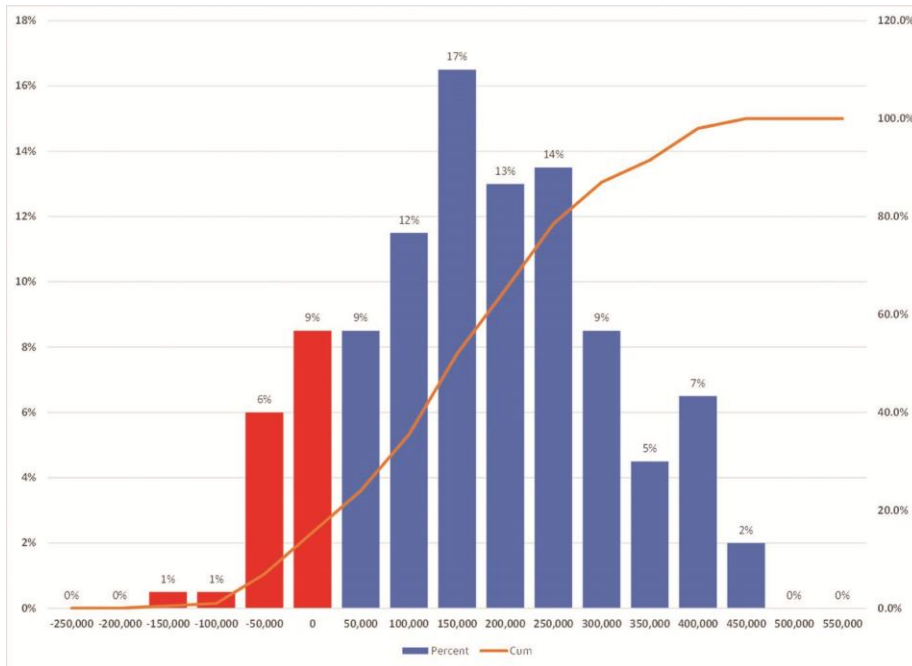


Figure 12.21: The risk profile of the investment

As we saw in *Figure 12.21*, it is close to a normal distribution, running the simulation again with 1,000 values instead of 200, will result in a better presentation, see *Figure 12.22*.

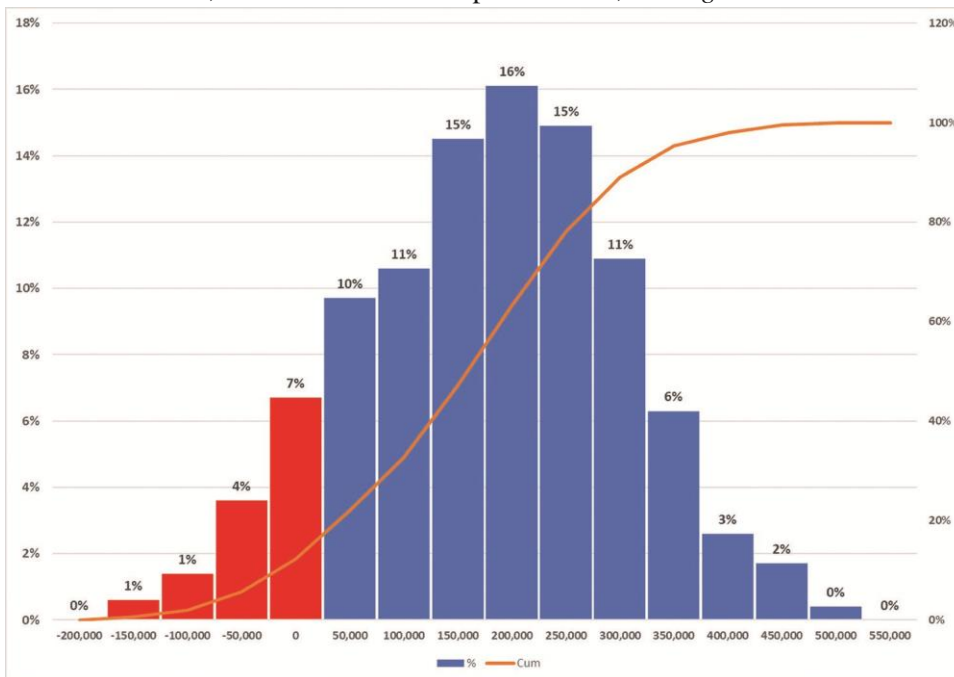


Figure 12.22: The risk profile of the investment with 1,000 runs

Using the data analysis ToolPak

Rather than using the Excel statistical functions for the calculations, you can use the same tool we used for *Figure 12.16*, the Analysis ToolPak to get the histogram. We use the same data used on the Chart1000 Tab.

In *Figure 12.23* we see the same results of the 1,000 simulations. Data Analysis report shows on the right the so-called Bins for the analysis, the ranges of the probability density function.

	A	B	C	D	E	F
1	Run	Simulation				
2		1 \$115,271.02				
3		2 177644.9901				
4		3 269352.1793				
5		4 77259.85424				
6		5 261661.8562				
7		6 297200.6887				-200,000
8		7 127234.1889				-150,000
9		8 31321.47832				-100,000
10		9 -73038.5598				-50,000
11		10 76506.41404				0
12		11 371569.8217				50,000
13		12 349731.0193				100,000
14		13 -17329.3945				150,000
15		14 -31397.3007				200,000
16		15 47338.15883				250,000
17		16 -56540.3245				300,000
18		17 163911.8253				350,000
19		18 84717.67639				400,000
20		19 384169.121				450,000
21		20 150708.6194				500,000
22		21 10390.64624				550,000
23		22 291783.9286				600,000
24		23 198073.3738				650,000
25		24 206940.1852				

Figure 12.23: The 1,000 simulations results and the bins for the data analysis

Using the Analysis ToolPak we activate the Histogram. See the steps taken in *Figure 12.24*.

1. Use the **Data** on the **Data** ribbon for the **Data Analysis**.
2. Select the **Histogram**.
3. On the **Histogram** menu select the data of B2:B1001. The bins F7:F24 are the same bins on the range shown in *Figure 12.23*. Check on **Cumulative Percentage**, then **Chart Output**.

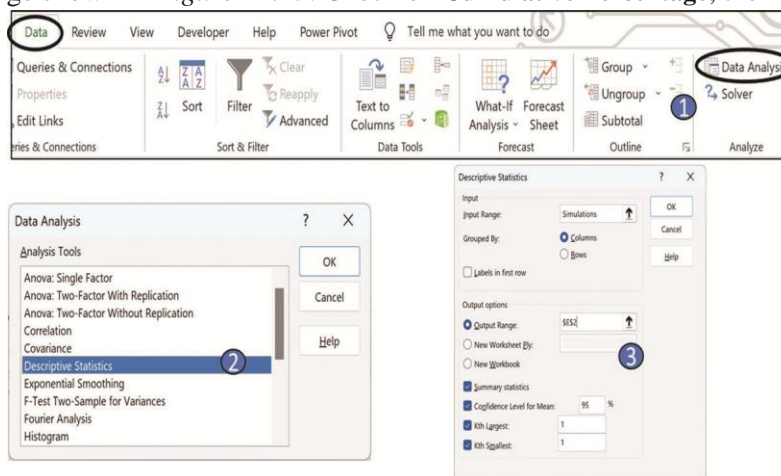


Figure 12.24: Using the histogram menu

Figure 12.25 displays the output of Data Analysis Histogram feature.

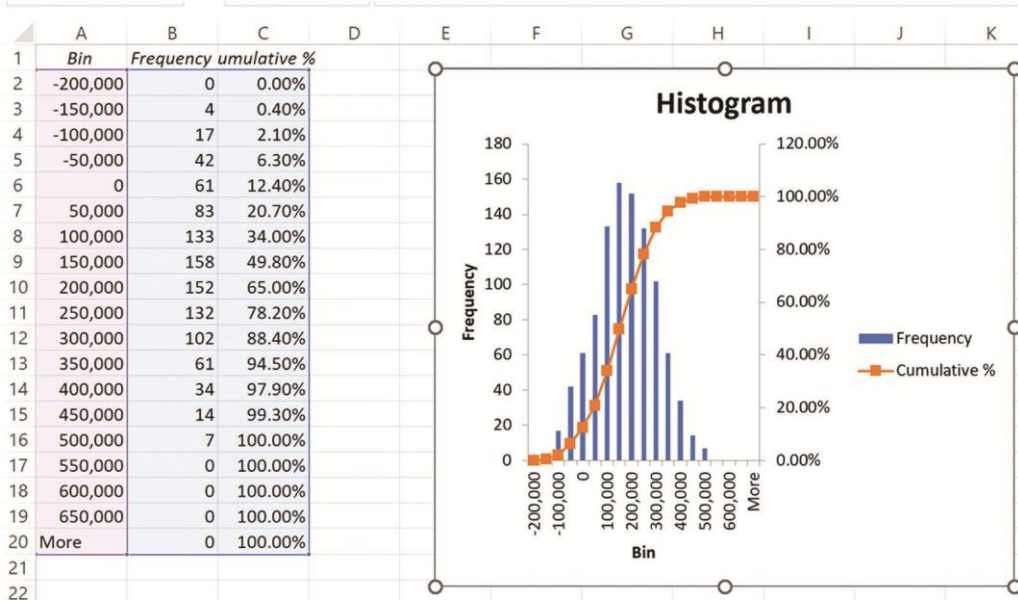


Figure 12.25: The histogram tool output

Simulations using other distributions

The random numbers generated by Excel are limited to **RAND** and **RANDBETWEEN**. We could utilize these functions to generate other distributions – but these are not as easy to apply.

The Data Analysis ToolPak has a set of random number generations with other distributions.

Using the data analysis ToolPak Random Number Generator

The Data Analysis ToolPak is on the far-right side of the Data ribbon as shown in *Figure 12.24* above. We have to go to **Data | Data Analysis** and choose **Random Number Generation** and we get the menu as shown in *Figure 12.26*. Each example will have its own sheet in the Excel file.

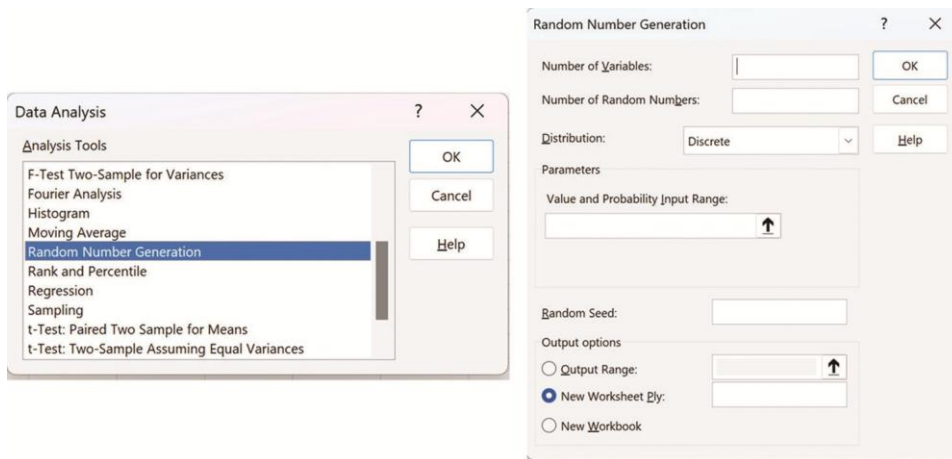


Figure 12.26: Activation the Random Number Generator of the Analysis ToolPak

Uniform distribution

The distribution is a rectangular distribution when the data is evenly spread. The **RAND()** is uniform between 0 and 1. The values of the random numbers are constant over the interval. With the Data Analysis Random Number Generator, we have the flexibility of generating a range of the values. In *Figure 12.27* we have an example of using this option. The output is on the right side of the figure.

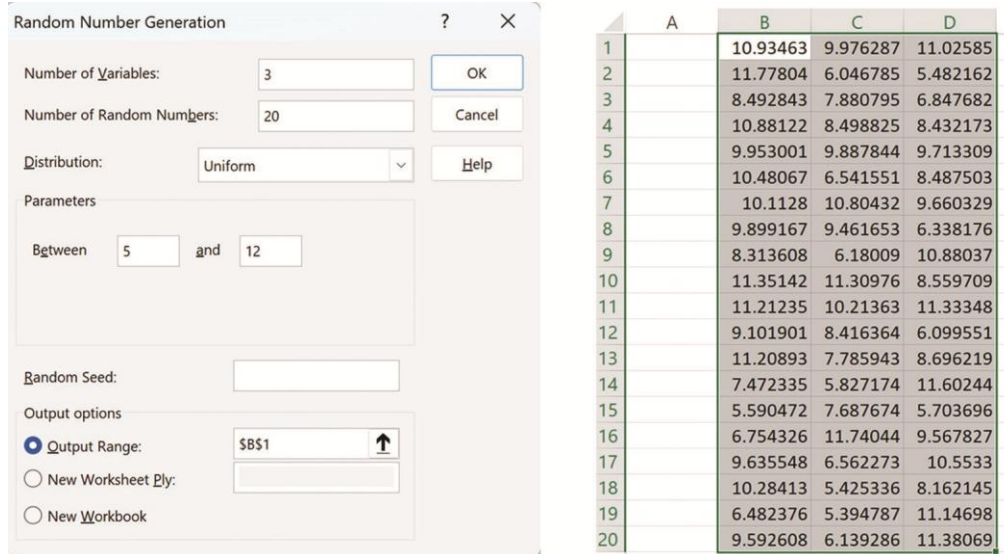


Figure 12.27: Using the Uniform random number generator

Normal distribution

Figure 12.28 shows the normal distribution of the same values. We have 60 values with an average of 0 and standard deviation of 1.

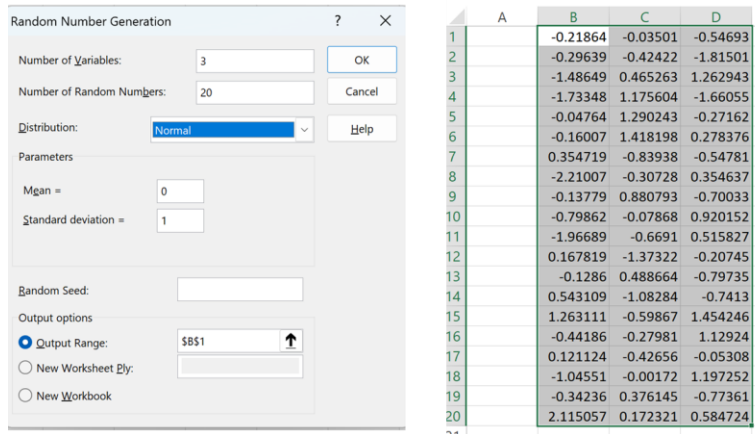


Figure 12.28: Using the Normal random number generator

Bernoulli distribution

This distribution is used when a single random experiment with outcome either success or failure is required. The outcome of a Bernoulli trial is a random variable with a Bernoulli distribution. Using a

conditional probability - p value of 0.3 – we expect 30 percent of the time a value of 1. *Figure 12.29* has 60 values with 19 of them being 1 (~30%). If you wanted to simulate flipping a coin use $p=0.5$.

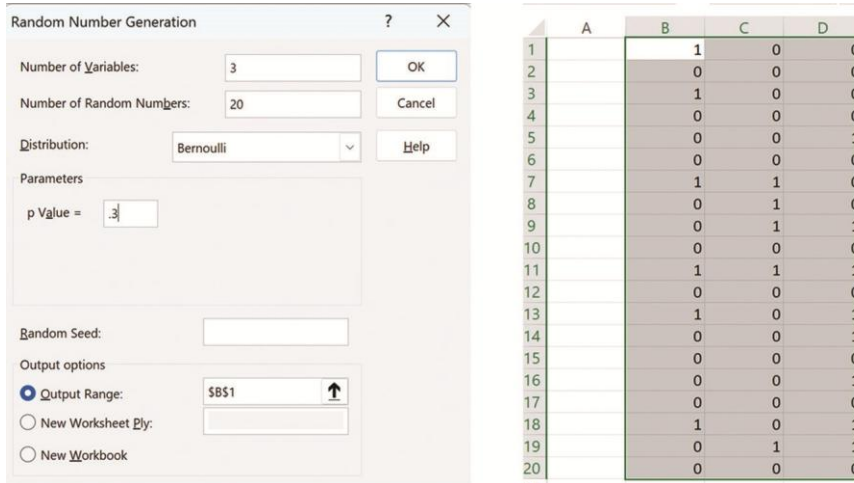


Figure 12.29: Using the Bernoulli Random Number Generator

Binomial distribution

With the Binomial distribution we will use $p=0.3$ and $n=5$ as an example. See *Figure 12.30*.

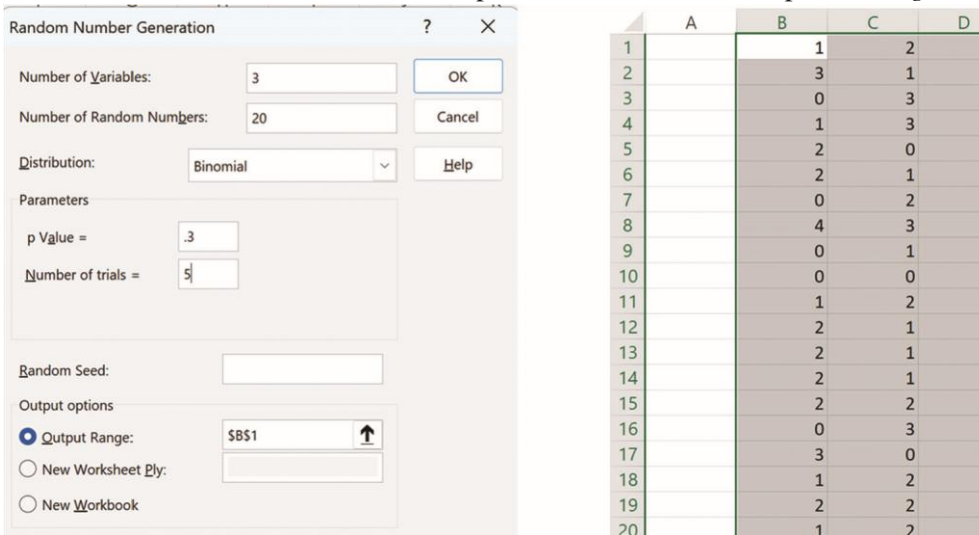


Figure 12.30: Using the Binomial Random Number Generator

Poisson distribution

This is another discrete distribution. An example is to predict or explain the number of events occurring within a given interval of time or space (such as interarrival, that is, the time between each arrival into the system and the next rate.) See *Figure 12.31*.

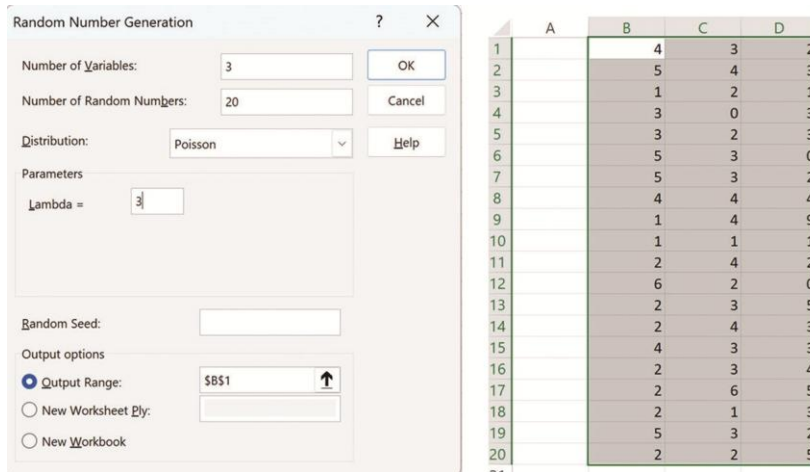


Figure 12.31: Using the Poisson Random Number Generator

Conclusion

This chapter introduced you to the concepts of Monte Carlo simulations in the area of Management Science. The chapter explained where and how to use the simulations and were shown how to apply each of these concepts. Even if this was a short introduction to the concept – you can apply it to your day-to-day decisionmaking skills.

The next chapter is about using Excel for Forecasting based on historical data.

Points to remember

- Simulations are used to imitate real life situations of operation, investment or other systems to gain insight into the behavior or the outcome.
- Simulations can also be used to investigate inaccessible past data – investigating potential risks.
- Excel’s random number generators enable us to create different statistical probability density functions to “mimic” realistic inputs for simulations.

Multiple choice questions

1. What is a simulation in Excel?
 - a. Using the Excel SIMULATE function
 - b. Using Excel to replicate real life situations of operation such as investments and others
 - c. Using Excel to solve macros
 - d. None of the above
2. What is an Excel random number generator?
 - a. A machine by which mechanical energy is changed into electrical energy
 - b. A process to produce a sequence of numbers that cannot be predicted better than by random chance

- c. A kind of excel autofill
- d. None of the above

Answers

1	b
2	b

Questions

We suggest that you attempt to address and solve each question with the tools you were provided. Use the answers to validate your results.

1. On the sheet name Budget of the Excel workbook named Chapter 12 Problems, use the function =NORM.INV(RAND(),600000,60000) for the annual demands.
 - a. Run the simulation 200 times (3 years each).
 - b. Use the Analysis ToolPak for the Descriptive Statistics for the statistics of the runs (average, high, low, and so on).
 - c. Use the Analysis ToolPak for the histogram of the risk profile of the investment
2. Use the Analysis ToolPak Random Number generator to generate 2 variables with 20 random numbers of the Normal distribution

Answers

1. The model is displayed in *Figure 12.32*.

	A	B	C	D	E	F	G	H	I
1	Assumptions								
2	Initial Investment	500,000.00 €		Capital Cost	8%				
3	Selling Price	3.00 €		Tax Rate	41%				
4	Variable Cost/Unit	1.75 €							
5	Annual Fixed cost	325,000.00 €							
6									
7			Average Annual Demand	600,000 units	Annual Standard Deviation	60,000			
8									
9	Year		1	2	3				
10	Demand		624,633	584,287	526,900	=NORM.INV(RAND(),600000,60000)			
11	Revenue		1,873,899	1,752,862	1,580,699	=E10*Selling_Price			
12	Fixed Cost		325,000	325,000	325,000	=Annual_Fixed_cost			
13	Variable Cost		1,093,107	1,022,503	922,075	=E10*Variable_Cost_Unit			
14	Profit before Tax		455,791	405,359	333,625	=E11-SUM(E12:E13)			
15	Tax		186,874	166,197	136,786	=IF(E14*Tax_Rate<0,0,E14*Tax_Rate)			
16	Profit after Tax		268,917	239,162	196,839	=E14-E15			
17									
18	Net Present Value	110,296.54 €	=NPV(Capital_Cost,C16:E16)-Initial_Investment						

Figure 12.32: The simulation model of question 1

- a. Create a new sheet “Simulation”.
 - I. Use the **Edit | Fill | Series**, to add the numbers 1-200 on column A following the word **Run** in cell A1.
 - II. Type the word **Simulation** in cell B1 and under it have the = sign linked to the cell B18 on the Budget (2) sheet.

III. Select A2:B201 and used the **Data | What if Analysis** and on the Column cell of the menu select an empty cell and hit **OK**.

IV. The simulation is complete and it is ready for the evaluations calculations as displayed in *Figure 12.33*.

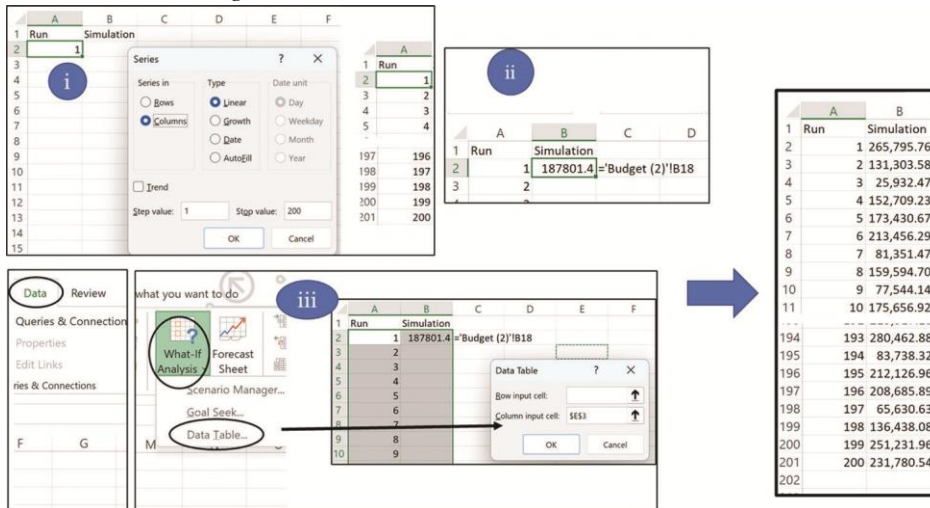


Figure 12.33: Running the simulation of question 1

b. Using the Data Analysis for the statistics. See *Figure 12.34*.

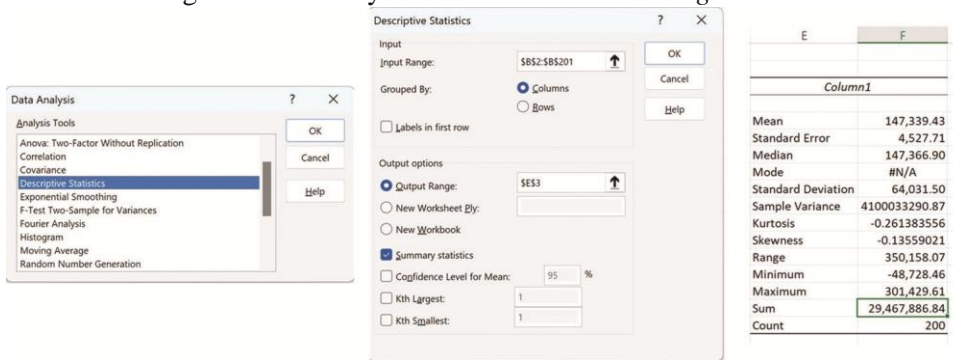


Figure 12.34: Simulations summary statistics

c. Using the Data Analysis for the simulation risk profile. See *Figure 12.34*.

Following the results obtained in (b.) and displayed in *Figure 12.33*, we created the bins range of -50,000 below the minimum value of -48,728.46, through 350,000 just above the maximum number of 301,429.61.

- We used the **Data Analysis Histogram** menu.
- Selected B2:B201 for the input range (the simulated values).
- Selected H4:H20 for the Bins.
- Checked on the Cuumulative Percentage and the Chart output.

We can see that we had only 1.50% of the cases that are 0 or less> Not a risky situation.

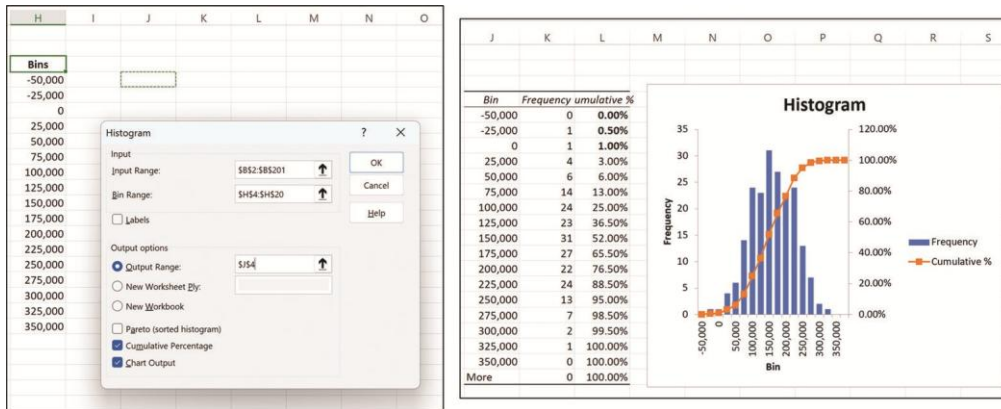


Figure 12.35: Simulations summary risk profile

2. Use the Analysis ToolPak Random in Figure 12.36 – we obtained the requested numbers. You can find it on the sheet named Random numbers.

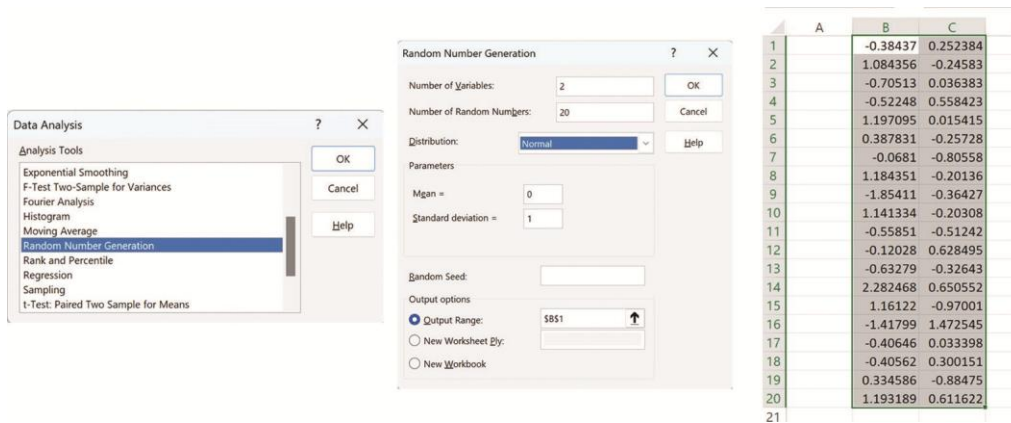


Figure 12.36: Random number generator values

Key terms

- **Monte Carlo Simulation:** A calculated technique that helps predict possible outcomes of an uncertain even – simulating with different probabilities.
- **Random Number Generator:** It is a technique to generate random numbers chosen from a pool of limited or unlimited boundary numbers which have no visible pattern for prediction.