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MONTE CARLO SIMULATIONS TO TEACH THE EFFECT OF LEAN METHODS TO IMPROVE BUSINESS PROCESSES

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ABSTRACT

This paper presents two Monte Carlo simulations that we use in our Operations Management course to support the teaching of Lean concepts. Students are experienced and inexperienced, international and domestic, and technically savvy and technically challenged, and the course is taught both online and on campus. The educational aims of the simulations are to teach our students: (1) the concept of variation and its impact on service system throughput; (2) how capacity buffers work and that they can add significant cost; and (3) how Lean approaches that remove non-value-added activities can result in customer experience improvements without adding significant cost. We achieve these aims through the use of two service system simulations – one that can be done manually and the other that uses Excel.

1 INTRODUCTION

Lean production methods play an important role in today's Operations Management classes. At the same time, waiting line modeling is also covered in most of these courses. However, in many textbooks, these two topics are not effectively integrated particularly in service organizations. For example, it may be important to understand how system performance (measured by customer queue time or system throughput) is enhanced by the use of Lean methods. Our goal in this paper is to show how simulations can be used to illustrate the effect that applying Lean methods can have on a service. We achieve this goal by developing Monte Carlo Simulations of various service systems. This topic is important because most of our students will likely get a job as a service provider and be asked to play a role in improving their business processes.

1.1 Boston University Metropolitan College

As one of the 17 degree-granting Boston University (BU) Schools and Colleges, the mission of Metropolitan College (MET, www.bu.edu/met) is to provide practical and timely professional education. Our graduate student body is compromised of two main groups who seek to earn a MS degree: (1) part-time working professionals, and (2) full-time students. The latter group consists primarily of individuals who have recently completed their undergraduate degree and therefore are inexperienced compared to the former group. We offer courses in both on-line and face-to-face formats serving both international and domestic audiences. In all of these classes, we have a mix of experience levels and technical sophistication. Our challenge is to make the course material effective for all of these students.

In the Administrative Sciences Department at MET, we find the use of Monte Carlo Simulation (MCS) particularly useful because it allows us to explain concepts by tailoring MCS complexity based on the experience level of students. Here, we describe two simulations that we use to support the teaching of "lean"

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concepts. These simulations are covered in the course titled Operations Management, which concerns the design, management, and improvement of business processes. This course is required for students who are earning MS degrees in Applied Business Analytics or Supply Chain Management.

1.2 Effective Use of Simulations

MCS has been used to enhance the teaching of management concepts in many management disciplines. However, care must be taken to ensure that the audience understands the relationship between the simulation and the real world. For example, we find that students with more experience tend to respond better to simulations than novices. Hence, the complexity of the MCS must be tailored to the student audience. A suggested framework is shown in Figure 1, where the complexity of the simulation is best targeted along the shaded diagonal. The region on the bottom-right should be avoided because students will not have the experience needed to make the connection between the real world and the simulation. A good approach to the bottom-left would be to create a manual simulation that is consistent with a computerized simulation. For example, a discrete uniform distribution from 1 to 6 can be simulated with a physical die roll or with an Excel function.

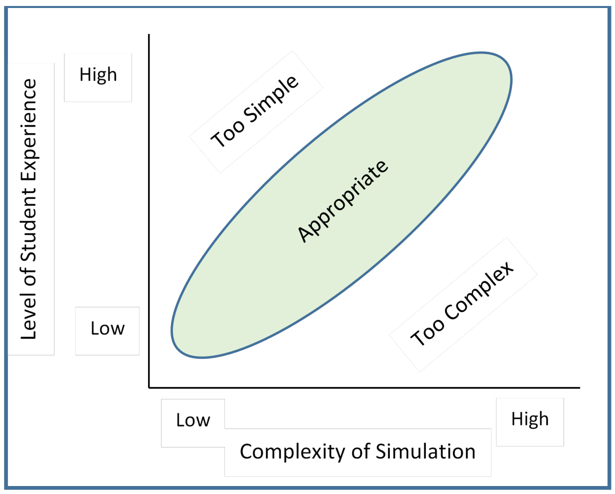

Figure 1: Targeted audiences for MCS.

1.3 The Importance of Process Improvement

Like many contemporary organizations, The Institute for Healthcare Improvement (IHI) advocates that everyone in health care should consider themselves having two jobs: to do the work and to improve how the work is done (IHI 2019). This is becoming true of any professional in any industry, and forms the basis for programs such as Lean and Six Sigma. Although these topics are often overlooked in university education, many graduates will find jobs in organizations that follow these practices. That is, they will be asked to play a role in process improvement. Although some may argue that these programs need not be covered in university courses, there are ways to provide comprehensive and relevant education that best prepares them to be a valuable contributor in their jobs.

In our Operations Management course, we seek to prepare students to work in these environments. In particular, almost all of our graduating students will be professional service providers to either external customers or internal customers of their firm. Therefore, we seek to focus our coverage on service processes, while appreciating the reality that these services may have internal customers. We think that it is important to improve these services, often called business processes, because they can have a critical impact on a firm's profitability.

1.4 Organization of the Paper

The educational aims of the use of MCS described below are to teach students: (1) the concept of variation and its impact on system throughput; (2) how capacity buffers work and that they can add significant cost; and (3) how Lean approaches that remove non-value-added activities can result in customer experience improvements without adding significant cost. In this article, two MCS examples are provided – the first is a simple simulation of a loan processing system and the second is a more complicated simulation of a hospital's emergency department.

We organize the remainder of the paper as follows. In Section 2, we provide background on service process characteristics and Lean management. In Section 3, we present the loan processing system simulation and discuss its use in our classroom. In Section 4, we describe the emergency department simulation and discuss its use in our classroom. Finally, in Section 5, we discuss the implications of this work.

2 BACKGROUND

In this section, we provide some background on the three important components of this paper. We discuss Lean management and its principles in Section 2.1, the characteristics of service processes in Section 2.2, and the relationship of this effort to prior work on MCS as well as the teaching of lean principles in Section 2.3.

2.1 Lean Management

Lean Production refers to the production methods used by Toyota Motor Manufacturing (Ohno 1988). It was named by John Krafcik based on a MIT study of automobile manufacturing facilities worldwide (Womack et al. 1990). Through the years, the methods of Lean production have also been applied to healthcare, government, non-profit, and other service firms. Hence, Lean Management (or just Lean) is a better title for this approach. In a nutshell, rather than seek economies of scale, Lean practitioners seek to remove the reasons for scale economies (e.g., lower fixed costs) and other characteristics that scale economies seek to accommodate. A Lean approach would typically start by defining value from the perspective of customers. Then, the value stream (collection of activities) that make up the process flow would be mapped (or flowcharted). Finally, those activities that do not add value (called wasteful) would be removed.

At Toyota, Shigeo Shingo identified seven categories of waste: overproduction, correction, motion, inventory, waiting, conveyance, and overprocessing (Dennis 2007). For example, in a hospital's emergency department (ED), consider the process used to test blood when ordered by a physician. The process flow would include value-added activities of drawing the blood, testing the blood, and evaluating the results. The total time to perform these three activities may be 15-20 minutes. In reality, the total processing time can be several hours because of the following wasteful activities: (a) waiting for the technician to draw the blood, (2) moving the blood to the ED outbox, (c) waiting for a volunteer to take the blood to the laboratory, (d) transporting the blood, (e) waiting for the laboratory technician to complete the previous tests, (f) waiting while the testing equipment is setup, (g) retesting the blood if the test is not successful, (h) waiting for the volunteer, (i) transporting the results to the ED, and (j) waiting for the physician to complete other activities before viewing the results.

2.2 Service Process Characteristics

In a research project consisting of 186 services, Maleyeff (2009) identified a number of operational characteristics that apply to services. The main characteristic of a service process is variable activity durations. For example, Figure 2 provides an example of the time to triage a patient at a hospital's ED. The average time was about 6.5 minutes, but the duration varied from about 1 minute to about 15 minutes. It is important to recognize that service duration variation is impacted by the presence of wasteful activities.

For example, in the hospital ED, the variation in the time to perform a blood test would be impacted by the wasteful activities listed above.

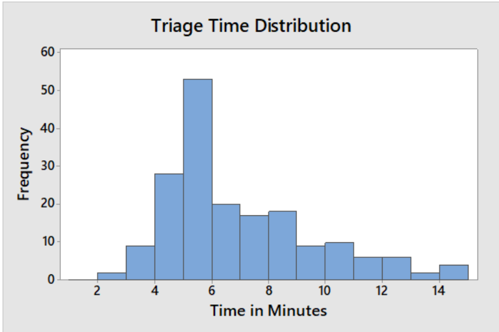

Figure 2: Patient triage time in minutes.

Another well-known characteristic of service processes is the inability to buffer uncertainty with inventory. In manufacturing, the effect of demand uncertainty can be mitigated by producing items in advance of their projected need. The extra items are called an inventory buffer. On the other hand, services are intangible and buffering with inventory is rarely possible. A capacity buffer can be created to mitigate demand and other uncertainties in a service process. Here, a planner reserves resource capacity to ensure that a facility can satisfy load requirements even when demand is somewhat higher than forecasted or when process uncertainties exist, including poor quality, process downtime, and inefficient work practices. But, capacity buffers can be costly, especially when equipment or labor costs are high. The cost of unused capacity is evident to managers because some resource capacity will go unused during most periods.

To reduce the cost for a capacity buffer, the process can be improved by removing many of the non-value added activities that are the source of much of its duration variation. Various methods of Lean can be used for this purpose such as standard work, 5S, poka-yoke, jidoka, visual workplace, and SMED (Womack and Jones 2003). These approaches can be implemented with lower costs than capacity buffers.

2.3 Teaching MCS and Lean Principles

There is a wealth of literature that discusses how various forms of simulation have been used to help instruct both undergraduate and graduate students in many different types of courses, e.g. see (Altiok et al. 2001; Freimer et al. 2004; Ståhl 2007; Standridge 2000). Saltzman and Roeder (2013) addressed the challenges faced when using simulations in the teaching of business courses. A survey by Jain (2014) revealed that almost 90% of top business schools teach MCS to their students. We also favor to use MCS in our Operations Management course because it accurately depicts the uncertainty and statistical variations inherent in business processes. Roeder and Miyaoka (2015) also discuss the use of simulation in an introductory Operations Management course but their focus is on the benefits and challenges of using a business simulation (e.g., a game) in the classroom.

In addition, the Winter Simulation Conference Proceedings over the last decade include several papers that discuss Lean manufacturing methods and how simulations and games are used to teach Lean methods. Tokola et al. (2015) provide an excellent summary of those papers. Later, Delago et al. (2016) developed a simulation-based game approach to teach Lean Manufacturing principles. The focus of these papers have mainly been the applications of Lean in manufacturing settings. Our focus is on service processes and the use of MCSs to teach Lean principles in service environments.

3 BASIC LOAN PROCESSING SIMULATION

The loan processing system simulation is utilized early in the Operations Management course. It mimics the processing of a loan application through six departments (i.e., six business processes) some of which may be outsourced or offshored (Figure 3). Each day, the number of new loan applications varies from 1 to 6, with each possibility equally likely. Each of the six departments can process 1 to 6 applications per day, also with equal likelihood. Therefore, the system is perfectly balanced because the average capacity of each process (3.5 applications/day) is the same as the average customer demand (3.5 customers/day). The simulation can be run manually (with a 6-sided die used to generate random data) or in Excel (with the *randbetween* function to generate random discrete uniform data). The choice of the die or Excel depends on the sophistication of the audience.

Figure 3: Loan approval simulation structure (baseline conditions).

The simulation is run for one month (i.e., 20 working days). Each department begins the month with an inbox consisting of 4 applications waiting to be processed. With a perfect balance and an average of 3.5 applications per day, it would appear that the system would complete an average of 70 applications in a one-month period. When the simulation is run manually, each group of about seven students performs the simulation for one month. After each group runs the simulation, the average monthly throughput (applications completed) is calculated. When the simulation is implemented using Excel, it can be run for many more months. A one-month simulation run is shown in Figure 4 – in this case, 51 applications were completed by the system.

Figure 5 shows simulated results (monthly throughput) for 100 iterations of the simulation. The average number of applications completed per month was about 54. This value is significantly lower than the demand rate (70 applications per month). The root cause of this discrepancy is the variation in activity times. Specifically, when daily activity times are shorter than the average, there will be unused capacity (because a department cannot process more applications than were present in their inbox). This unused capacity contributes to the difference between the demand rate and the completion rate. The average difference of about 16 applications per month is due to the excessive number of times unused capacity is realized.

With this simulation utilized early in the Operations Management course, several concepts important to business process managers can be illustrated. Perhaps the most important concept is variation. W. Edwards Deming once stated “If I had to reduce my message to management to just a few words, I’d say it all had to do with variation.” (Deming 2000). The monthly throughput of the loan processing system varies a great deal from month to month, probably much more than a unenlightened manager would expect. This inability to appreciate variation can lead to poor decision making. For example, a manager may see that one department has a large inbox at the end of a month and conclude that workers in this process were not working hard enough during the previous 20 days. The fallacy of this approach is illustrated by re-running the simulation with a focus on inbox sizes, which will vary randomly across the six processes.

The Excel simulation is then used to illustrate the use of a capacity buffer by changing the parameters of the random number of applications completed in each department. For example, if the random number generator is changed so that the number of applications processed to 1 to 7 (instead of 1 to 6), the average

Loan Processing Simulation

4 ...Initial InBox   1 6 ...Process Capacities (Cap)

		Process A			Process B			Process C			Process D			Process E			Process F		
Day	Demand	InBox	Cap	Move	InBox	Cap	Move	InBox	Cap	Move	InBox	Cap	Move	InBox	Cap	Move	InBox	Cap	Done
1	2	4	6	4	4	6	4	4	5	4	4	2	2	4	3	3	4	4	4
2	1	2	4	2	4	6	4	4	6	4	6	6	6	3	5	3	3	4	3
3	1	1	3	1	2	6	2	4	2	2	4	4	4	6	3	3	3	4	3
4	3	1	1	1	1	1	1	4	3	3	2	5	2	7	2	2	3	3	3
5	5	3	6	3	1	2	1	2	4	2	3	2	2	7	3	3	2	4	2
6	1	5	2	2	3	3	3	1	6	1	3	6	3	6	6	6	3	5	3
7	2	4	2	2	2	2	2	3	4	3	1	5	1	3	5	3	6	5	5
8	2	4	5	4	2	6	2	2	3	2	3	4	3	1	6	1	4	4	4
9	6	2	4	2	4	5	4	2	2	2	2	2	2	3	4	3	1	6	1
10	4	6	2	2	2	4	2	4	5	4	2	3	2	2	4	2	3	2	2
11	4	8	2	2	2	6	2	2	4	2	4	2	2	2	6	2	3	6	3
12	5	10	1	1	2	3	2	2	5	2	4	2	2	2	6	2	2	3	2
13	5	14	1	1	1	6	1	2	3	2	4	5	4	2	1	1	2	5	2
14	1	18	6	6	1	3	1	1	3	1	2	4	2	5	5	5	1	4	1
15	2	13	6	6	6	4	4	1	2	1	1	4	1	2	3	2	5	3	3
16	3	9	2	2	8	3	3	4	6	4	1	2	1	1	4	1	4	4	4
17	2	10	3	3	7	1	1	3	6	3	4	4	4	1	4	1	1	3	1
18	6	9	4	4	9	5	5	1	4	1	3	6	3	4	5	4	1	2	1
19	1	11	2	2	8	2	2	5	3	3	1	3	1	3	1	1	4	3	3
20	5	10	5	5	8	3	3	4	4	4	3	5	3	3	5	3	2	1	1
	61			55			49			50			50			51			51

Figure 4: Excel simulation (one month).

capacity in each department increases to 4.0 applications/day. Because the average demand rate remains 3.5 applications/day, this change would incorporate a capacity buffer of 12.5% (0.5 divided by 4). By running the simulation, it is shown that this capacity buffer increases average throughput to about 57 applications per month. By changing the number of applications processed in each department to 2 to 7, the average capacity increases to 4.5 applications/day. This change would incorporate a capacity buffer of 22.2% and the simulation shows an increase in throughput to an average of about 66 applications per month. These simulation results are shown in Figure 6.

The simulation can also be used to show how Lean methods can help business processes achieve better results without the need for high cost capacity buffers. For example, consider the use of Lean methods to standardize work thereby lowering the variation in activity times. If the random number generator changes the number of applications processed in each department to 2 to 5 (instead of 1 to 6) monthly throughput improves the average of about 59 applications per month. If the random number generator changes the

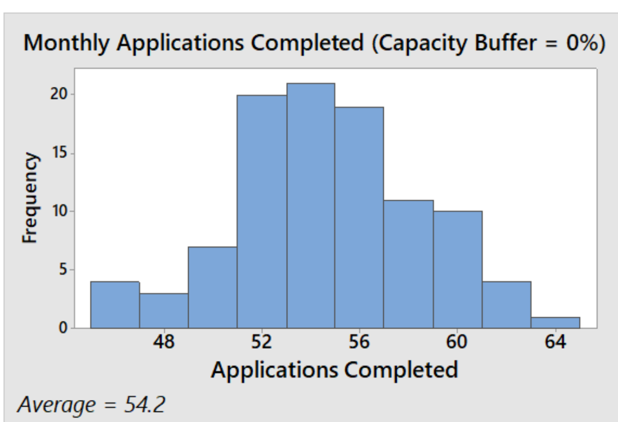

Figure 5: Simulation results (no capacity buffer).

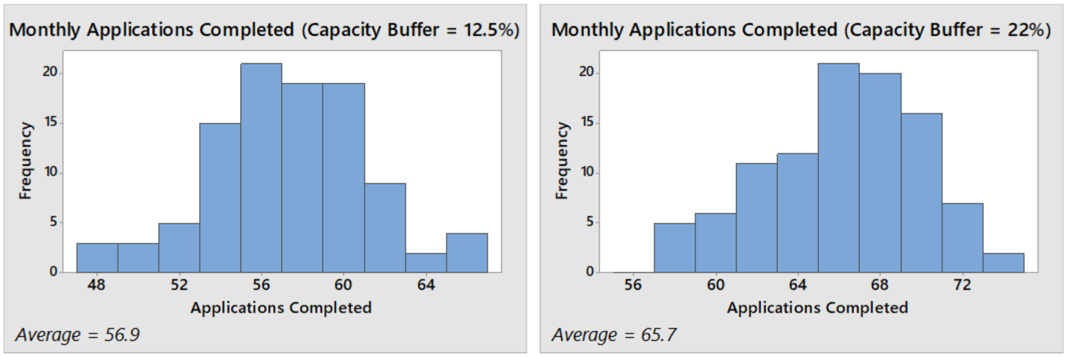

Figure 6: Monthly throughput with capacity buffering.

number of applications processed in each department to 3 to 4, average monthly throughput increases to about 65 applications per month. In both of these cases, the average number processed in each department remains 3.5 per day, but throughput is improved.

Although these results are interesting, they are also not entirely realistic because Lean methods would not create a situation where the *good days* (where a 6 is rolled) would occur any less frequently. In fact, in the actual situation, Lean methods may reduce the frequency of the bad days (e.g., where workers spend time correcting errors). Therefore, each department's capacity would more likely change to 2 to 6 (an average of 4.0 per day, with reduced activity time variation) or 3 to 6 (an average of 4.5 per day, again with reduced activity time variation). As shown in Figure 7, the first change increases average throughput to about 63 applications per month and the second change increases average throughput to about 69 applications per month. When demonstrated to students in class, these changes illustrate why the use of Lean methods to reduce variation can have a profound effect on system performance.

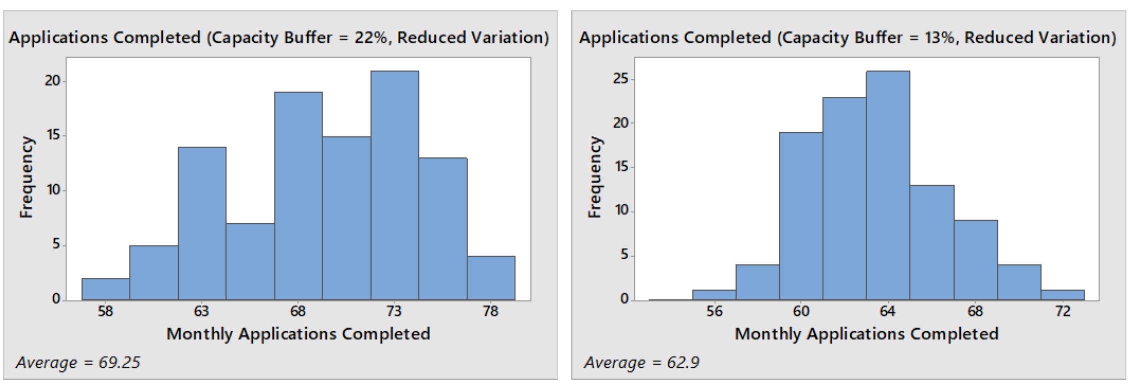

Figure 7: Monthly applications completed with lean methods.

In summary, the loan process system simulation can be used to show how service systems perform in the presence of activity time variation, which is inherent in many services. This knowledge would be important to current and future service managers. As an aside, it is also useful for illustrating the use of various statistical displays to compare data sets. For example, box-and-whisker plots can be used to compare all of the scenarios describe above. As shown in Figure 8, adding costly capacity buffers can indeed improve monthly throughput, but the use of Lean methods to remove some wasteful activities can achieve similar results with lower costs.

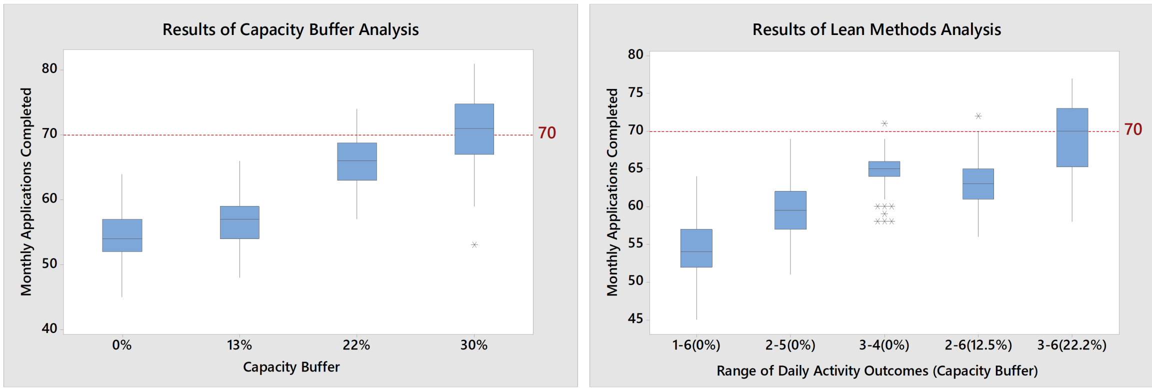

Figure 8: Comparison of all scenarios.

4 MORE COMPLEX EMERGENCY ROOM SIMULATION

The second simulation is based on a hospital's emergency department (ED). This simulation was developed by one of the authors during their work as a consultant. It is now used in the Operations Management course to help students appreciate the use of MCS in the real world, and to illustrate the relationship between Lean approaches and service queue time. The consulting project was motivated by a variety of metrics at the hospital that were associated with patient turnaround times in the ED. As shown in Figure 9, the percentage of patients waiting longer than 6 hours had been increasing at a slow pace but recently experienced a dramatic increase (the actual data are not shown for proprietary reasons).

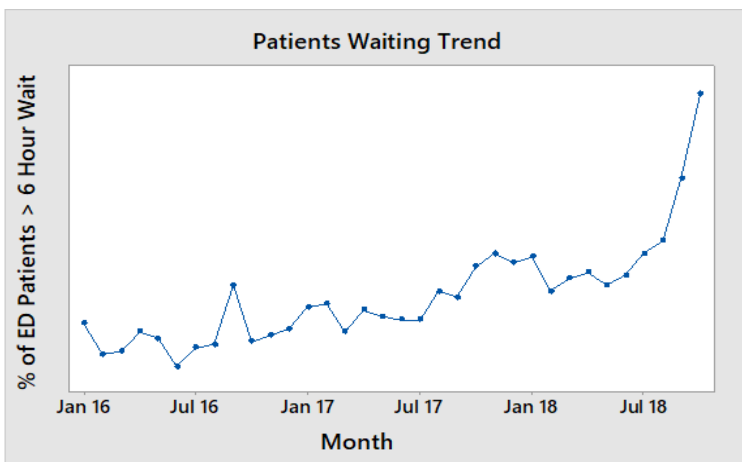

Figure 9: Motivation for emergency department study.

A simplified flow diagram for a typical patient is shown in Figure 10 (extremely critical patients follow a somewhat dissimilar flow). After each patient arrives, they are evaluated by a triage nurse if one is available (otherwise the patient waits), then the patient is registered if a clerk is available (otherwise the patient waits), then the patient is assigned a bed if one is available (otherwise the patient waits). Once in a bed, the patient is seen by a physician if one is available (otherwise the patient waits). Throughout their time in bed, the patient will also experience various tests (blood, imaging, etc.) that usually require other resources that will cause additional waiting. Finally, a discharge order is written and the patient is either moved to a ward in the hospital or sent home. Patients being discharged to a hospital ward will wait in their ED bed until they are moved.

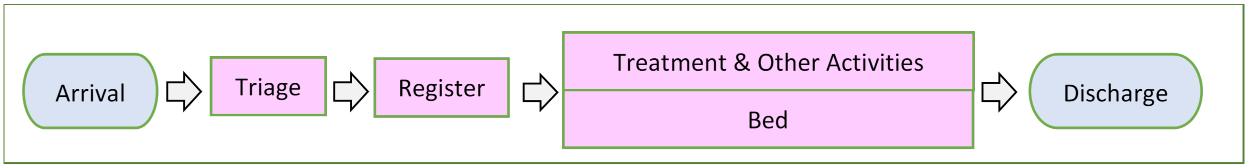

Figure 10: Simplified emergency department patient flow.

A MCS was developed that mimicked ED patient flow using data collected from the hospital. Data were collected for patients entering the ED during a one-month period. For example, the triage time was shown in Figure 2. Analysis of the data for each main activity showed that all service times were adequately represented by a gamma distribution, where the coefficient of variation was approximately 50%. The MCS was created in Excel with Poisson patient arrivals and gamma service times. The key resources were the triage nurse(s), the registration clerk(s), the treatment physician(s), and the bed(s). Service times included all value-added activities (triage, physician consultation, image interpretation, etc.) as well as other activities that currently exist but do not add value (such as the time devoted to non-value-added activities after a blood test is ordered). These wasteful activities were important to account for because the simulation would be used to assess the impact of reducing time spent on wasteful activities.

A base case was created by experimenting with various average bed service times until the simulation generated results consistent with observed patient turnaround times at the hospital. The parameters used to create the base case are shown in Table 1. The key parameter is the 135 minute average service time for "other activities" (i.e., service time in a bed). Using these parameters, patient turnaround time (TAT) averaged about 373 minutes, which includes queue time for a bed of about 174 minutes.

Table 1: Simulation inputs (parameters are shape, scale of gamma servcie time).

Process Step	**Resource**	**Distribution**	**Average**	**Parameters**	**Number**	**Utilization**
Triage	Nurses	Gamma	6.5 Minutes	4, 1.625	1	43%
Registration	Clerks	Gamma	9 Minutes	4, 2.25	1	60%
Treatment	Physicians	Gamma	24 Minutes	4, 6	2	80%
Other Activities	Beds	Gamma	135 Minutes	4, 33.75	12	88%

The simulation showed an interesting result that has implications for managers. By plotting the waiting times for 1000 consecutive patients, the stability of the waiting time is analyzed. As illustrated in Figure 11, patient TAT was unstable over time because the mean waiting time changes across the 1000 simulated customers. To put this result in perspective, this ED served about 100 patients per day. On some days (e.g., patient numbered 100-199) average turnaround times was relatively low, while on other days (e.g., patients numbered 400-499) average turnaround times was much higher. Students being shown this result are made aware of its management implications. That is, a supervisor looking at daily patient outcomes, may reasonably conclude that something extraordinary happened to cause the discrepancy in these results. The reality is that the uncertainty of the congested ED experienced these results in quite a natural way with nothing extraordinary occurring. Any action taken by the supervisor based on these results would be at best a waste of time. At worst, it can result in ineffective changes and deflate staff morale.

It is clear from the MCS results that the bottleneck resource in the ED is beds, where 12 beds are currently available and the base case average bed queue time is 174 minutes. An obvious solution to the long queues for beds would appear to be the addition of another bed in the ED. However, like many EDs, in this hospital the space was already full and no room existed to add more beds. However, there was agreement among the staff that some of the wasteful activity times could be reduced so that the bed utilization would decrease. In particular, a subsequent data collection found that the time to remove a patient from a bed after a discharge order was written averaged about 90 minutes.

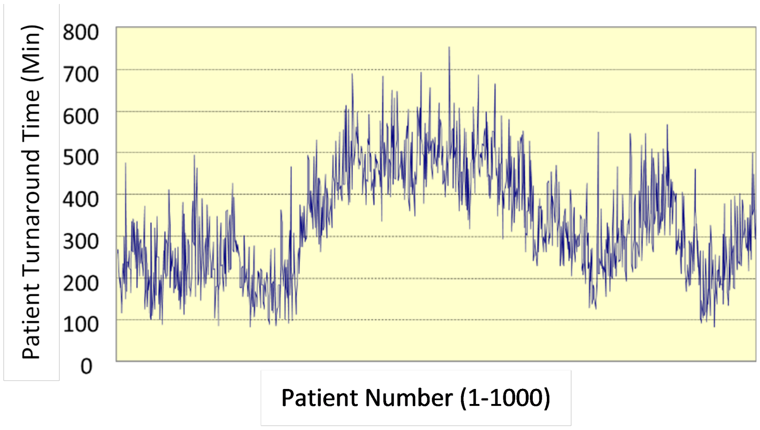

Figure 11: Patient turnaround times in minutes (base case simulation results).

In the classroom, the use of the MCS to support the effort to reduce wasteful activities using Lean methods is demonstrated. In particular, the other activity (i.e., bed) average service time was changed to determine a target reduction that would make patient TAT acceptable. After experimenting with various scale reductions, it can be shown that an average other activity service time of 120 minutes (from the current 135 minutes), would be sufficient. This change reduces the bed utilization to 80% (from 88%). As illustrated in Figure 12, the MCS results showed a stable patient TAT and a reduction of its average to about 225 minutes (from 373 minutes in the base case). In this scenario, bed queue time is reduced to about 42 minutes (from 174 minutes). Most students find this result remarkable because a 15 minute reduction in service time saved 132 minutes of queue time. In the lecture on waiting line models, this result is shown to be consistent with queuing theory and would be anticipated by many researchers and instructors.

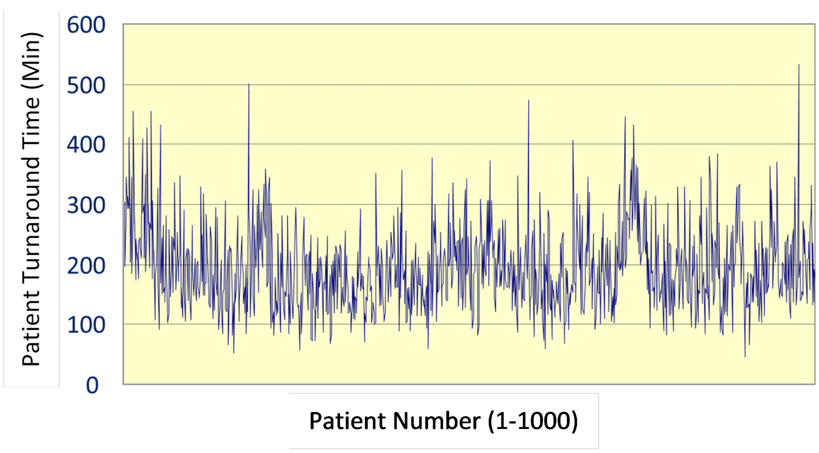

Figure 12: Patient turnaround times in minutes (activity time reduction simulation results).

Table 2 summarizes the results of the simulation study that is demonstrated to students using the ED simulation. These results are used to motivate the need to better understand the theory and application of waiting line models and how real world situations and actions affect queue times. This knowledge is important for current and future business process managers and those taking part in process improvement activities for services with variable activity times.

Students are informed that, with the help of the simulation model, ED administrators and staff developed solutions to reduce time spent on wasteful activities. A standard work process was implemented with the cooperation of other hospital departments to remove discharged patients from the ED in a timely manner.

Table 2: Summary of simulation results.

Scenario	Other Activity Average Time	Bed Utilization	Average TAT	Average Bed Queue
Current State	135 Min	88%	373 Min	174 Min
Target State	120 Min	80%	225 Min	42 Min

More visual devices were employed to keep everyone appraised of the patients whose test results were available. Rather than waiting for the blood to arrive at the laboratory to start setting up equipment, the ED notified the laboratory when the order for the tests was written, thus reducing waiting for the setup. With the Lean approach, rather than investing in more resources to improve the patient experience, costs were not increased and the patient experience was improved.

5 DISCUSSION

The simulations described above are used in the classroom to integrate topics such as statistical variation, waiting line modeling, and Lean methods. In our experience, an important "aha" moment occurs when the simulations are associated with queuing theory. In particular, the MCS can illustrate the well-known hockey stick phenomenon. As illustrated in Figure 13, queue time tends to increase as server utilization increases in a nonlinear pattern. This display was created using a M/M/s queuing model with average arrival rate of 4 customers per hour and average service time of 15 minutes per customer. It is evident that a resource utilization less than about 85% tends to show a more linear pattern, but when utilization moves above 85%, queue times increase dramatically. It is why rubbernecking on highways (when each car slows down a bit to look at an accident on the other side of the highway) can cause traffic delays.

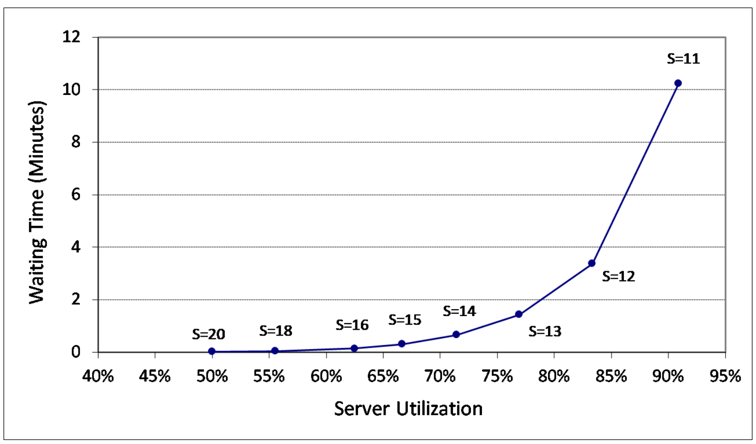

Figure 13: "Hockey stick" phenomenon.

Students are shown the similarity of the theoretical pattern in Figure 13 with the data shown in Figure 9. This comparison makes a lasting impression on students because, although the M/M/s results are abstract, they are better able to relate the simulation results to a real queuing system. Prior to the use of these simulations, explanations of the nonlinear hockey stick phenomenon were based on repeated employing the M/M/s model only, and the practical impact of this phenomenon was lost of many of those students.

Finally, students and practitioners are familiar with the better, cheaper, faster (BCF) mantra in business. With the use of MCS, students and practitioners can learn how to better understand the effect that variation has on BCF business process metrics, and how the use of Lean methods can achieve better performance outcomes. Unlike the costly practice of adding more capacity to achieve throughput goals (i.e., sacrificing cheaper to achieve faster), removal of wasteful methods can have a disproportionate effect on faster while adding little or no additional costs.

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