Teaching Performance Modeling via Software and Instructional Technology

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Joint work with **Nanshan Chen, Priya Natarajan**

Outline

- PM Courses at OSU
- Instructional Technology in Lectures
- Teaching PM Software in Lab (Priya and Nanshan)

Performance Modeling (PM) Education

- PM education is part of the curriculum of many CS/OR Depts around the world
  - A comprehensive survey on PM courses last decade: **de Nitto (WEPPE 2017)**
  - Lessons on teaching analytical PM: **Tay (ICPE 2019)**

- New challenges for teaching PM today
  - Incorporate new topics: AI/ML, Big Data, Cyber physical systems, Information/Economic/Health crisis
  - **Embrace the proliferation of digital technologies in teaching/learning**

Performance Modeling Courses at OSU

- Undergraduate PM course:
  - ISE4100: Stochastic Modeling and Simulation
  - 4 credit units

- Graduate PM courses
  - ISE6300: Simulation for System Analytics and Decision-Making
  - ISE7300: Stochastic Processes
  - Both 3 credit units

Course Objectives (Undergraduate course)

Expected Learning Outcomes

- understand the roles of PM and simulation play in improving existing systems and building new ones
- learn how to model uncertainty in real-world systems
- learn the basics of M/M/c queues and and know the benefits of queueing theory
- know how to implement simulations in both EXCEL and ARENA and offer solutions to customers.
- know how to apply simulation output analysis to get insights over many alternative solutions.
- complete a **projec**t: use simulation to analyze a system, competently apply model building, analysis, explore alternatives and make better decisions

Classroom Technologies for Teaching PM

- Live Demo
- In-class Polling
- Kahoot! Games

Live Demo in Teaching PM

Live demo can be powerful in teaching PM

- uncertainty modeling, Monte Carlo simulation via spreadsheets

- queueing concepts, performance modeling, and discrete-event simulation via software (Arena)

Live Demo via Spreadsheets Simulation

- **Spreadsheet simulation**: using spreadsheets to build simulation models, perform simulation live, and report results.

- **Example 1**: Help Rupert Sell Newspaper
  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.

Question: How many newspapers should he buy?

Common Pitfall: planning via average

- The average demand for newspapers is 2000.
- Suppose Rupert plans for the average case and buy 2000 newspapers
- You might expect his profit as follows:

Quantity to order		2000
Price buy	$ 0.80	
Investment	$ 1,600	
Expected Demand		2000
Price sale	$ 1.00	
Sales		2000
Revenue	$ 2,000	
Profit	$ 400	

- <u>Question</u>: Is $400 a reasonable estimate of the profit we might expect?

Let's Help Rupert Simulate

Generate Random Demand:

- Trial by Random Draw on input D~ DiscreteUniform(1500,2500),
- Collect the corresponding profit
  - ➢ P = 1*min(D, 2000) – 0.8*2000

Spreadsheet Simulation: Help Rupert sell Newspaper

Order Quantity: 2000 *Order Price: $0.80*

Demand ~ U(1500, 2500) *Sale Price: $1.00*

Run	Demand *(input RV)*	Sales	Revenue	Profit *(Output RV)*
	=RANDBETWEEN(1500,2500)	*=MIN(B6,2000)*	*=C6*1*	*=D6-2000*0.8*
1	1560	1560	$1,560	-$40
2	2264	2000	$2,000	$400
3	2214	2000	$2,000	$400

Let's Help Rupert Simulate (cont)

Repeat many trials, & conduct statistical analysis on outputs

<u>Experiment:</u>

Simulate 100 days of demand/sales

<u>Input RV:</u>

D ~U(1500,2500)

<u>Output RV:</u>

P = min{D,2000}*$1 – 2000*$0.8

<u>Output Analysis</u>:

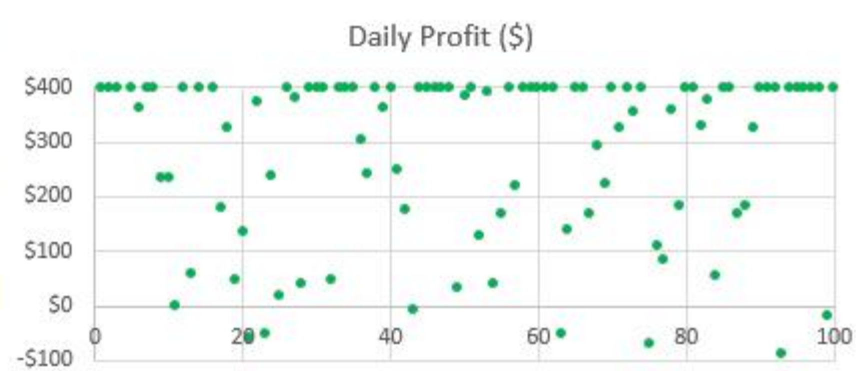
mean profit = $283

sample stdev = 158

95% CI = ($252, $314)

	A	B	C	D	E
1	Spreadsheet Simulation: Help Rupert sell Newspaper				
2		*Order Quantity: 2000*	*Order Price: $0.80*		
3		*Demand ~ U(1500, 2500)*	*Sale Price: $1.00*		
4	**Run**	**Demand**	**Sales**	**Revenue**	**Profit**
5		*(input RV)*			*(Output RV)*
6		*=RANDBETWEEN(1500,2500)*	*=MIN(B6,2000)*	*=C6*1*	*=D6-2000*0.8*
7	1	2333	2000	$2,000	$400
8	2	2206	2000	$2,000	$400
9	3	2373	2000	$2,000	$400
106	100	1995	1995	$1,995	$395
107	Expected Demand			2000	
108	*(Profit based on Expected Demand)*			*$400.00*	
109	Sample Mean Demand			2018	*=AVERAGE(B7:B106)*
110	*(Profit based on Sample Mean Demand)*			*$400.00*	*=MIN(D109,2000)-2000*0.8*
111	**Sample Mean Profit**			**$282.62**	*=AVERAGE(E7:E106)*
112	**Profit Sample Std Dev**			**$157.80**	*=STDEV.S(E7:E106)*
113	**95% C.I. for Mean Profit**		**$251.69**	**$313.55**	*=D111 ± CONFIDENCE.NORM(0.05,D112,100)*

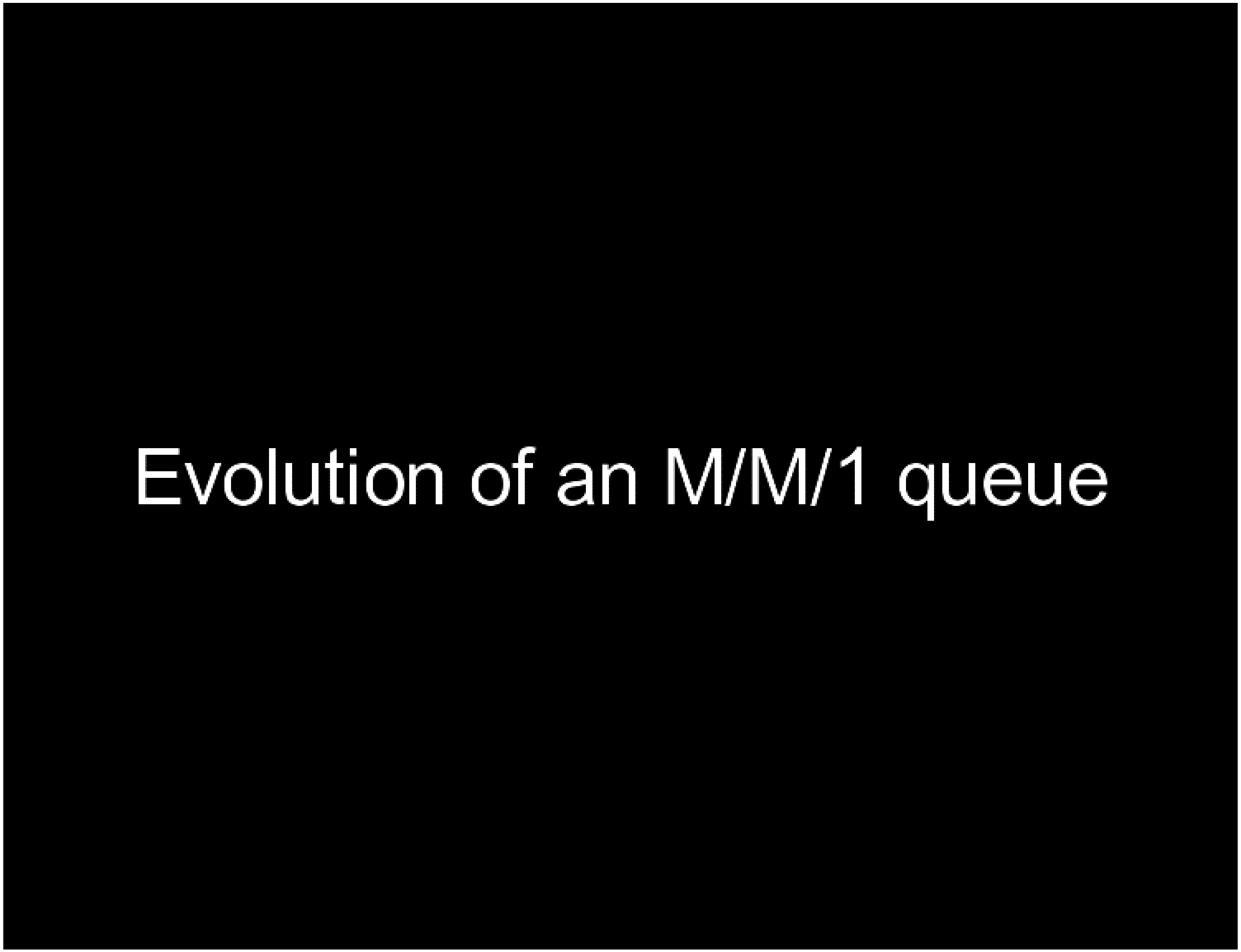
Generate New Sample



Live Demo via Spreadsheets

- Random number generation is easy
  - "Live" function – every time any cell changes in the worksheet, a new sample is produced
- Random draws from various *distributions*, collects corresponding (random) outputs instantly
- Monte Carlo does not yield "the right answer"!
  - Produces a collection of output results and involves **statistical estimation** for the metric of interest
  - All estimates (mean, stdev, C.I.) are random variables
  - Central Limit Theorem: convergence when many random draws simulated

Live Demo of Queueing Systems (via Simulation Software)



Benefits of Live Demo

- view the technology-supported practices “in action”, helps students to engage and take a more active role in learning
- allow the instructor to direct attention to the most important features (e.g., by demo in slow motion)
- empower the students to “think on the spot” and identify useful strategies to improve the system performance

In-Class Polling

- Can be conducted effectively via classroom technology
  - Instructor pose a question to the class
  - Students respond simply a click away
  - Students' responses and statistics tabulated and displayed instantly

- Benefits
  - Engage students and broaden participation
  - Anonymity makes students more comfortable to participate
  - Instant feedback makes the learning more effective
  - Instant feedback enables instructor a quick assessment

Teaching Little's Law via Polling

- ***<u>Example 2</u>***: 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?

- **<u>In-class Polling scenarios</u>**:
  - Conduct an initial poll, asking the students to use their common sense to answer the question
  - Open discussions, have students explain their reasons
  - Teach Little's Law, present a systematic way to derive solution
  - Conduct another in-class exercise using polling

Kahoot! Games

- Gamification: one of the most effective teaching method
  - Create a more enjoyable and engaging learning experience (Vlachopoulos and Makri 2017)

- Kahoot! Games: a popular game-based learning platform
  - 70 million active users monthly (Wang and Tahir 2020)
  - Instructor create a quiz and have users play/compete in a gamified setting
  - Anonymity option allows a quick review of students' knowledge
  - Can be used for formative assessment or as a break from traditional classroom activities
  - Fast and efficient grading
  - More engaging and fun than standard test on paper

Kahoot! Games

<u>Example 3:</u> Teaching Poisson Processes via Kahoot!

- Knowledge point:
  - *"Inter-arrival times of a Poisson process with rate l are i.i.d. exponentially distributed random variables with mean 1/l".*

- Focus on important concepts and common pitfalls

Tips on Question Design

- Must carefully think through the learning goals, questions, and answers (Graham, 2015)

- Tips to design high-quality multiple-choice quiz questions (Terada 2018)
  - Don’t list too many answers;
  - Avoid trick questions;
  - Use simple question formats;
  - Make it challenging, but not too difficult; and
  - Follow up with feedback.

Let’s Kahoot!

Scan the QR code below or type
https://kahoot.it
into your browser to play Kahoot!

Link to game

Lab Sessions

- Covers the use of PM software Arena Simulation, by Rockwell Automation and companion tools
  - Arena Input Analyzer
  - Arena Output Analyzer
  - Arena Process Analyzer
- Lab is conducted by TA’s
  - ISE 4100 (undergrad): Priya Natarajan
  - ISE 6300 (grad): Nanshan Chen

Current Lab Structure

- Lab sessions are 1 hour per week
  - Review statistical concepts
  - Cover the software basics
  - Provide help with homework / exam review
- Software is taught via follow-along-demonstration, homework lab assignments, lab-related questions on exams
- Troubleshooting is performed live and serves as an additional teaching method
- Videos of key concepts are recorded, typically 10 – 20 minutes in length.

Remote Lab Structure

- Students express challenges following along with live demonstrations due to limited monitor space
- Demonstrations are prerecorded, students watch on their own time and can pause when needed
- Scheduled lab time is reserved for guided peer-to-peer learning
  - Students are selected at random to present their models regardless of completeness or correctness. No points deducted for incorrect models
  - Troubleshooting is performed live and serves as an additional teaching method

Insights & Best Lab Practices

- Fully remote learning not ideal for lab sessions
  - Difficult to view video conferencing and simulation software simultaneously
  - Students less likely to interrupt and ask questions
  - Instructor loses non-verbal feedback from students
- Possible for students can learn the software via demonstration on their own time
- In-person time is best reserved for troubleshooting and covering in-depth concepts
- Videos are best helpful when shorter and cover fewer concepts
- Accountability via randomized student presentation of modeling helps students learn-through-teaching

Lab for Graduate PM Course (Nanshan)

- Lab is more than learning the operation of Arena.
- **Applying** knowledge learned in class.
- Ability to **build** model and **understand** the math/stat behind it is more important.

- Components of the lab
  - Review concepts and theories learned in class (slides)
  - Introduce the new aspects/features/approaches in Arena (screenshare)
  - Learn through examples: electronic assembly system, call center system, inventory system, etc. (screenshare)
  - Q & A
  - Lab will also be used as homework review before midterm/final

Concluding Remarks

- Technology is a good supplement for teaching PM
- Live demos can help teach important statistical concepts
- Kahoot! games are fun and more engaging
- Simulation software applies statistical concepts and clarifies the input-output transformation
- However, technology cannot completely replace traditional approaches
  - Key concepts & step-step reasoning best explained via lectures
  - Visual cues provide instant student-instructor feedback

Questions?


thank you
danke
謝謝
ngiyabonga
teşekkür ederim
gracias
merci
obrigado
bedankt
dziękuję
sukriya
kop khun krap
go raibh maith agat
mochchakkeram
tapadh leat
terima kasih
arigatô
dakujem
grazie
takk
taiku
спасибо
Баярлалаа
рахмат
мерси
хвала
dank je
hvala
maururu
sagolun
감사합니다
ありがとう
ευχαριστώ
mersi
barka
welalin
tack
spas
kia ora
faafetai lava
vinaka
blagodaram
misaotra
matondo
paldies
grazzi
mahalo
kiitos
dankie
dhanyavad
nanni
nandri
bayarlalaa
gracie
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tanemirt
diolch
dhanyavadagalu
shukriya
trugarez
djiere dieuf
tau
mamnun
asante
manana
obrigada
tenki
murakoze
chokrane
xiexie
спасибі
дякую

Little’s Law

The Conservation Equation – Little's Law

- Conservation equation (a.k.a. Little's law)

$$\hat{L} = \hat{\lambda}\hat{w}$$

Average # in system ($\hat{L}$); Arrival rate ($\hat{\lambda}$); Average System time ($\hat{w}$)

$$L = \lambda w \quad \text{as} \quad T \to \infty \ \text{and} \ N \to \infty$$

- Holds for almost all queueing systems or subsystems (regardless of the number of servers, the queue discipline, or other special circumstances).
- *G/G/1/N/K* example (cont.): On average, one arrival every *4* time units and each arrival spends *4.6* time units in the system. Hence, at an arbitrary point in time, there is *(1/4)(4.6) = 1.15* customers present on average.