Introduction to Problem Solving Using a Monte Carlo Spreadsheet Simulation

David Greenburg
The CITADEL School of Engineering

Dimitra Michalaka
The CITADEL School of Engineering

James Righter
The CITADEL School of Engineering

At The Citadel, data collection, analysis, and problem solving is taught as part of the technical project management course for junior and senior engineering students. Many real world problems have such a broad scope or are so complicated that they resist a purely analytical solution. One technique for analyzing these complex problems is simulation. This paper describes the efforts to introduce students to spreadsheet-based Monte Carlo simulation modeling to support problem solving. Students can master spread-sheet-based simulation especially easily, and can expand their skill set by being taught to use real world data sets. The instruction introduces students to spreadsheet modeling with excel software and the fundamental aspects of data collection, analysis, and simulation modeling. The instruction aims to provide students with modeling skills to support problem solving. Students can master spread-sheet-based Monte Carlo simulation, and can expand their skill set by doing so. This paper describes the use of spreadsheet-based Monte Carlo simulation and briefly explores the underlying methodology using Excel to support the instruction.

INTRODUCTION

Simulation is a useful technique to address real world system problems in order to obtain data that can be used to make predictions about the system. Monte Carlo simulation involves the collection of historical data and the development of frequency distributions to support probabilistic analysis to make inferences about the system being studied. Project planning is an important activity that involves the careful study of historic data to project future demand outcomes. In many situations, engineering managers have access to a good deal of historical data which can be used to develop forecasts for the future. This paper discusses the development of a module to introduce the use of Monte Carlo Simulation to aid in project planning, forecasting and decision making. This paper describes our approach to incorporate simulation modeling as part of a technical project management course for undergraduate engineering students. The instruction is designed to complement two existing courses (PMGT 401 and CIVL 305). Due to the availability and ease of learning Excel software can be used to complement lectures and homework assignments.
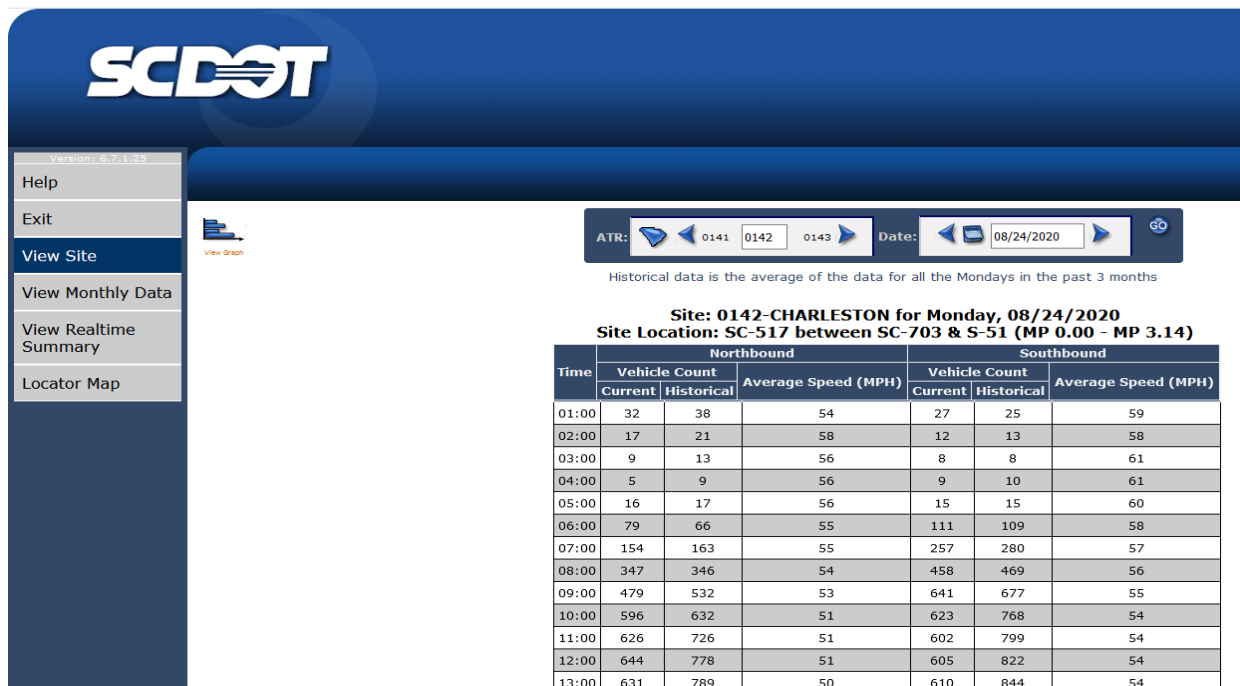
Engineers are often involved in the management of projects that require the scheduling of constrained resources to include labor, equipment and materials and other activities relating to the project. Scheduling is a central and integral process for effective technical project management[1]. The success of any technical project is judged by how well it achieves a defined outcome for cost, schedule, and performance[2]. Most projects would not be undertaken if management had little confidence in a successful outcome and once started are subject to being cancelled if the forecasted outcome does not meet expectations.

Monte Carlo Simulation Relevance

Monte Carlo Simulation is an important tool for decision-making as it deals with the collection, analysis and use of historical data to make future estimates that are used in making decisions and solving problems[3]. It can be used by technical project managers to forecast the occurrence of outcomes when random variables are present. These simulations use random number generators to simulate random effects and gain knowledge just as we would if we took many samples of a real event. The wide availability of computers allows us to easily perform simulation and integrate its use into the curriculum.

Our approach to teaching Monte Carlo Simulation emphasizes sound data collection approaches by introducing students to readily available primary sources of raw data. One such source is the South Carolina (SC) Traffic Polling and Analysis System (TPAS) which provides near real-time traffic count information at over 160 Continuous Count Stations (CCS) statewide[4]. These stations collect hourly traffic volume data through permanent sensors installed in the roadway. Faculty have previously used TPAS data to teach students statistical forecasting techniques[5]. Students are shown how to access the TPAS and download an excel data file containing raw data for a specified period. An example of the data available is shown in Figure 1.

FIGURE 1
SC DOT TPAS DATA FOR CCS 0142

Help
Exit
View Site
View Monthly Data
View Realtime Summary
Locator Map

ATR: 0141 **0142** 0143   Date: 08/24/2020

Historical data is the average of the data for all the Mondays in the past 3 months

Site: 0142-CHARLESTON for Monday, 08/24/2020
Site Location: SC-517 between SC-703 & S-51 (MP 0.00 - MP 3.14)

Time	Northbound			Southbound		
	Vehicle Count		Average Speed (MPH)	Vehicle Count		Average Speed (MPH)
	Current	Historical		Current	Historical	
01:00	32	38	54	27	25	59
02:00	17	21	58	12	13	58
03:00	9	13	56	8	8	61
04:00	5	9	56	9	10	61
05:00	16	17	56	15	15	60
06:00	79	66	55	111	109	58
07:00	154	163	55	257	280	57
08:00	347	346	54	458	469	56
09:00	479	532	53	641	677	55
10:00	596	632	51	623	768	54
11:00	626	726	51	602	799	54
12:00	644	778	51	605	822	54
13:00	631	789	50	610	844	54

Students are asked to download data for a specific time interval to use in developing cumulative probability distributions for modeling future traffic flow. This paper describes how we teach students to use Monte Carlo simulation using Excel spread sheets and common built in functions to aid in problem solving and decision making.

Developing a Monte Carlo Model

The Monte Carlo method incorporates the development of a cumulative frequency distribution based on collected historical data. By generating a table of random numbers to simulate values and fitting them to the expected frequency distribution we can use the random numbers to forecast the possible outcomes of an uncertain event. Excel is an ideal tool to generate random numbers to simulate variables of interest such as traffic flow. Generating a large number of random variables allows us to simulate a variable's behavior. This process is repeated again and again while assigning the variable in question with many different values. Once the simulation is complete, the results are averaged together to provide an estimate. Our Monte Carlo simulation example problem models predicted future traffic counts for a specific road section in need of maintenance. The problem statement presented to the students asks them to plan the optimum time to shut down a section of SC Highway 517 for needed road maintenance that will take 3 hours from start to finish. The measure of optimality being the lowest traffic count for a specific time of day in order to minimize disruption to traffic flow. Students are advised to follow the following steps:

1. Collect historical source data and identify the variables of interest which include traffic counts for the following specific time periods:
   a. 00:00 – 02:59
   b. 03:00 – 05:59
   c. 06:00 – 08:59
   d. 09:00 – 11:59
   e. 12:00 – 14:59
   f. 15:00 – 17:59
   g. 18:00 – 20:59
   h. 21:00 – 23:59

2. Build a cumulative probability distribution for each variable being modeled like the one shown in Table 1. SC TPAS data is analyzed to determine the relative frequency of traffic flow during each time period. The probability of each outcome is found by dividing the frequency of observation by the total flow.

TABLE 1
PROBABILITY DISTRIBUTION FOR THE FASIMULATED TRAFFIC COUNT

Frequency	Probability of Occurrence	Cumulative Probability	Random Number Intervals	Simulated Traffic Count
43	0.006	0.006	0 – 6	59
44	0.006	0.012	7 – 12	66
733	0.102	0.114	13 – 114	1030
1444	0.201	0.315	115 – 315	2023
1654	0.230	0.545	316 – 545	2283
1754	0.244	0.789	546 – 789	2447
1193	0.166	0.954	790 – 954	1642
328	0.046	1.000	955 – 1000	450
7193	1.00			10000

3. Establish random number intervals to represent the range of possible traffic counts for each time period.

Use the RANDBETWEEN function in Microsoft Excel to create tables of 10,000 random integers to simulate traffic flow. Excel 2016 uses a very high quality algorithm, which has been shown by NIST to be suitable for samples of up to 10^{13} [6].

FIGURE 2
SIMULATED FREQUENCY DISTRIBUTION AND ESTIMATES

M12 | fx =COUNTIFS('Rand#1'!$A$1:$A$10000,">=0",'Rand#1'!$A$1:$A$10000,"<=6")

	Current	Historical	Average Speed (MPH)	Current	Historical	Average Speed (MPH)	Frequency	Probability of Occurrence	Cumulative Probability	Random Number Intervals	Simulated Traffic Count
11	12	25	48	13	16	44					
12	14	12	48	8	8	57	43	0.006	0.006	0 - 6	59
13	4	6	49	6	6	47					
14	10	5	48	0	4	N/A					
15	7	12	47	9	10	47	44	0.006	0.012	7 - 12	66
16	29	27	47	34	43	45					
17	96	101	48	153	146	47					
18	259	229	47	310	333	46	733	0.102	0.114	13 - 114	1030
19	379	403	45	485	492	44					
20	417	443	45	417	495	45					
21	419	478	45	401	486	45	1444	0.201	0.315	115 - 315	2023
22	400	523	44	389	535	46					
23	512	575	42	432	609	45					
24	450	529	44	453	573	45	1654	0.230	0.545	316 - 545	2283
25	458	550	45	433	526	46					
26	532	600	43	430	527	44					
27	507	612	45	466	521	45	1754	0.244	0.789	546 - 789	2447
28	377	542	46	468	535	46					
29	335	436	45	370	481	46					
30	292	392	41	228	354	45	1193	0.166	0.954	790 - 954	1642
31	103	365	42	103	212	44					
32	81	188	44	67	107	45					
33	58	96	46	31	51	46	328	0.046	1.000	955 - 1000	450
34	16	44	49	19	25	48					
35							7193	1.00			10000

82420 | Rand#1 | 82520 | Rand#2 | 82620 | Rand#3 | 82720 | Rand#4 | 82820 | Rand#5

Pressing F9 on the keyboard will generate new random number values for a new simulation. Students can press F9 a few times and watch the traffic flow estimates change as well as their associated plots shown in Figure 3.

FIGURE 3
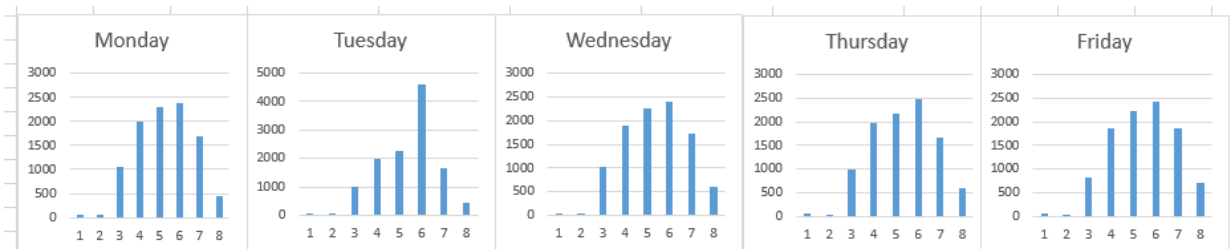## PLOTS OF SIMULATED TRAFFIC FLOW

Figure 3 shows the results of daily traffic count simulations based on a flow of 10,000 vehicles occurring the three-hour time periods for each day. Students are next asked to analyze and interpret the expected traffic flows and make a recommendation as to which time period on which day is the least intrusive time to close the road and conduct maintenance. Students were generally able to quickly master the basic concepts of Monte Carlo simulation using Excel and gained confidence in gathering data and incorporating modeling to aid in analysis and decision making. Based on positive feedback from the students we intend to introduce more modeling based assignments in future courses.

CONCLUSIONS

Informed decision-making plays a crucial role in the effective management of every project. Employing Monte Carlo Simulation techniques is an easy way to reduce risks and make important decisions. Having a good knowledge of simulation techniques can play an important role in the management and operations of technical projects[7]. This introduction to Monte Carlo Simulation provides students with the knowledge and practical experience in building useful predictive models using readily available excel software. By focusing on the concepts of valid data collection, model building, analysis, interpretation, and presentation vice the mechanics of calculation students gain abilities and confidence needed to solve realistic problems.

ENDNOTES

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[3.] T. J. Schriber, T. J., "Simulation for the masses: Spreadsheet-based Monte Carlo simulation," *Proceedings of the 2009 Winter Simulation Conference (WSC)*, Austin, TX, USA, 2009, pp. 1-11, doi: 10.1109/WSC.2009.5429310.

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[5.] Greenburg, D. and Righter, J. (2020), "Introduction To Forecasting Methods For Engineering Students Using R," *Proceedings of the American Society of Engineering Education, Southeastern Section Annual Conference.*

[6.] https://www.engineering.com/AdvancedManufacturing/ArticleID/18106/Introduction-to-Monte-Carlo-Simulation.aspx

[7.] Subramanyan, H. and K Moorthy, K. (2016) Designing and Evaluating Simulation Games For Professional Project Management Education. 2016 Project management Symposium, University of Maryland.