Economic Simulations for Risk Analysis

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Abstract

Simulations using spreadsheets provide a method to address a pivotal weakness in most engineering economics courses: Estimates of cash flows are almost never correct. Initial estimates can be in error by 25% or more, and errors in final estimates can exceed 10%. Minor economic analyses simply use best estimates on the premise that the mistakes will average out as design after design is implemented. On the other hand, risks associated with larger, more expensive projects are extremely important to any company and hence to careers.

Texts frequently show how to use spreadsheets containing single estimates of cash flows. This paper shows how to incorporate risk into such classroom examples quickly and easily by using Microsoft's Excel. It illustrates extending the simple example in Table 1 into the spreadsheet shown in Table 3 first by explaining how to generate random cash flows. Then it describes how to perform the simulation using a macro, compute statistics, and plot results, concluding with a discussion of classroom use. A copy of the spreadsheet can be obtained by emailing the author at ristroph@usl.edu.

Cash Flow Model

Table 1 shows a simple problem involving the internal rate of return (IROR) of a single project, a common economic measure. The cash flows in cells B4 through B7 (B4:B7) have the IROR of 9.70% shown in B8. The entry in B8 is = IRR(B4:B7, 0.1), where B4:B7 is the location of the cash flows and 0.1 is an initial estimate of the IROR. The simulation logic can support a model of any degree of complexity, as long as it results in a single economic measure placed on the first worksheet.

Table 1. Cash Flows

	A	B
1	**Cash Flow Model**	
2		
3	Year	Cash Flow
4	0	–10,000
5	1	4,000
6	2	4,000
7	3	4,000
8	IROR	9.70%

Now suppose that the estimates of cash flows are thought to be accurate to within 10%. For example, consider year 0 where 10% of 10,000 is 1,000. Any value between -9,000 and -11,000 is equally likely to occur. Similarly, each cash flow for years 1 through 3 can independently vary between 3,600 and 4,400.

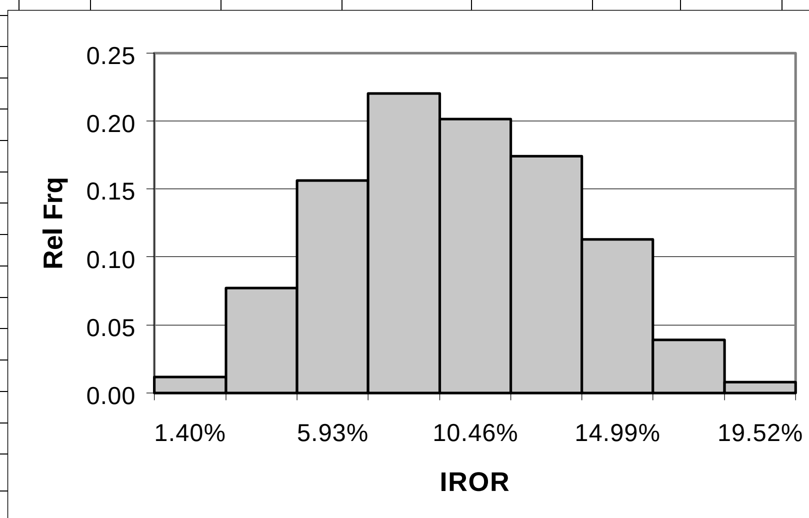
Excel supplies the function RAND() that randomly generates numbers between 0 and 1, so the transformation a+RAND()*(b-a) generates numbers on the interval (a, b). Thus revising B4 through B8 so that they appear as in Table 2 results in the desired random cash flows. Pressing F9 causes the spreadsheet to recalculate and generate a new set of random numbers. The first time F9 is pressed, 11.35% might appear in B6, whereas the second time it might be 9.62%.

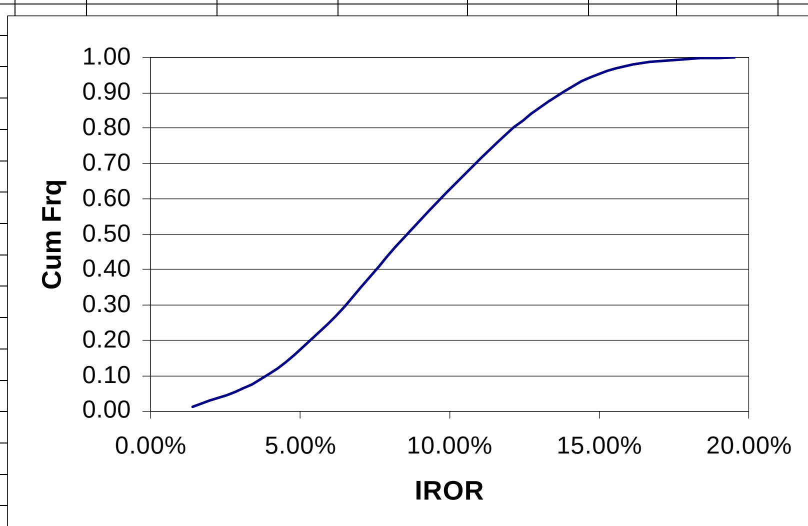
Table 2. Random Cash Flows

	B
3	**Cash Flow**
4	= –9000 – RAND()*2000
5	= 3600 + RAND()*800
6	= 3600 + RAND()*800
7	= 3600 + RAND()*800
8	= IRR(B4:B7, 0.1)

Figure 1. Example of Economic Simulation

	A	B	C	D	E	F	G	H	I	J
1	**Economic Simulation**				Min	Avg	Max			
2	Measure Row:		13		0.27%	9.86%	20.65%			
3	Measure Col:		2		Plot increment:		2.26%			
4	Number Obs:		2000							
5					Cell Max	Mid Pt	Label	Freq	Rel Frq	Cum Frq
6	Obs				2.54%	1.40%	1.40%	23	0.01	0.01
7	9.28%				4.80%	3.67%	3.67%	154	0.08	0.09
8	10.09%				7.07%	5.93%	5.93%	312	0.16	0.24
9	2.74%				9.33%	8.20%	8.20%	440	0.22	0.46
10	13.66%				11.60%	10.46%	10.46%	403	0.20	0.67
11	13.04%				13.86%	12.73%	12.73%	348	0.17	0.84
12	8.62%				16.13%	14.99%	14.99%	226	0.11	0.95
13	5.94%				18.39%	17.26%	17.26%	78	0.04	0.99
14	6.88%				20.65%	19.52%	19.52%	16	0.01	1.00
15	13.65%									
16	9.16%									
17	5.95%									
18	5.33%									
19	6.42%									
20	13.71%									
21	6.02%									
22	7.07%									
23	6.54%									
24	7.12%									
25	8.99%									
26	10.82%									
27	10.85%									
28	14.85%									
29	12.19%									
30	8.46%									
31	7.48%									
32	7.33%									
33	8.34%									
34	11.43%									
35	17.43%									
36	7.05%									
37	12.26%									
38	9.26%									
39	9.43%									
40	7.12%									
41	4.17%									
42	13.97%									
43	7.53%									
44	12.57%									
45	4.45%									
46	16.69%									
47	7.03%									
48	8.42%									
49	2.21%									
50	13.40%									
51	12.52%									





Simulation Using a Macro

Table 3. Data for Macro			
	A	B	C
1	Economic Simulation		
2	Measure Row:		8
3	Measure Col:		2
4	Number Obs:		2000

Diligently pressing the recalculate key F9 and recording each observation for a few thousand times would eventually allow a histogram such as the one shown in Figure 1 to be created, but macros provide an easier way to accomplish this. First declare the macro's data on the second sheet of the workbook as shown in Table 3. Cells C2 and C3 indicate the row and column number of the economic measure that will be observed. In this case, the IROR value is in B8 or row 8, column 2 of the first sheet. Cell B4 contains the number of observations, where a few thousand generally gives good results.

Now enter the macro using the following steps:

1. Select Tools | Macro | Record New Macro …
2. Respond to the resulting prompt and name the macro Simulate and click the OK button.
3. Immediately stop the recording by pressing the Stop Recording button that will appear on the screen. This creates a Visual Basic for Applications (VBA) subroutine that is edited in the next step.
4. Select Tools | Macro | Macros, and when the dialogue box appears click the Edit button.
5. Now enter code so that the macro, a VBA subroutine, appears similar to Table 4. Any text after a single quote is a comment and does not have to be entered.
6. Check the code carefully, so no debugging will be necessary. Then close VBA via File | Close and Return to Microsoft Excel.
7. Run the macro by selecting Tools | Macro | Macros and clicking Run.

Table 4. Subroutine Simulate

```
Sub Simulate()

' Input macro data from spreadsheet
  MRow = WorkSheets(2).Cells(2, 3)          ' Measure row
  MCol = WorkSheets(2).Cells(3, 3)          ' Measure col
  NumObs = WorkSheets(2).Cells(4, 3)        ' Number obs

' Record observations
  Row = 7                                   ' Obs start row
  For Obs = 1 To NumObs
    WorkSheets(2).Cells(Row, 1) = WorkSheets(1).Cells(MRow, MCol)
    Row = Row + 1
  Next Obs

' Put Cursor at top of Sheet
  Range("A1").Select

End Sub
```

The macro's code is self-explanatory once it is understood that Worksheets(i).Cells(j, k) refers to the value in worksheet number *i*, row *j*, column *k*. The initial section inputs data from the spreadsheet using VBA's Cells function. Then each observation is stored before returning the cursor to the top of the sheet. New random numbers are generated automatically during the subroutine's execution, so each observation is different.

Simulation Statistics

The results of the simulation are stored on the second sheet. Computing the minimum, average, and maximum value of the observed economic measures is done using the MIN(*range*), AVERAGE(*range*), and MAX(*range*) functions. In this case *range* equals A7:A2006, but changing the number of observations extends or contracts this range. The function OFFSET(A1,6,0,C4,1) will compute the correct range by starting at A1, going 6 rows down to A7 and 0 rows to the right, and using a height and width of C4 (2,000) rows by 1 column. Table 5 shows these entries, insofar as space allows. For example, the complete entry for E2 is MIN(OFFSET(A1,6,0,C4,1)).

Table 5. Simulation Statistics

	E	F	G
1	Min	Average	Max
2	=MIN(OFFSET(A1,6,0, …	=AVERAGE(OFFSET(A1,6,0, …	=MAX(OFFSET(A1,6,0, …
3	Class Width:		=(G2-E2)/9

The histogram contains 9 classes, so the width of each class is 1/9 of the maximum minus the minimum observation. The FREQUENCY(*ObsRange*,*ClsMaxRange*) function computes the frequencies of each class, where *ObsRange* is the range of the observed economic measures and *ClsMaxRange* is the range of the maximum values for each class. As before, the OFFSET function computes the range of the observations, and the 9 maximal class values are always in E6:E14. Table 6 shows the entry =FREQUENCY(OFFSET(A1,6,0,C4,1),E6:E14) in cells H6:H14. Since FREQUENCY is an array function, it must be input by selecting the entry cells (H6:H14), typing the entry, and then pressing Ctrl + Shift + Enter.

Table 6. Cells and Frequencies

	E	F	G	H	I	J
5	Cls Max	Mid Pt	Label	Freq	Rel Frq	Cum Frq
6	=E2+G$3	=E6-G$3/2	=TEXT(F6,"0.00%")	=FREQ…	=H6/C$4	=I6
7	=E6+G$3	=E7-G$3/2	=TEXT(F7,"0.00%")	=FREQ…	=H7/C$4	=J6+I7
8	=E7+G$3	=E8-G$3/2	=TEXT(F8,"0.00%")	=FREQ…	=H8/C$4	=J7+I8
---	---	---	---	---	---	---
13	=E12+G$3	=E13-G$3/2	=TEXT(F13,"0.00%")	=FREQ…	=H13/C$4	=J12+I13
14	=G2	=E14-G$3/2	=TEXT(F14,"0.00%")	=FREQ…	=H14/C$4	=J13+I14

The other entries in Table 6 require less explanation. The maximum value of the first class in E6 equals the minimal observation plus the class width. Thereafter each class maximum increases by the class width, and the last maximum is set exactly equal to the maximum of all observations to avoid round-off error. Column F contains the mid-point of each class so it can be used for the XY plot of the cumulative relative frequency. Column G contains the same values formatted as text so they can be used for the column chart of relative frequency. The relative frequencies in column I equal the frequencies in column H divided by the number of observations, and the cumulative relative frequencies are a running sum of the relative frequencies. Enter cells E8:J14 by copying cells E7:J7, except for E14.

Graphics

The relative frequencies are displayed using a column chart, and the cumulative relative frequencies are plotted with an XY chart. The procedures for either graph uses the Chart Wizard that is activated by clicking its button (a colored column chart) on the standard tool bar. The process for column chart is described below in detail, and then the similar method for the XY chart is summarized.

Column charts expect the horizontal axis labels (e.g., the IROR's) to be text values and the vertical axis labels (e.g., the relative frequencies) to be numbers. The data in G6:G14 and I6:I14 are set up in this format.

1. Select G6:G14 by dragging it, and then hold down the Ctrl key and drag I6:I14 to select it also.
2. Click the Chart Wizard.
3. Its default selection is the desired bar chart, so click Next.
4. The data has already been placed in default order, so click Next.
5. Click the Options tab and then:
   a) Enter *IROR* as the Category(X) value.
   b) Enter *Rel Frq* as the Value (Y) axis.
6. Click the Legend tab and remove the check mark next to Show Legend, thereby removing the legend.
7. Click Next and accept the default option of storing the plot as an object in the second worksheet by clicking Finish.
8. The chart appears in the sheet. Drag it below the cell values, and then drag a corner to size it to about 15 rows high and 8 columns wide.
9. Now begin right clicking different parts of the chart to edit them. Right click:
   a) *IROR* to change its font size to 11 points.
   b) Category (horizontal) axis to change its font size and label spacing.
      i) Select the Font tab and set it to 10 points.
      ii) Select the Scale tab and set Number of categories between tick-mark labels to 2.
   c) *Rel Frq* to change its font size to 11 points.
   d) Value (vertical) axis to change its font size to 10 points.
   e) Any column (i.e., bar) to format the data series.
      i) Click the Patterns tab, Fill Effects, Pattern tab. Then set the foreground color to black (at the top left of the palette) and the background to white. Select the cross hatched pattern (right side, second from bottom) and click OK.
      ii) Click the Options tab and set the gap width between the columns to 0. Click OK twice.
   f) Plot area (gray background) to set it to white.

Creating the XY plot begins with selecting the data for the chart, F6:F14 and J6:J14. Then execute the wizard and in the first step declare that the Chart type is XY (Scatter) and the

Chart sub-type is the one with smooth curves and no markers. Accept the suggested chart data in the second step, and proceed to the third step. Declare the axis titles and remove the legend, then go to the fourth step where the chart is placed and sized on the second worksheet. Finally, edit it much as before. When formatting the axes, it might be necessary to set the minimum and maximum values on the Scale tab.

Classroom Use

Economic simulations require a knowledge of Excel that most students do not have. If there is sufficient time, then students can use this paper to extend their knowledge. Otherwise, the professor can prepare a workbook for students with a simple example such as the one used for this paper. An easy way to distribute the workbook is to put it on a web site or on a read-only disk that is accessible from a network. Sending the workbook via email is another option. Once the student has a working model, changes are fairly simple since the simulation design uncouples the cash flow model from the simulator as much as possible.

Students quickly grasp the concept of simulation and usually have fun executing the macro. Run times that are between 1 to 10 minutes can be expected. The model presented in this paper requires a little more than a minute on a 200 MHz machine to generate and analyze 2,000 observations. Of course, the option of diligently pressing F9 and recording the results manually is always an alternative.

It is a good idea to run the simulation more than once to get a feel for how much the results can vary between runs. Setting the number of observations to a high value reduces inter-run variation. A knowledge of statistics is required to make more definitive statements about model variability, but a few thousand observations should be enough to make a decision.

The cash flows in this paper are always equally likely numbers from some interval (a, b), so students sometimes ask what happens if the numbers are not equally likely. Excel supports sampling from other types of distributions. For example NORMINV(RAND(),4000,200) produces normally distributed variates with mean 4,000 and standard deviation 200, and the BETAINV function generates variates from the beta distribution that can take on many shapes. Additionally, the expression = – LN(1-RAND()) / λ generates exponential deviates with parameter λ, where λ should be replaced with a number or a cell reference.

Students frequently want to know what is *the* answer, so it is necessary to explain that decisions under risk are ultimately subjective. This can be illustrated to students by seeing how many would be willing to wager $1 on a flip of a coin. Then steadily increase the stakes to $2, $3, and more. The expected value of each wager is the same, but there will be progressively fewer takers as the stakes increase. Each person's response to risk is different. Simulation serves to quantify the risk associated with a project, but it cannot replace the decision maker.

Excel's macro language provides a convenient, inexpensive way to teach students how to perform economic analyses under risk. The software is readily available, and separating the cash flow model from the simulator allows analyses of a truly impressive scope of realistic problems. Readers using this procedure or related ones are urged to contact the author at ristroph@usl.edu so that ideas can be exchanged via group mailings.

Biography

Dr. John H. Ristroph is a Professor of Engineering and Technology Management and a registered Professional Engineer in Louisiana. His B.S. and M.S. are from LSU, and his Ph.D. is from VPI&SU, all in industrial engineering. He has taught engineering economics and various computer applications for over twenty-five years. The material in this paper is used as a handout in both undergraduate and graduate classes.