Using Industrial Engineering and Other Tools to Improve Healthcare: Two Case Studies

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Background

• Undergrad in applied math
• 5 years in freight transportation consulting
• PhD in Operations Research – aviation applications
• 11+ years at U of Michigan in IOE Department
  – Focus on applied combinatorial optimization
  – Applications in aviation, freight transportation, manufacturing, energy, aerospace – and progressively more and more healthcare
  – Center for Healthcare Engineering and Patient Safety
Motivation

- 17% of US GDP
Motivation

- Personal costs are rising rapidly
Motivation

International Comparison of Spending on Health, 1980–2008

Average spending on health per capita ($US PPP)

Total expenditures on health as percent of GDP

Source: OECD Health Data 2010 (Oct. 2010).
Motivation

- Quality trailing all other developed nation
Motivation

• Lots of areas where the US excels in healthcare...
• ...but they are also driving up costs!
• The current system is failing
  – Long waits for care in many cases
  – Lots of errors, unintended harm
  – Inequities in care
  – Unsustainable cost growth
IOM Goals

• 2005 seminal report issued jointly by IOM and NAE:

• Six major goals for the U.S. healthcare system:
  – Safe
  – Effective
  – Timely
  – Patient-centered
  – Efficient
  – Equitable

• Importance of “a vigorous new partnership” between engineering and healthcare to overcome the challenges that prevent us from reaching these goals
OR/MS Opportunities for Impact

• Why is this partnership important?
  – Systems perspective
  – OR/MS ability to translate complex real-world problems into mathematical models that can be analyzed and optimized
  – Use of data to drive decisions

• Decision making may be as critical to care as devices or drugs, but data does not automatically translate to good decisions

• How do we improve the quality of decision making in medicine?
Really Interesting OR Problems

• Merging large amounts of population data with very limited patient-specific data
  – Prediction
  – Classification

• Planning for expensive, capacity-constrained resources with planned and emergent demand streams

• Optimization under ill-defined objective functions
But the OR is the easy part

• The hardest challenges in healthcare are not mathematical
  – Communication
  – Culture
  – Competing objective criteria
  – Competing decision makers/constituents
  – Autonomous decision makers
  – Understanding the briar patch of healthcare finance
My Selfish Goals

• Find projects that are going to have short-term healthcare impact, be satisfying from a “societal” standpoint
  – Undergrads, masters
• Find projects that are going to have long-term mathematical impact, be satisfying from a “geek” standpoint
  – PhD students
Transplant Surgery Training: Merging Scheduled Shifts with Random Surgical Opportunities
Acknowledgements

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• Professor Mark Daskin, Professor Jacob Seagull
• Dr. Rishi Reddy, Dr. Andrea Obi, Dr. Jennifer Chung
• SURE summer team
Motivation for Computer Simulation

• Cardio thoracic surgeons don’t always think about probability the way engineers do
• Policy makers limiting work hours don’t always think about probability the way engineers do
• Policy makers setting training certification levels don’t always think about probability the way engineers do
• We are failing to adequately train transplant surgeons in a timely manner – may lead to shortage of surgeons very soon – conflict between ACGME and UNOS
Motivating question:

- If you have, on average, 40 transplants per year...
- If you have four residents...
- If each resident is on call every fourth night...
- What is the probability that each resident gets 10 transplants over the course of the year?
• Motivating question:
  – If you have, on average, 40 transplants per year...
  – If you have four residents...
  – If each resident is on call every fourth night...
  – What is the probability that each resident gets 10 transplants over the course of the year?
  – Hint: It’s not 1!
Description of Computer Simulation

• A way to demonstrate these probabilistic issues to people not used to thinking about probability
• A way to analyze policy questions
• A way to evaluate alternative scheduling paradigms
Demo
Key Take-Aways

• Language is important ... for both sides! (“stochastic”, “mediastenoscopy”)
• Educating our partners is important
• Potential for policy impact as well as operations
• A little technical skill can go a long way
• Ground work for bigger, more “interesting” problems
Scheduling Pediatric Emergency Medicine Residents at UMHS
Acknowledgements

• Ongoing collaboration with many talented contributors
  – Fall 2013 Team
    • UMHS Chief Resident: Dr. Jenny Zank
    • Students: Young-Chae Hong, Elizabeth Perelstein, Zak VerShure, Ishan Mukherjee, Tomas Molfino
  – Winter 2013 Team
    • UMHS Chief Resident: Dr. Micah Long
    • Students: Young-Chae Hong, Ariella Rose, Elizabeth Perelstein
  – Fall 2012 Team
    • UMHS Chief Resident: Dr. Micah Long
    • Students: Young-Chae Hong, Mindy Alberty
  – Spring/Summer 2012 Team
    • UMHS Chief Resident: Dr. Micah Long
    • Students: Young-Chae Hong, Boying Liu, Tara Lynn O’Gara, Mindy Alberty
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 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
What is the general problem?

• Given a set of residents to be trained and a set of shifts to be covered, build a schedule that satisfies all patient care, educational, and other requirements
What is our specific problem?

• Assigning residents to shifts to cover the pediatric emergency department in Mott Children’s Hospital at UMHS

• Eight overlapping shifts per day

• Month-long schedule (but conflicting *switch dates* depending on the resident)

• Approximately 15 residents per month, coming from four or five different residency programs
What are the rules?

- Patient care requirements:
  - 8 overlapping shifts every day of the month
  - Every shift has to have exactly one resident assigned
  - Exceptions: 10a – 7p and 12p – 9p shift coverage is optional
    - Not all of these shifts can be left uncovered for the entire month
    - Ideally one of the two “flex shifts” should be covered each day
  - Certain shifts cannot be assigned to an intern
  - Certain overlapping pairs of shifts require a Peds resident on at least one of the two shifts
  - ...

What are the rules?

- Resident availability
  - Senior residents switch on the first of the month
  - Interns switch on the 27th of the preceding month
  - Pre-assigned vacation time must be respected
  - Continuity clinics/post CC
  - Some shifts are pre-assigned to certain residents/key programs
  - 10-hour rule
  - First and last shifts must recognize boundaries of other rotations
  - ...
What was the current state?

- Schedules typically built by Chief Residents
- Limited decision support
- No formal training
- Hard to satisfy all rules
- Unlikely to make everyone happy
Why is it hard to schedule manually?

- 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
- If a requirement changes, you have to start from scratch
Why is it getting even harder?

• Number of residents is set and fixed externally (i.e. a program can’t independently increase the number of residents to increase staffing)
• ACGME (American College of Graduate Medical Education) limits the amount of duty hours, patterns and frequency of time off, etc.
  • Have made some major increase to limitations in the past
  • Current talk about further tightening of restrictions
• This means there is not a lot of slack in the system, and it’s likely to get worse
How do we solve it?

• Mixed integer programming approach
  – $x_{rsd} = 1$ if resident $r$ is assigned to shift $s$ on day $d$, else $0$
• Feasibility constraints are straightforward to model
• Run time using C++ and CPLEX on a standard PC is minimal (a few seconds at most)
• Finding a schedule that satisfies the rules is already progress over what exists (especially given time required)
• But not all feasible schedules are equally good
How to “optimize”?

• No one clear objective function, but many important metrics
  – Equity across residents
    • Number of shifts
    • Number of night shifts
    • General quality of schedule
  – “Bad sleep patterns”
  – Personal requests
  – Post-continuity clinic calls
  – Flex shift coverage
  – Transition shift coverage
How to “optimize”?

- We could treat this as a multi-criteria objective function, assign weights to normalize, and solve
  - Weights are hard to find
  - Convergence can slow dramatically
- Is “optimal” the right goal???
  - Is this an engineering construct that we’re imposing inappropriately?
How to “optimize”? 

• Our approach: 
  – Set boundaries on the metrics 
  – Define as hard constraints 
  – Search for a feasible solution 
    • If found, review and decide what to tighten next 
    • If not found, loosen the boundaries 
  – Repeat until satisfied
How is it working?

• Remarkably well!
• Schedule is of higher quality than manual schedules (dramatically)
• Chief Resident time requirement is much decreased
• “Buffer” to allocations of favoritism
• Ability to smoothly and quickly recover from data errors and last-minute changes
• “Unbelievable – this was literally a life saver. Amazing job – I’m very thankful.”
Where do we go next?

• Research
  – When infeasible, why?
  – More complex sleep patterns, cross-resident requirements/request, cross-day requirements/requests
  – Generalization

• Practice
  – Make operational/sustainable/affordable for Peds Emergency Medicine at UM
  – Expand to other programs’ Peds Emergency Medicine service
  – Expand to other Peds services (e.g. NICU scheduling)
  – Expand to other fields of residency (e.g. psych, surgery...)

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Questions and Discussion