Spreadsheet Based Monte Carlo Simulation
Sub Topics

• Concept and approach

• Examples

• Automated experimentation with different input parameters

• Questions and problems
Simulation Modeling High Level Steps

• For one of the problems in Topic 1 we listed the following steps:

  • Determine the inputs to the simulation
  • Determine the possible value each input can take on
  • Determine the likelihood of each possible value
  • Determine how the inputs are mapped to the output(s)
  • Repeat the following procedure a large number of times
    • Randomly generate each input using the distribution of their likelihood
    • Map the inputs to the outputs
    • Count the number of times each output occurs
  • Divide the number of times each output occurs by the number of times the procedure is followed to get the likelihood of each output
Simulation Modeling High Level Steps

• We can summarize this with a smaller set of steps:
  • Determine and characterize the inputs to the simulation
  • Determine the outputs you wish to get from the simulation
  • Build a model to generate the inputs and transform them to get the desired outputs
  • Repeatedly generate outputs from the model with different randomly selected inputs
  • Statistically summarize the outputs
Spreadsheet Based Monte Carlo Simulation - Concept

- So – why should we use spreadsheets for Monte Carlo simulation?
  - Spreadsheets are familiar and relatively easy to use
  - Spreadsheets can generate random numbers
  - Spreadsheets can replicate calculations by:
    - Repeating them
    - Using data tables
    - Using macros to recalculate the spreadsheet and save the outputs

- So - why not use spreadsheets to perform Monte Carlo simulations?
Spreadsheet Based Monte Carlo Simulation - Approach

• Enter, label, and create range names for all parameters and distributions

• Use the spreadsheet to build a model of the problem
  • Use parameters & distributions defined above
  • Use RAND() to generate random numbers

• Replicate single sample a large number of times
  • Recalculation (not a good idea)
  • Using rows (or columns)
  • Using data tables
  • Using macros

• Compute summary statistics
Problem 1 – Income Statement

• An organization has:
  
  • Income accounts
    • Fixed monthly income from rent of $100,000
    • Random monthly income from sales between $800,000 and $1,000,000
  
  • Expense accounts
    • Monthly rental expense of $80,000
    • Monthly labor expense of $700,000
    • Monthly contract labor expense uniformly distributed between $0 and $200,000
Problem 1 – Income Statement

- The organization would like to know:
  - The expected value of their monthly net income
  - The standard deviation of their monthly net income
  - Whether monthly net income might ever be negative?
  - If yes, the likelihood that net income will be negative in a particular month?
  - If yes, the likelihood that net income might be negative two months in a row?
  - The frequency distribution of its net income

Let's answer these questions using a spreadsheet based Monte Carlo Simulation
Problem 1 – Income Statement

• Build an income statement in the spreadsheet
  • Approach 1
    • Build it like you would any other financial statement (vertically)
    • Replicate it 100 times (horizontally)
    • Use spreadsheet if function to identify negative income months
    • Use spreadsheet if function with and function to find two consecutive months with negative income)
    • Calculate summary statistics
Problem 1 – Income Statement

• Build an income statement in the spreadsheet

  • Approach 2
    • Build it in a any way you want
    • Use a data table to replicate the net income calculations 100 times
    • Use spreadsheet if function to identify negative income months
    • Use spreadsheet if function with and function to find two consecutive months with negative income
    • Calculate summary statistics

• How do you get the data table to generate new random numbers?

• What do you specify for your column input cell?
Problem 1 – Income Statement

- After answering these questions, the organization would like to answer the same questions with respect to the additional income and expenses
  - Increased sales because of new equipment between $50,000 and $250,000
  - Interest Expense for loan for new equipment $50,000
  - Depreciation expense for new equipment $50,000
Problem 1 – Income Statement

• Let’s recap what we just did in a more systematic order:
  • Enter, label, and create range names for all parameters & distributions
  • Use the spreadsheet to create a model of the problem
    • Use parameters & distributions defined above
    • Use RAND() to generate random numbers
  • Replicate single sample a large number of times using rows or data tables
  • Compute summary statistics
Need For Optimization

• In the previous example there was no need to optimize the process

• Sometimes we need to select optimal parameter value(s)

• Possibilities include:
  • Trying out all possibilities
    • Manually
    • Data table
    • Using macros
  • Trying out different values in a structured manner
    • Binary search if searching for a specific value
    • Hill climbing
    • Response surfaces
  • Other approaches
When

Monte Carlo spreadsheet simulation should be considered when:

• It is necessary to compute characterize results of a random process

• When it would be hard to do so more directly

• When the process can be readily modeled in an understandable way in a spreadsheet
Sub Topics

• Concept and approach

• Examples
  • Automated experimentation with different input parameters
  • Questions and problems
Problem 2 – Loading Dock

• An organization operates a loading dock
  • They start each morning at 9:00 and don't stop for lunch
  • They would like to handle as many trucks as possible
  • Because of union rules and excessive overtime costs, they need for their crew to leave before 5:30 at least 80% of the time

• Trucks:
  • Arrive randomly at the rate of 6 per hour, i.e. the interarrival times are exponentially distributed with a mean of 10 minutes
  • Are handled one at a time by the whole crew
  • Take between 0 and 20 minutes to be handled with equal likelihood, i.e. the service time is continuously and uniformly distributed between 0 and 20 minutes
Problem 2 – Loading Dock

• How can the organization:
  • Maximize the number of trucks handled
  • While ensuring that their 80% rule is met?
Problem 2 – Loading Dock

- Let's assume for a moment that the best way for the organization to address this problem is to select a time at which the loading dock will turn away trucks.
- One way of determining the best time is to simulate the loading dock.
- For this problem, today we can think of simulation as a black box.

We could then try to run this simulation black box with several different times at which the loading dock would turn away trucks.
Problem 2 – Loading Dock

• Build that black box in a spreadsheet

• Start by entering parameters (with range names and labels):
  • Start minute (540)
  • Average arrival rate
  • Average interarrival minutes
  • Min minutes per truck (0)
  • Max minutes per truck (20)
  • Door shut minute
  • Target leave minute
Problem 2 – Loading Dock

• Build that black box in a spreadsheet – cont’d.

• Build simulation for one day
  • One row for each truck; allow for enough rows*** for maximum possible truck arrivals between start time and target leave time
  • One column for:
    • Arrival start process minute
    • Interarrival minutes
    • Truck arrival minute; note that the next truck’s arrival start process minute takes place when this truck arrives
    • Service minutes; set to 0 if truck arrives after door close
    • Service start minute; set to 0 if truck arrives after door close
    • Waiting minutes (not needed but informative); 0 if truck arrives after door close
    • Service completion minute; 0 if truck arrives after door close
  • Fill in the cells for those columns for each row
  • Add column to last row with a 1 if done before or on target leave time
Problem 2 – Loading Dock

• Generating (pseudo) random exponentially distributed interarrival times in Excel:
  • The average interarrival minutes value is stored in a range named Average_Interarrival_Minutes
  • Enter the Excel formula -Average_Interarrival_Minutes * ln(1 – rand())

• Generating (pseudo) random uniformly and continuously distributed service times in Excel
  • The minimum minutes per truck value is stored in a range named Min_Minutes_Per_Truck
  • The maximum minutes per truck value is stored in a range named Max_Minutes_Per_Truck
  • Enter the Excel formula Min_Minutes_Per_Truck + (Max_Minutes_Per_Truck – Min_Minutes_Per_Truck) * rand()
Problem 2 – Loading Dock

• Build that black box in a spreadsheet – cont’d.

  • Replicate the days a larger number of times (e.g. 400) by replicating the rows a large number of times

  • Determine the percentage of time the crew leaves on time (create label and range name for that calculation)
Problem 2 – Loading Dock

• Build that black box in a spreadsheet – cont’d.

• Determine the best leave time
  • By trying out different door shut minutes one at a time, e.g. 720, 725, 730, . . . 1050
  • By using a data table to try out several different door shut minutes at the same time
  • What is your result?
Problem 2 – Loading Dock

• Are there other analytical approaches to analyzing this problem?

• If so will they be easy for managers to understand?

• Will they have limitations?

• Will the analysis be easy to do and verify?
Problem 3 – Loading Dock

• We assumed that the best way for the organization to address this problem is to select a time at which the loading dock will turn away trucks

• Let’s next try a second approach in which:
  
  • Every time a truck service begins its time is recorded
  
  • Immediately before a truck arrives
    
    • We perform many runs of a simulation serving trucks already there, plus one, starting now
    
    • Using a randomly generated value for the remaining time needed to process the truck currently being served; let $x = \max(\text{min minutes per truck, time already spent})$
      then remaining time = $x + (\max \text{ minutes per truck} - x) \times \text{rand()} - \text{time already spent}$
    
    • Using randomly generated values for the complete processing times for the other trucks
    
    • To decide whether we should accept the incoming truck
    
    • And determine the percentage of runs in which the crew has to stay past 5:30

• We could then test that approach against the previous approach to see which is better (use hypothesis tests which will be discussed in topic 4)
Problem 4 – Failure Analysis

• An organization has a particular component that fails frequently.

  • They have detected that the likelihood of 0, 1, 2, 3, 4, 5, 6 failures/week is 0.06, 0.13, 0.25, 0.28, 0.20, 0.07, 0.01

  • They would like to determine the following statistics regarding the number of failures they can expect in 48 weeks:
    • The minimum
    • The maximum
    • The mean
    • The standard deviation
    • The range of failures they can expect per 48 weeks 95% of the time
    • A histogram of the distribution of failures per 48 weeks
Problem 5 – Optimal Repair Analysis (Render)

- 4 pen printer
- Cost per pen $8.00
- 1 hour to replace 1 pen; 2 hours to replace all 4 pens
- Cost per hour down time $50.00
- Hours between plotter failures (1 pen replace): 10, 20, 30, 40, 50, 60, 70; probability: .05, .15, .15, .20, .20, .15, .10
- Hours between plotter failures - 4 pen replace: 100, 110, 120, 130, 140; probability: 0.15, 0.25, 0.35, 0.20, 0.05
- Should we replace pens if one pen fail, or all pens when one pen fails?

- Note that we should interpolate hours since failure can take place at 11.5 hours, not just at 10, 20, . . .; to simplify the problem we do not interpolate hours
Problem 6 – Farmer’s Coop (Render)

• Background:
  • A farmers coop has a silo they man every year for a short period each year during the harvest season (until all trucks are emptied)
  • They wish to minimize the cost of manning the silo and the waiting costs over the whole unloading period

• Parameters:
  • Trucks Per Day: 0, 1, 2, 3, 4, 5; Probability: .16, .24, .32, .19, .06, .03
  • Processing rate: 1 truck/crew member/day
  • Holding cost: $100/truck/per night
  • Labor cost: $120/day/crew member
  • Days of operation: 24
  • There are 0 trucks at start

• How many days do we need to simulate for each trial
• How many crew members should there be?
Problem 7 – Revenue Management/Production Overbooking

• A manufacturer has a number of units of manufacturing capacity
• It rents out individual units to customers for a day at a time
• It would like to maximize its revenues
• Some small percentage of customers don't show up
• It would like to determine how many customers it should book
• There is a cost for overbooking when the customers do show up
Problem 7 – Revenue Management/Production Overbooking

• 100 units capacity (each day)

• Probability of a no show for a reservation is .1

• Profit from a unit of capacity is $1000 per unit time

• Cost of overbooking a unit of capacity is $2000 per unit time

• What should the booking limits be to maximize average net income over a 200 day period

• Simulate a total of 20000 days (100 x 200 day periods)

• Manufacturer always gets as many reservations as it can take
Problem 7 – Revenue Management/Production Overbooking

• Should we be simulating for more years?

• What if the overbooking cost becomes very high?
Problem 8 – Revenue Management/Production Overbooking

• What if a second and higher class of service is added:
  • 100 units of capacity
  • Probability of no show the higher class customers is .2
  • Profit per unit of this capacity is $3000
  • Overbooking cost of this capacity is $10,000
  • Overbooked type one customers can be upgraded to type two service (they still pay type one service cost)
• What should the booking limits for both classes of service be?
Problem 9 - Inventory Control

• The goal of most inventory control problems is to tradeoff:
  • The cost of holding extra inventory
  • The cost of ordering
  • The cost of not having enough inventory

• Subject to imperfect information about:
  • Demand
  • Delivery times

• The problem is complicated by the need to track
  • Leftover inventory
  • Inventory on order
Problem 9 - Inventory Control

• Optimal inventory control frequently involves setting:
  • A reorder point
  • A reorder up to point

• When trying a lot of values for both quantities make sure that the reorder point is less than or equal to reorder up to point
Problem 9 - Inventory Control (Render)

- Starting inventory of 14 cars
- Carrying/Holding cost/car/month: $600
- Ordering cost: $570
- Profit per car: $4350
- Demand/month: 6, 7, 8, 9, 10, 11, 12, frequency 3, 4, 6, 12, 9, 1, 1
- Delivery Months: 1, 2, 3, 4, probability .44, .33, .16, .07
- Assume that deliveries are made at 08:00 on first day of month
- Assume purchases are made at 08:01 on first day of month
- Assume orders are placed at 08:02 on first day of month
- 24 month analysis (100 samples)
Problem 9 - Inventory Control

• What should the reorder and reorder up to points be

• Simulate 100 times for 24 months
Simulation Modeling & Analysis - Topic 2 - Monte Carlo Spreadsheet Simulation

Sub Topics

• Concept and approach
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• Questions and problems
Automated Experimentation With Different Input Parameters

• In general, data tables are less helpful when we wish to experiment with more than two input parameters

• To facilitate experimentation with more than two input parameters I have created a spreadsheet called TroyWareSimulationRunner

• To use this spreadsheet:
  • Open it
  • Build your simulation
  • Create range names for all of your input and output parameters
  • Enter those names in different columns of the second row on the InputsAndOutputs sheet
  • Enter sets of input values to be experimented with in subsequent rows
  • Run the TroyWareSimulationRunner macro
Automated Experimentation With Different Input Parameters

This spreadsheet has a TroyWareSimulationRunner macro in it which:

- Starts with the first row of values in the InputsAndOutputs sheet (which is row 3 of the sheet)
- Copies parameters from a row of the InputsAndOutputs sheet into ranges used by your simulation
- Runs the simulation as you have defined it
- Copies the results of the simulation back into the same row of the InputsAndOutputs sheet

To use this spreadsheet:
- You need to define and give range names to all of your input parameters
- You need to define and give range names to all of your simulation outputs (e.g., mean, standard deviation, ...)
- Starting in column A, you need to specify in row two of the InputsAndOutputsSheet the range name of each of these ranges
- Starting in column A, you need to specify in row one of the InputsAndOutputsSheet whether the corresponding column is an input (INPUT) or an output (OUTPUT)
- For each combination of inputs you wish to simulate, fill in the inputs, starting in row 3 of the InputsAndOutputs sheet
- To run the simulation for each set of inputs that you have already entered, run the TroyWareSimulationRunner macro

Other notes:
- To see the list of range names in the spreadsheet depress the control key and while holding it down enter the F3 key
- You may wish to delete all existing range names before starting so they don't conflict with your range names
- Make sure you spell and capitalize range names on the InputsAndOutputs sheet exactly as they are defined
Automated Experimentation With Different Input Parameters

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Automated Experimentation With Different Input Parameters

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Automated Experimentation With Different Input Parameters
Automated Experimentation With Different Input Parameters
Sub Topics

• Concept and approach

• Examples

• Automated experimentation with different input parameters

• Questions and problems
Questions

• 1) In your own words list the four reasons for using spreadsheets for Monte Carlo Simulation

• 2) In your own words list the steps for using spreadsheets for Monte Carlo Simulation

• 3) In your own words list the approaches that can be used to repeat samples for Monte Carlo Simulation in spreadsheets

• 4) In your own words explain the approach used to solve/optimize problem 6

• 5) In your own words explain the approach used to solve/optimize problem 7

• 6) In your own words explain the approach used to solve/optimize problem 9

• 7) In your own words explain the approach used to solve problem 10

• 8) In your own words explain the approach used to solve problem 11

• 9) In your own words list the three approaches that can be used to try out different parameters when using spreadsheets for Monte Carlo Simulation

• 10) In your own words list the different approaches that can be used to organize models for financial models, time based events, and customer demand/inventory type problems

• 11) In your own words briefly explain the purpose and value of TroyWareSimulationRunner and how to use it
Problems

10) Problem 11.14 from Render

11) Problem 11.15 from Render

12) Problem 11.17 from Render

13) Problem 11.24 from Render

14) Problem 11.38 from Render

15) Problem 11.47 from Render

16) Red Rose Tea often include a figurine in their tea boxes. When they release a new set of figurines they typically include 10 new figurines. As Phil's wife collects those figurines, Phil's mother tries to buy enough of those tea boxes whenever a new set of figurines is released to ensure that his wife gets all of the new figurines. Assuming that it is equally likely that each figurine will be found in each box, Phil's sister wishes to know how many boxes of tea Phil's mother should buy when the new figurines are released to ensure that Phil's wife is likely to have received all 10 figurines with a 99% probability.

Answer Phil's sister's question using approach 1) spreadsheet simulation and approach 2) probability theory. Note that it is possibly to generate uniformly distributed integers between one and 10 inclusive in excel using the formula =randbetween(1,10)
Problems

17) Investment Portfolio Analysis - You have found an investment whose rate of return per year is uniformly distributed between 0 and 20%. Build a spreadsheet Monte Carlo Simulation to determine the rate of return over a 20 year period if you invest $10000 in it at the beginning of the 20 year period. Replicate your work to determine the probability distribution for the return on investment after 20 years.

18) Investment Portfolio Analysis - Modify the analysis of the previous problem to determine the probability distribution for your 20 year return rate if instead of investing all $10,000 into a single investment whose rate of return per year is uniformly distributed between 0 and 20%, you instead invest $1000 each into of 10 different investments each having the same rate of return and each being totally uncorrelated with each other. Explain the change of results and how diversification impacts long term return on investment (after 20 years).

19) Investment Portfolio Analysis - Modify the analysis of the previous problem to determine the probability distribution for the return on investment after 20 years when half of the return of each investment is correlated with each other and the other have is totally uncorrelated with each other?
Problems

20) Project Management - A project consists of a series of tasks (see diagram below for the tasks that are lettered from A through O and whose mean task times are in parenthesis next to the task letter). Each task may be required to wait for other tasks to have been complete (see same diagram where numbered rectangles are used to indicate task ordering, i.e. tasks C and F cannot start until task A is finished.) The standard deviation of the time for each task is 1, and those times are normally distributed. Note that to calculate a normally distributed random value in excel one uses the formula =Norm.Inv(rand(), mean, stdev)

Create a sample set of computations that computes using randomly generated times, the earliest end time of each task, the earliest end time of the whole project, and the slack time for each task. Repeat that sample 100 times and use it to compute the minimum, maximum, average value and standard deviation of the end time of the whole project and the slack time for each task.
21) Cancer Surgery Delays - The chief of surgery wishes to understand why surgery delays are more than 4 weeks. You have discovered that surgeries cannot take place until the second week after they are requested as it takes at least a week to make sure the patient is properly prepared for the procedure. You are given the request week, the OR minutes, and the OR week for one surgeon for 166 procedures that were requested and performed over a 97 week period. The chief wishes for you to generate weekly random surgery demand and OR time requirements data from a lookup table based on the actual data of this surgeon grouped into 10 minute brackets (except for weeks when there are 0 minutes of demand or OR time in which case a 0 minute bracket should be used). The chief is providing you this data on a spreadsheet named Topic02.Problem21.Data.xlsx He wishes for you to build a spreadsheet model to use that data to determine the number of weeks delay from the time a cancer surgery is requested to the time it is performed. He has indicated that he is not concerned about fitting surgeries into particular days. Patients who have to wait for surgical procedures more than 12 weeks have either passed away or gone to another surgeon. The chief wishes for you to determine:

- a) the average amount of lost surgery request minutes per year due to patients having to wait more than 12 weeks,
- b) the average amount of surgery request minutes that are more than four weeks old,
- c) the average fraction of surgery request minutes that are more than four weeks old,
- d) the average amount of OR time unused each week
21) Cont'd. Hints:

• Use 1 row for each week

• Use individual columns to indicate the number of needed OR minutes for cancer surgeries that are 12, 11, 10, \ldots, 0 weeks old, where the 0 weeks old minutes would come from this week’s new requests

• Use individual columns to indicate the number of OR minutes spent this week on 12, 11, 10, \ldots, 3, 2 week old surgery requests; surgeries cannot be performed this week if they are only 0 or 1 weeks old

• Before each of the columns in the previous set of columns add a column to track the OR minutes remaining for the week; the value for the OR minutes remaining for the 12 week old surgeries should be set to the available OR minutes for the week

• Note that in addition to the problems in this document you should be able to do most or all of the problems in Render Chapter 11
Problems

22) Solve Render 11.38 to determine average waiting time for customers arriving 40 minutes or later after the system starts.

23) Solve Problem 22 with 1 queue and 2 servers and service minutes of 2, 4, 6 and 8 rather than 1, 2, 3 and 4. Hints:
   - In each row you will need to keep track of when each server becomes available
   - You will need to pick the first server that becomes available to serve each arrival

24) Solve problem 22 in a manner that lets you compute the average number of customers in the system. Hints:
   - Each row should correspond to either an arrival or service completion event
   - In each row you need to track the next time of each type of event
   - In each row you need to determine the type of event that is occurring in that row (by the next time of each event) and then process that event
   - In each row you need to track the number of customers in the system before the event and after the event, the start time of the process, and the duration of the process from the end of the previous event to the end of this event
   - Average number of customers in the system equals the sum of the product of the duration of each row (after the 40 minutes) times the number of customers in the system in that row before the event of the row, divided by the total duration of each row after the 40 minutes.
Problems

25) Build a spreadsheet simulation, where the rows correspond to customer arrivals, a simple queuing process in which workers bring jobs to a organization's service facility that operates 24/7. Inter-arrival times are exponentially distributed with a mean of 11 minutes and service times are exponentially distributed with a mean of 10 minutes. Assume that the cost of customer waiting while their job is being processed is $1 a minute but that the benefit of processing each job is $100. Use the simulation to determine the average net benefit (gross benefit less waiting cost) generated by the facility, computed over 100 runs of the simulation, where each run processes 400 jobs.

26) When customers bring their jobs to the above facility the operator of the facility is able to determine how long it will take to process their job. The manager of the facility wishes to take advantage of that fact to maximize the net benefit provided by the service facility. The manager suspects that the operator should reject all jobs that will have to wait more than a predetermined amount of time and that doing so will preclude negative net benefits, and also reduce large waiting times for subsequent customers. The manager wants you to determine the optimal amount of time in whole minutes that customers will be allowed to wait before the operator will reject those customers' jobs.
27) The manager would like you to rebuild the simulation for problem 25 to see the effect of having two servers when the mean inter-arrival time drops to 5.5 minutes. **HINT:** To do this you will need to keep track for each customer when each server becomes available and to then use the server that becomes available first for that customer.

28) The manager would like you to rebuild the simulation from problem 25, with the original inter-arrival time of 11 minutes, so that the simulation can be used to determine the average number of workers that wait at any specific time. To do this you will need to build a simulation in which the rows correspond to either arrival events or service completion events.

29) The manager has realized that the operator is not always very good at determining the length of time specific jobs will take in advance of doing those jobs. Thus in context of the simulation built for the previous problem the manager wishes you to determine the number of workers already waiting at which time the operator should not accept additional work so as to maximize the benefits less waiting costs generated by the facility.

30) As an alternative to the previous problem in which the operator stops accepting jobs, the manager wishes you to determine the optimal number of waiting customers at which a second operator ought to be brought in to help the first operator, and a second (possibly different) threshold at which the second operator should go back to his or her other work. While the manager does know the values, he does know that there is a cost per unit time for the second operator, and a startup cost for taking the operator away from his or her other work.