Teaching Performance Modeling via Software and Instructional Technology*

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ABSTRACT

Performance modeling and analysis has become a common practice to assist the development of modern information networks and service systems. The teaching of performance modeling today is faced with several challenges: one should not only incorporate new topics to reflect the changing world ranging from information to economic to health crisis, but also embrace the proliferation of various forms of digital technologies in classroom teaching and learning. In this talk, the authors will share their stories in teaching performance modeling utilizing software and digital technologies, with the purpose to foster further reflections and discussions.

KEYWORDS

Teaching Performance Modeling, Instructional Technology, Simulation Software, Blended Learning, Interactive Web-based Learning, Kahoot! games

1 Introduction

Since the seminal work of A. K. Erlang (Erlang 1909) in the early 19th century on the modeling of telephone traffic, performance modeling and measurement have grown into a discipline and have evolved significantly. Various mathematical techniques were brought into this field, including probability and queueing theory, stochastic processes, complex analysis, statistics, simulation, control theory, machine learning, information theory, optimization, and distributed algorithms. The application areas extended from telephone networks to Internet and Web applications, from manufacturing systems to supply chain, from call centers to workforce management, from single computer systems to large-scale parallel computing infrastructures.

Performance modeling education has been part of the curriculum in many computer sciences and industrial and system engineering departments around the world. For a comprehensive survey on Performance Modeling (PM) courses during the last decade, we refer the reader to the work of de Nitto Personè, in their conference paper at WEPPE 2017 (de Nitto 2017) and a later technical report [6]. As technology is becoming an integral part of our everyday lives, the trend in ubiquitous technology has also found its way into the learning process at every level of education. The teaching of performance modeling today is faced with several new challenges: one should not only incorporate new topics to reflect the changing world ranging from information to economic to health crisis, but also embrace the proliferation of various forms of digital technologies in classroom teaching and learning. U.S. Department of Education states that technology "infuses classrooms with digital learning tools, expands course offerings and experiences; builds 21st century skills; increases student engagement and motivation; and accelerates learning;" and "has the power to transform teaching by ushering in a new model of connected teaching" [13]. The aim of this article is therefore to share the authors' own stories on integration of software and instructional technologies in teaching performance modeling and engineering, with the purpose to foster further reflections and discussions.

The rest of the article is organized as follow. Section 2 introduces the syllabi of the performance modeling courses taught at OSU. Section 3 shares a few classroom technologies that the author finds useful in teaching PM. Section 4 focuses on how PM software was taught in lab sections using a blended learning model. Concluding remarks are presented in Section 5.

2 Performance Modeling Courses at OSU

At the Ohio State University, in the department of Integrated Systems and Engineering, there are two levels of course offerings on Performance Modeling: 1) a 4 credit-hour undergraduate-level course, titled *Stochastic Modeling and Simulation,* that is required for undergraduate ISE students and; 2) a 3 credit-hour graduate-level course, titled *Simulation for System Analytics and Decision-Making*, that is required for Master's and Ph.D. students and open to advanced undergraduate students as an elective course. These two offerings cover generally the same material, with the graduate-level course going into further detail in theory and methodology development.

The primary objective in both courses is to teach students how to build and analyze performance models of complex real-world systems and to use simulation and optimization methods to assist decision making under uncertainty and develop system improvement recommendations. The relative accessibility of performance modeling methodologies combined with the far-reaching real-world applicability of modeling and simulation explains why such a course is viewed as a key course for preparing students who will be going out to work in industry, as well as one of the best ways to introduce new students to systems engineering.

The objective of the course is for the students to learn how to:

[1]. Identify the roles simulation plays in improving existing systems and designing and building new ones,
[2]. Identify the theoretical foundations and limitations of simulation (i.e., how historical data relates to expected values),
[3]. Implement simulations in both EXCEL and ARENA to offer solutions to customers,
[4]. Determine reasonable distributions for helping to predict future events (i.e., goodness of fit testing and empirical distributions),
[5]. Apply simulation output analysis to get insight over many system options,
[6]. Recognize the basic M/M/C queue and know the benefits of queuing theory, and
[7]. Apply input analysis, output analysis, and answer a question using real input data.

The 4 credit-hour undergraduate course focuses on basic uncertainty modeling and simulation concepts and is offered twice per year with an average class size of 80 students, thus resulting in about 160 students completing the course per year. The 3 credit-hour graduate course adds more depth and focuses on performance modeling, queueing, and simulation integrated with statistical analytics and decision-making. It is offered once per year with an average class size of 40 students. The 16-week course structure has 2 components: 1) a lecture component (twice per week for undergraduate, once per week for graduate) and 2) a lab component (once per week). Lectures are dedicated primarily to teaching students the theoretical aspects of performance modeling and simulation. The purpose of the lab section is for students to learn how to use the Arena software simulation package to build and analyze a variety of simulation models. In this way, the lab is meant to build practical simulation software skills and reinforce the theoretical concepts covered in lectures.

3 Teaching PM with Classroom Technology

With the proliferation of various digital products (e.g., laptops, iPads, smart phones, etc.) in our daily lives, it becomes handy to incorporate these ubiquitous technologies as part of the education process. When teaching performance modeling, I use several technologies to in my classroom. For example, I use Carmen, the OSU online education system for announcements, assignments, and course content. I use TopHat for attendance and in-class exercises. I use videos to demonstrate successful stories and ask students to record videos for their project presentations.

In this paper, I would like to share a few classroom technologies that I find particularly useful in teaching performance modeling: Live demo via software and spreadsheets, In-class polling, and Kahoot games.

3.1 Live Demo via Software and Spreadsheets

Live demonstration using software and spreadsheets has become an indispensable approach for me in teaching performance modeling, queueing, and simulation. In my opinion, live demonstrations not only help the instructor teach students more, but also makes the learning process more enjoyable.

When introducing queueing systems to the students, I often run a live demo or a pre-recorded short video of the demo. For example, when teaching discrete-event simulation for queueing systems, I would first run a live demo of a single-server drilling service as shown in Figure 1 below. Using the demo, we then establish a few important concepts: 1) the system is stochastic involving one or more random variables as inputs; 2) the system is dynamic (as opposed to static) that it evolves over time; and 3) the states such as the server status, and the number of jobs in queue, only changes at a discrete set of points in time. We can further discuss the basic elements of a queueing model, different metrics to measure the performance, and possible actions that can help improve the performance.

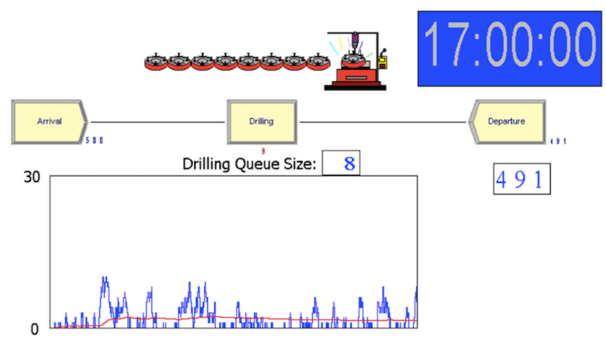

Figure 1: Live demo example: evolution of a single-server queue

The benefits of teaching PM using live demos are obvious. By illustrating the concepts using demos, students can view the technology-supported practices "in action", which helps students to engage and take a more active role in learning. It allows the instructor to direct attention to the most important features (e.g., by demo in slow motion). It also empowers the students to "think on the spot" and identify useful strategies to improve the system performance.

I also use spreadsheets extensively in my teaching. Spreadsheet simulation refers to using spreadsheets to build simulation models for real world systems, perform simulation experiments, and report the results. It is one of the most convenient way to teach stochastic modeling and demonstrate the variability of output due to the input uncertainty. Using spreadsheets, we can easily model situations that present uncertainty, generate random samples, and display the corresponding outputs in the spreadsheets thousands of times.

An example I often use in teaching Monte Carlo simulation is the classical Newsvendor problem:

Example 1: Rupert is going to get into the newspaper business. Each newspaper sells for $1 and costs him $0.80. Demand for the newspapers is uncertain, but he believes that it is reasonable to model demand as being Uniformly distributed from 1500 to 2500. How many newspapers should he buy?

After explaining how to use Excel to sample the random demand following the Uniform distribution, we can quickly generate the following simulation in spreadsheets in Figure 1. With the spreadsheets, we can play out the uncertainty in inputs, show that the uncertainty in outputs is typically not a linear function of the inputs as shown in Figure 2. We can further demonstrate the classical idea of repetitive sampling, how to generate confidence intervals based on central limit theorem and teach the key steps of Monte Carlo sampling.

Spreadsheets Simulation				
Run	demand	sales	revenue ($)	profit ($)
1	2062	2000	3000	1000.00
2	1709	1709	2563.5	563.50
3	1858	1858	2787	787.00

Figure 2: A spreadsheets simulation example

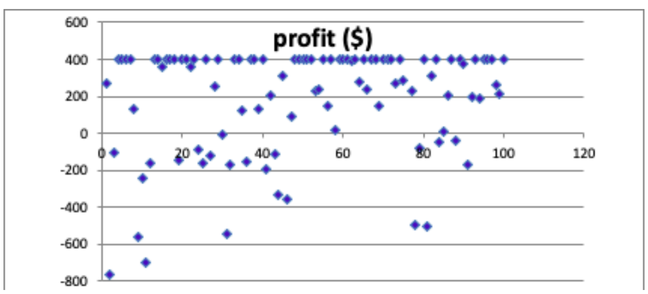

Figure 3: Spreadsheets demo: stochastic nature of outputs

Using spreadsheets in teaching performance modeling and simulation can be powerful. First and foremost, it helps the students experience the uncertainty easily. Charts on a printed page are *dead* while spreadsheet representations are *live* in that students can interact with the concepts underlying them. Second, spreadsheets are easy to implement and familiar to most students. Furthermore, it is an attractive technology because students are likely to use spreadsheets in future projects and careers.

3.2 In-class Polling

In-class polling can be conducted most effectively via classroom technology. With a polling system whether web-based or software-based, an instructor can pose a question to the class and have students respond simply a click away. The students' responses and statistics can then be tabulated and displayed instantly. Although we can pose a question and solicit answers from the entire class without relying on a technology, e.g., by showing of hands or using paper ballots, none of the traditional methods can achieve such an efficiency. In fact, the benefits of in-class polling are multi-fold. First, it can actively engage the students and broadens the participation. The option of responding anonymously makes students more comfortable to participate, even among shy students (Martin 2007). Second, the instant feedback, both to the instructor and to the students, makes the learning more effective.

For example, when teaching Little's law in queueing theory, I use the following example:

Example 2: Arrivals to a self-service gasoline pump occur at rate 12 per hour. Each car spends on average 6 minutes in the system. What is the expected number of cars in the system?

I would then conduct an initial poll, asking the students to use their common sense to select from a few possible answers. With the initial polling, the students' responses are probably all over the places. We will start a discussion phase, having the students explain their reasonings. I will then present a systematic way, on how to use Little's Law, to set up the problem and derive the correct answer.

After explaining the theory, I will give the students a few minutes for questions, we then conduct another in-class exercise using the poll again. This time, most of the students should be able to get the correct answer.

According to Levey (2018) and Martin (2007), the benefits of integrating polling into traditional lectures are multi-fold: 1) Higher levels of engagement (i.e., more students actively engaged more often); 2) Instant feedback, both to the professor and to the students; and 3) The option of anonymity in responding (Martin 2007).

3.3 Kahoot! Games

Another tool I frequently use in teaching PM is Kahoot (Kahoot![8].), which is a game-based learning platform where anyone can create a set of questions and have users play. This tool offers teachers the ability to create more engaging quizzes than a standard paper test which can be used to review students' knowledge, for formative assessment or as a break from traditional classroom activities. It provides a fast and efficient grading of the quiz relieving the teacher of this task. The rationale behind gamifying anything is to make the content more accessible and the learning process more fun. Instead of taking a test on paper, using Kahoot the users are offered the same testing situation but in a gamified setting. Most research on gamification suggest that it is an effective tool for creating a more enjoyable and engaging software system (Vlachopoulos and Makri 2017). It is among the most popular game-based learning platforms, with 70 million monthly active unique users (Wang and Tahir 2020).

When designing the quiz questions for the Kahoot games, I often use multiple choices to design my questions. Often, I focus on the important concepts and common pitfalls. For example, when teaching Poisson processes in my performance modeling course, I use the following question in my Kahoot quizzes. In this question, we are focusing on the knowledge point that

"Inter-arrival times of a Poisson process with rate λ are i.i.d. exponentially distributed random variables with mean $1/\lambda$".

A few important concepts are emphasized: 1) connection between Poisson process and interarrival time; 2) relationship between average arrival rate and mean interarrival time; and 3) the random nature of the actual arrival times.

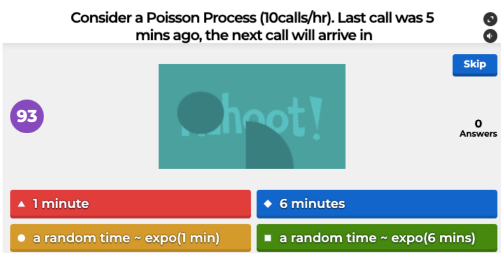

Figure 4: A sample quiz question via Kahoot! Games

To get an impactful learning experience out of the Kahoot! games, one must carefully think through the learning goals, questions, and answers (Graham, 2015). The following five research-backed tips have been suggested by Terada (2018) when designing high-quality multiple-choice quizzes. 1) Don't list too many answers; 2) Avoid trick questions; 3) Use simple question formats; 4) Make it challenging, but not too difficult; and 5) Follow up with feedback.

Since the use of Kahoot! games in teaching PM, the students' feedback has been extremely positive. The benefits are multi-fold: it helps to boost students' excitement, encourage curiosity and involvement for a topic, identify knowledge gaps, and use wrong answers as a teaching opportunity (Dellos 2015). According to the study of Johns (2015), Kahoot! also helps students with test anxiety to build confidence and improve their self-esteem.

4 Teaching Performance Modeling Software

4.1 Traditional Design of Lab Section

Traditionally, lab sessions consist of the lab instructor building simulation models using the ARENA simulation software package, displayed on an overhead projector, with the students following along and building the models simultaneously on their own computers, with the lab instructor stopping to troubleshoot problems as they arise. With this approach, problems seeing the instructor's model on the projector or keeping up with the pace of the lecture are common among the students. From an educational perspective, this time in lab is poorly spent because the students are simply copying the instructor's actions, rather than creatively thinking through each of the necessary decisions that are critical to using simulation. Anecdotally, we have observed significantly less retention of material than expected. Further, we find that many students' software capabilities, particularly as demonstrated on the end-of-quarter team project, do not develop past the first few labs.

4.2 A Pilot Virtual Lab Experiment

In 2010, my colleague, Dr. Theodore T. Allen, (see, Allen and Artis 2010) pilot tested a "virtual lab instruction" approach as a replacement for the traditional classroom lab sections. First, web-based recordings of each weekly lab tutorial were created for students to access via Carmen, the OSU online education system. As the academic quarter progresses, the lab instructor provides links to each weekly lab available on Carmen so that students may go in and access each lab tutorial at any time. The purpose of the web-based lab structure is to allow students to learn at their own pace, with the ability to reflect on what they have learned, to have a more effective lab experience.

The virtual lab was implemented for a few semesters and the learning outcomes of this pilot experiment are presented in Allen (2013). While it was reported that there were not significant losses in student outcomes, two important findings with this approach have also been observed: 1) students' satisfaction rates dropped significantly in comparison with previous traditional lab offerings; 2) the students' knowledge of Arena, particularly as demonstrated in the end-of-quarter team projects, was noticeably lower than in the traditional lab.

We attribute these two findings to a few reasons. First, since each web-based lab is simply an hour-long tutorial with no interaction required or monitoring system in place, students were not properly motivated to do the web-based labs, particularly as the semester progressed and labs become more challenging. The lack of interaction also makes the learning experience frustrating. In addition, the lack of monitoring allows some students to simply skip watching the tutorials, and so they just never learn the material. Thus, in many cases the introduction of the web-based tutorials results in students being exposed to less Arena material than the traditional labs. Such negative impacts on attendance and learning have also been observed in other studies on lecture webcasting (Deal 2007).

4.3 Enhanced, Interactive Web-based Labs

To address the above problems, we developed an enhanced web-based lab framework for the Performance Modeling and Simulation Lab. Our general goal is to continue in the direction of Allen and Artis (2010) by moving the lab sections towards a web-based framework. As previously stated, simply providing web-based versions of the traditional labs is insufficient. More effective methods are needed to engage the learners to a place where they are managing and leading their own learning (Conrad and Donaldson, 2004).

We decide to incorporate within the lab structure the proper motivation for students to work through and complete each of the online lab lessons. Hence, we propose a more complete, interactive web-based framework that not only offers the benefits and conveniences of online lab instruction, but which motivates students to perform the lab activities on a weekly basis.

Interaction-based Lab Lessons

A key aspect of implementing a successful web-based lab framework is to ensure student interaction with each lab tutorial. Based on what we have observed, without this motivation students will simply not follow through with doing each of the labs. A student may do the first few labs, but as the difficulty increases, he/she becomes less inclined to put forth the effort. We combat this by creating several shorter tutorial lessons instead of a single long-form lesson, and we propose two levels of student/software interaction.

1. *Multiple-choice quizzes either at the beginning of or during each lab session*. Questions should be sufficiently detailed so that students may have to go back and review the appropriate section of the tutorial. Later questions may not have been explicitly answered in the tutorial but will require students to creatively build upon what was discussed in the tutorial, likely requiring students to open the Arena software and investigate for themselves.
2. *Weekly Presentations* – Each lab session, students are selected at random to share their computer screens and present the model they created alongside the online lesson. Regardless of the completeness or correctness of the model, this gives the instructor the opportunity to troubleshoot with the student, and to provide further tips and insights into the modeling concepts covered. The instructor then prompts the watching students to ask questions following the "Guided Reciprocal Peer Questioning" approach [19].

By making these quizzes and lab participation a portion of the lab grade, students have the necessary motivation to work through the lab materials. Further, the structure of the quizzes and lab sessions ensures that students can use the material, think through decisions creatively, and are able to ask the correct questions when they find their knowledge incomplete.

The above enhanced, interactive Web-based labs have been adopted for many semesters, with much improved students' satisfactory rates and learning outcomes. The benefits are multi-fold.

- **Improved student retention and understanding.** In the short term, students would directly benefit from more learner-centered instruction. The easily visible, self-paced, and interactive learning activities prompt students to be more engaged and think about the "how" and "why" for simulation events.
- **Significant reduction in operating expense.** Under the traditional approach, the course requires a lab for 3 hours a week for every 30 students (the current maximum lab capacity) creating a potential bottleneck that could inhibit program growth. The web-based interactive lab effectively eliminates the bottleneck by greatly reducing the marginal effect of students on instructional costs.
- **Enable recruiting of distance learning students.** With the web-based framework, this popular introductory course can be a global course offered to learners with access to a computer. This could further lead to growth by interesting students from other distance learning offerings.

4.4 Other Observations

With the introduction of new technology, there are inevitably unforeseen problems that arise. Instructors should encourage frequent, ongoing student feedback to resolve these problems immediately. For example, students without access to a dual monitor computer setup reported difficulty in watching the instructional videos or attending online lab sessions and following along with the software simultaneously. This feedback resulted in the instructor pausing more frequently during live demonstrations to allow students time to switch windows, update their models, and then switch back to the lab session.

During the pandemic, lab sessions of our simulation courses were held online in 2020. Distance teaching of the lab materials that require hands-on experience (e.g., using Arena to build a model) has created some obstacles in efficient communication with students. The use of the technologies provides both instructor and students with ample benefits. We offered synchronous lab sessions, but attendance was not mandatory. The lectures were recorded to the cloud for future view. This flexibility of learning provides students with freedom to adjust their learning pace and accommodate with their own study habit for better results. We also hold extensive office hours to troubleshoot any problems the students encounter.

5 Concluding Remarks

We shared our success stories in teaching Performance Modeling via software and classroom technologies. We demonstrated that by developing live demo via software and spreadsheets simulation, conducting software-enabled polling and Kahoot games in classrooms, it can help **boosting engagement, participation, and motivation** by creating more inclusive, fun, competitive, game-based learning experiences when teaching performance modeling. We also presented our exploratory pilot project in teaching software in our lab sections by using an Interactive Web-based videos integrated with a blended learning model. We hope that our method and experiences on teaching performance modeling using software and digital technologies can be leveraged by other PM educators in the field.

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