AN ENGINEER'S PERSPECTIVE ON HOW TO IMPROVE HEALTHCARE DELIVERY

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AUGUST 3, 2019

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MY BACKGROUND

- Undergraduate degree in applied math (but did an honors thesis on a healthcare application)
- Six years in the trucking industry (actually related to healthcare delivery…)
- PhD in aviation planning (even *more* related to healthcare delivery!)
- Almost 20 years at UM on the faculty in Department of Industrial and Operations Engineering
- Transition from freight and passenger transportation to healthcare
- Inaugural Associate Director of Center for Healthcare Engineering and Patient Safety

CHEPS

CHEPS

Rx

A prescription to address system complexity in healthcare

INNOVATING HEALTHCARE DELIVERY

FOSTERING LEARNING

BUILDING COMMUNITY

POSITIVE IMPACT THROUGH...

Research
Education
Implementation
Outreach
Dissemination

CHEPS: OUR MISSION

FOSTER LEARNING

Providing experiential learning opportunities for students, faculty, and practitioners from across the campus and beyond

INNOVATE HEALTHCARE DELIVERY

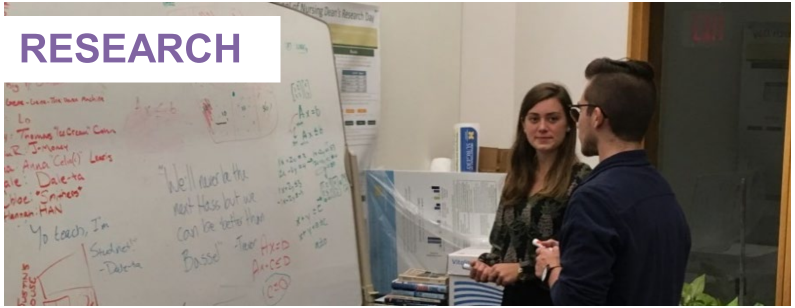
Bringing together teams from across a wide spectrum of disciplines to make an impact by solving complex real-world healthcare problems

BUILD COMMUNITY

Nurturing a vibrant and diverse community of individuals working, learning, and having fun together

CHEPS: HOW WE DO IT

RESEARCH

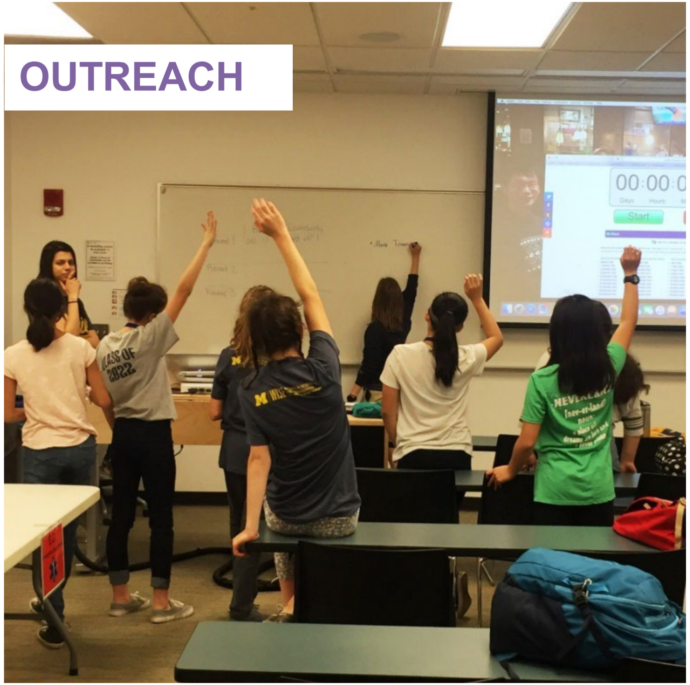


EDUCATION

IMPLEMENTATION

CHEPS: HOW WE DO IT

OUTREACH



DISSEMINATION

COMMERCIAL BREAK

- Shameless plug for undergrad (and other) research assistants
- Praise for Erkin Otles and his contributions to the research of newly-minted PhD Emily Boltey, School of Nursing

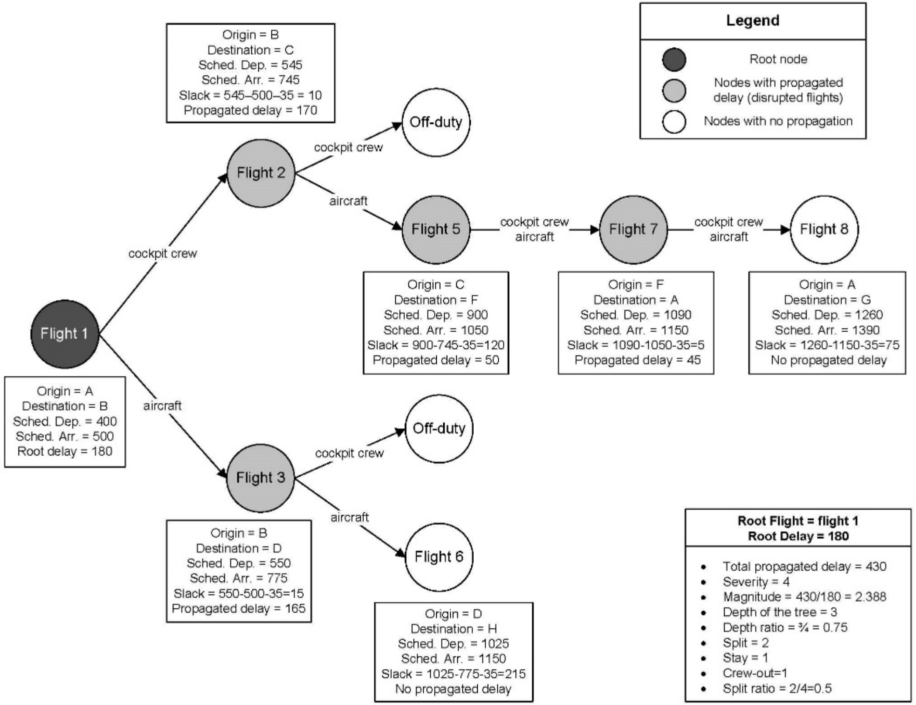
EXAMPLE OF A COMPLEX SYSTEM: PASSENGER AVIATION

- **Propagation of flight delays:**
  - Flight from BOS to DTW is delayed due to weather. This causes…
  - …flight from DTW to LAX to be delayed, due to unavailable cockpit crew
  - …flight from DTW to ORD to be delayed, due to unavailable aircraft
  - …flight from DTW to SEA to be delayed, due to unavailable cabin crew

EXAMPLE OF A COMPLEX SYSTEM: PASSENGER AVIATION

- **Propagation of flight delays:**
  - In turn, the delayed DTW to LAX flight causes more downstream flights due to unavailable aircraft and cockpit and cabin crews…
  - …and lots of other flights to be delayed due to blocked gates!

EXAMPLE OF A COMPLEX SYSTEM: PASSENGER AVIATION



PASSENGER AVIATION -> CHEMOTHERAPY INFUSION

- A patient scheduled to have an outpatient chemotherapy infusion goes through phlebotomy, the lab, the clinic, the pharmacy, and the infusion center
- If phlebotomy is backed up, patient's labs are resulted late, clinic visit is delayed, delaying pharmacy order, delaying drug prep, delaying infusion visit

PASSENGER AVIATION -> CHEMOTHERAPY INFUSION

- The clinic delay makes the oncologist late for her next patient (and the patient after that and the patient after that…)
- This patient is then delayed for radiation treatment (and thus the radiation patient after that and the patient after that…)

PASSENGER AVIATION -> CHEMOTHERAPY INFUSION

- **Both scenarios have similar changes:**
  - Significant sources of delay and variability
  - Shared resources across a time and space network
  - Potential for propagation of delays
- **The same mathematical models that represent this network-wide propagating delay effects in aviation are relevant for patient scheduling … and the resulting recommendations take a very similar form!**

EXAMPLE OF A COMPLEX SYSTEM: FREIGHT TRANSPORTATION NETWORK DESIGN

- My new pair of running shoes shipped from Seattle to Ann Arbor
- Too expensive to transport just my Aasics (cost of a driver + fuel + tolls + amortization of the vehicle) – need to pool with other freight to share this cost
- What if there isn't enough freight going from Seattle to Ann Arbor?
- Consolidation networks: Warehouses throughout the country to reconfigure loads (like hub airports)

EXAMPLE OF A COMPLEX SYSTEM: FREIGHT TRANSPORTATION NETWORK DESIGN

- **Key design questions:**
  - Where to build consolidation centers
  - What packages to assign to what CCs

FREIGHT TRANSPORTATION NETWORK DESIGN -> SCREENING VETERANS FOR DIABETIC RETINOPATHY

- Veterans have a higher risk for diabetes than the general population
- This in turn puts them at a higher risk for diabetic retinopathy and other eye diseases
- Screening is critical to identify eye disease before (permanent) symptoms develop
- Many veterans live in rural areas, limited access to ophthalmologists

FREIGHT TRANSPORTATION NETWORK DESIGN -> SCREENING VETERANS FOR DIABETIC RETINOPATHY

- Preliminary research shows that initial screening by a specialized technician, followed up by image reading by an off-site ophthalmologist, can be a successful screening substitute
- Given a finite budget, a set of patients ("packages"), and their home addresses, where should we build screening clinics and who should be assigned to which clinic?
- Network design!

ANOTHER EXAMPLE: ED OVERCROWDING

Many emergency departments are experiencing significant overcrowding

- Long waits to be seen
- Patients on stretchers in hallways

What operational changes might help improve this?

Obvious guesses:

ANOTHER EXAMPLE: ED OVERCROWDING

Many emergency departments are experiencing significant overcrowding

- Long waits to be seen
- Patients on stretchers in hallways

What operational changes might help improve this?

Obvious guesses:

- More ED doctors
- More ED nurses
- More ED rooms/beds

ANOTHER EXAMPLE: ED OVERCROWDING

Less obvious guesses:

- Better inpatient discharge processes
- Improved processes in radiology
- More social workers
- Improved transportation infrastructure

HOW DOES CHEPS HELP TO IMPROVE SUCH COMPLEX SYSTEMS?

- **Patient flow issues**
  - Glaucoma clinic
  - Outpatient infusion
  - Asthma and the pediatric ED
- **Access issues**
  - Eye screening in the VA
  - Aortic dissection transfers and the cardiac ICU
  - Colonoscopy appointment scheduling

WHAT TYPE OF WORK DO WE DO AT CHEPS?

- **Provider scheduling**
  - Block scheduling
  - Trauma attending call scheduling
  - Jeopardy and Nights
  - Peds ED shift scheduling

WRAPPING UP: WHY SHOULD YOU CARE?

- **A.k.a. "What I hoped you've learned":**
  - It's about the *whole* patient experience (and family experience and provider experience)
  - You don't have to be an expert in everything (in fact, you can't be)
  - Recognize and value expertise in others (not just in medicine but outside as well, e.g. engineers); know what exists outside your own skillset and where to go for support
  - Collaboration, mutual respect, and joy are critical to success!

DISCUSSION

"The Team, The Team, The Team"

HOW DO I DEFINE CARE DELIVERY

- **Obvious**
  - Diagnosis
  - Treatment planning
  - Treatment delivery

HOW DO I DEFINE CARE DELIVERY

- **Obvious**
  - Diagnosis
  - Treatment planning
  - Treatment delivery
- **Less obvious but still important: holistic patient (and care giver… and provider!) needs**
  - Financial stressors
  - Support system (patients receiving support…and *providing* support)
  - Patient preferences and priorities
  - Broadening the definition of personalized medicine/precision health

TRADE-OFFS

- "Patient vs profit"
- Patient vs patient
- Patient vs self
- …nothing exists in a vacuum
- …every aspect of patient care impacts a large and complex system

WHAT IS MEDICAL RESIDENCY?

Transition period between medical school and fully independent/unsupervised practice

- Four years of med school
- First year of residency – “Intern”
- Two or more years of residency
- Possibly one or two additional years as “Chief Resident”
- Possibly more years as a “Fellow”

During all of this time, providing patient care (albeit with the oversight of a more senior “attending” physician – supervision decreases over time)

WHAT IS MEDICAL RESIDENCY?

A key issue: Dual role of residency

- Learning experience: Residency (and Fellowship) are parts of the medical education training process
- Patient care: Residents/Fellows provide a significant amount of the patient care in teaching hospitals and the associated clinical system

A typical resident might engage in all of the following activities:

- "Continuity clinics"
- Shifts on service
- Seminars, formal educational activities
- Research

INHERENT TIME CONFLICTS

How to schedule residents' time

- Need adequate patient coverage with a limited pool of residents
- Need adequate training opportunities
- Need adequate rest – fatigue increases risk of error
- Need to address resident satisfaction, personal life

Not just quantity of hours but pattern

- Continuity of care
- Sleep issues (especially associated with overnight shifts)
- Opportunities for different medical experiences

ED SHIFT SCHEDULING

- Assigning residents to shifts at the pediatric emergency department
- Monthly schedules
- Heterogeneous workforce (different levels, different programs)
- Resident-specific needs (education; personal)
- Program-specific needs (patient care)

WHY IS THIS HARD?

	6		1		4		5	
		8	3		5	6		
2								1
8			4		7			6
		6				3		
7			9		1			4
5								2
		7	2		6	9		
	4		5		8		7	

The more squares you fill in, the fewer choices you have left for what is valid

Once you make a mistake, you might not know it for a long time

Once you realize something is wrong, it can be very hard to back track and correct

HOW SHIFT SCHEDULES ARE TYPICALLY BUILT

- Schedules typically built by Chief Residents
- Limited decision support
- No formal training
- Hard to satisfy all rules
- Unlikely to make everyone happy

OPTIMIZATION PROBLEMS

- *Optimization* is the use of mathematical models and algorithms to make the best possible decisions in a complex, important, quantitative (and deterministic) situation.
- The *model* provides a mathematical representation of the set of feasible choices (*solutions*).
- The *algorithm* provides a means for evaluating these feasible solutions and selecting the best one.

OPTIMIZATION PROBLEMS

An optimization problem is defined by:

A set of decisions to be made

A well-defined set of candidate choices for each decision

Clearly-defined rules governing which combinations of decisions are feasible

A metric that allows us to compute and compare the values of different sets of decisions

FORMULATIONS / MODELS

***Formulation* or *model* – mathematical representation of an optimization problem**

- Decisions => variables
  - Each decision should be thought of as a question that can be answered by a single number
- Goal => objective function
- Rules => constraints
- "Parameters" are the input data that is given to you

ASSIGNING RESEARCH PROJECTS

I have 5 graduate students to advise, and 5 research projects I'm involved in. Based on interest, ability, etc., I can determine a value v_{sp} to assigning student s to project p. How can I maximize the overall value of my research group?

ASSIGNING RESEARCH PROJECTS

Maximize the value of the assignments

Subject to:

Every student is assigned one project

Every project is assigned one student

Does student s get assigned to project p, yes or no?

ASSIGNING RESEARCH PROJECTS

Max

$v_{11}\ x_{11} + v_{12}\ x_{12} + \ldots\ v_{15}\ x_{15} +$

$v_{21}\ x_{21} + v_{22}\ x_{22} + \ldots\ v_{25}\ x_{25} +$

…

$v_{51}\ x_{51} + v_{52}\ x_{52} + \ldots\ v_{55}\ x_{55} +$

St

$x_{11} + x_{12} + \ldots\ x_{15} = 1$

$x_{21} + x_{22} + \ldots\ x_{25} = 1$

…

$x_{51} + x_{52} + \ldots\ x_{55} = 1$

$x_{11} + x_{21} + \ldots\ x_{51} = 1$

$x_{12} + x_{22} + \ldots\ x_{52} = 1$

…

$x_{15} + x_{25} + \ldots\ x_{55} = 1$

All variables restricted to be either 0 or 1

SHIFT SCHEDULING AS AN OPTIMIZATION PROBLEM

How do we formulate the rules?

- Every shift needs a resident
- Every resident needs between 12 and 16 shifts
- Every resident needs between 2 and 5 night shifts
- Interns cannot work the first or last shift of the day
- Every resident has a day-of-week they cannot work

SHIFT SCHEDULING AS AN OPTIMIZATION PROBLEM

Every shift needs a resident:

SHIFT SCHEDULING AS AN OPTIMIZATION PROBLEM

Every shift needs a resident:

- For each shift, we will have a separate constraint
- The constraint states that, across all residents, exactly one must be chosen

SHIFT SCHEDULING AS AN OPTIMIZATION PROBLEM

Every resident needs between 12 and 16 shifts:

SHIFT SCHEDULING AS AN OPTIMIZATION PROBLEM

Every resident needs between 12 and 16 shifts:

- For each resident, we will have a separate constraint
- This constraint will sum all of the shifts assigned to that resident and constrain this sum to be between 12 and 16

SHIFT SCHEDULING AS AN OPTIMIZATION PROBLEM

Every resident needs between 2 and 5 night shifts:

SHIFT SCHEDULING AS AN OPTIMIZATION PROBLEM

Every resident needs between 2 and 5 night shifts:

- For each resident, we will have a separate constraint
- This constraint will sum all of the shifts *that are classified as night shifts* assigned to that resident and constrain this sum to be between 2 and 5

SHIFT SCHEDULING AS AN OPTIMIZATION PROBLEM

Interns cannot work the first or last shift of the day:

SHIFT SCHEDULING AS AN OPTIMIZATION PROBLEM

Interns cannot work the first or last shift of the day:

- For each of these shifts, the decision variable is automatically set to “No”

SHIFT SCHEDULING AS AN OPTIMIZATION PROBLEM

Every resident has a day-of-week they cannot work:

SHIFT SCHEDULING AS AN OPTIMIZATION PROBLEM

Every resident has a day-of-week they cannot work:

- For each invalid assignment, automatically set the variable to “No”