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

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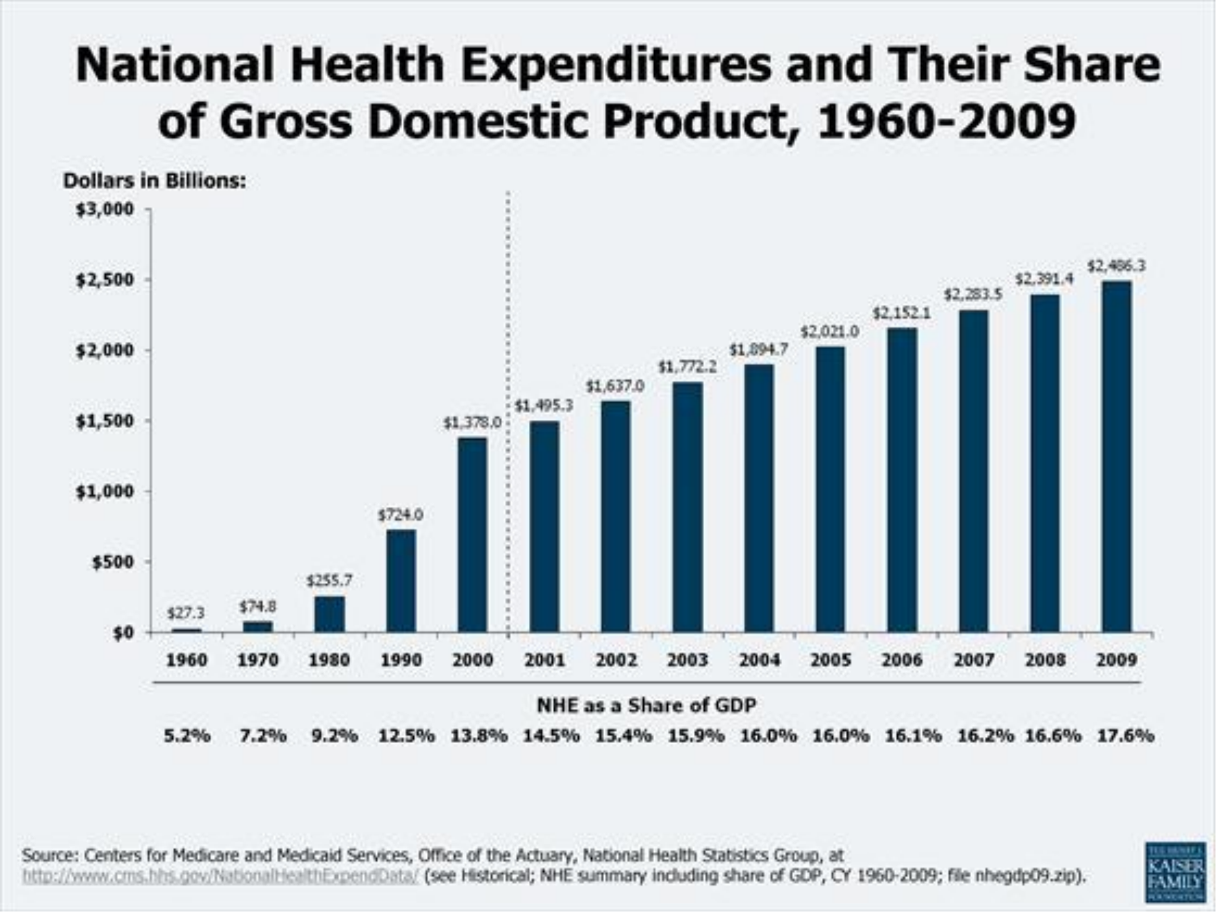
CHEPS Center for Healthcare Engineering & Patient Safety

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



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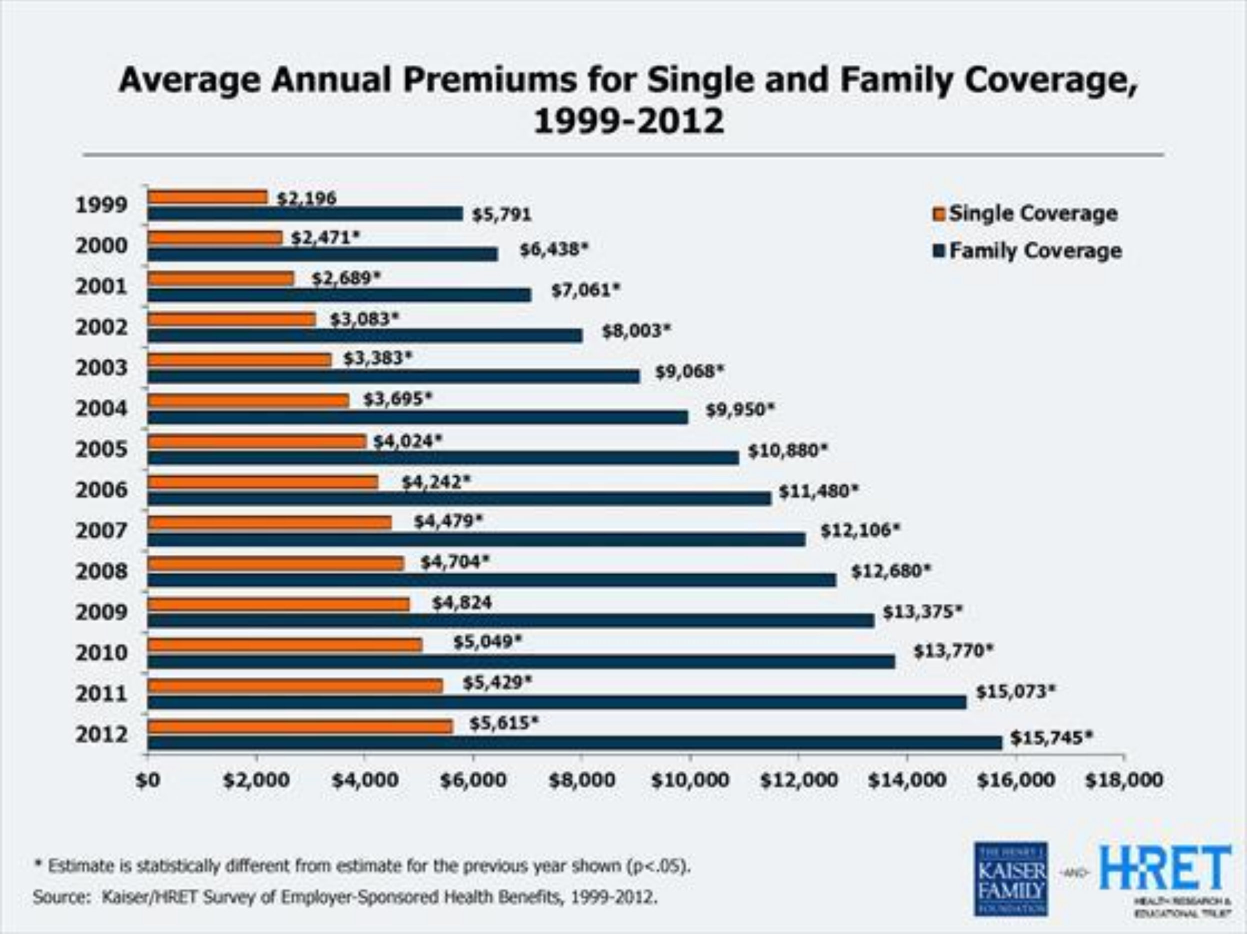
Motivation

- Personal costs are rising rapidly



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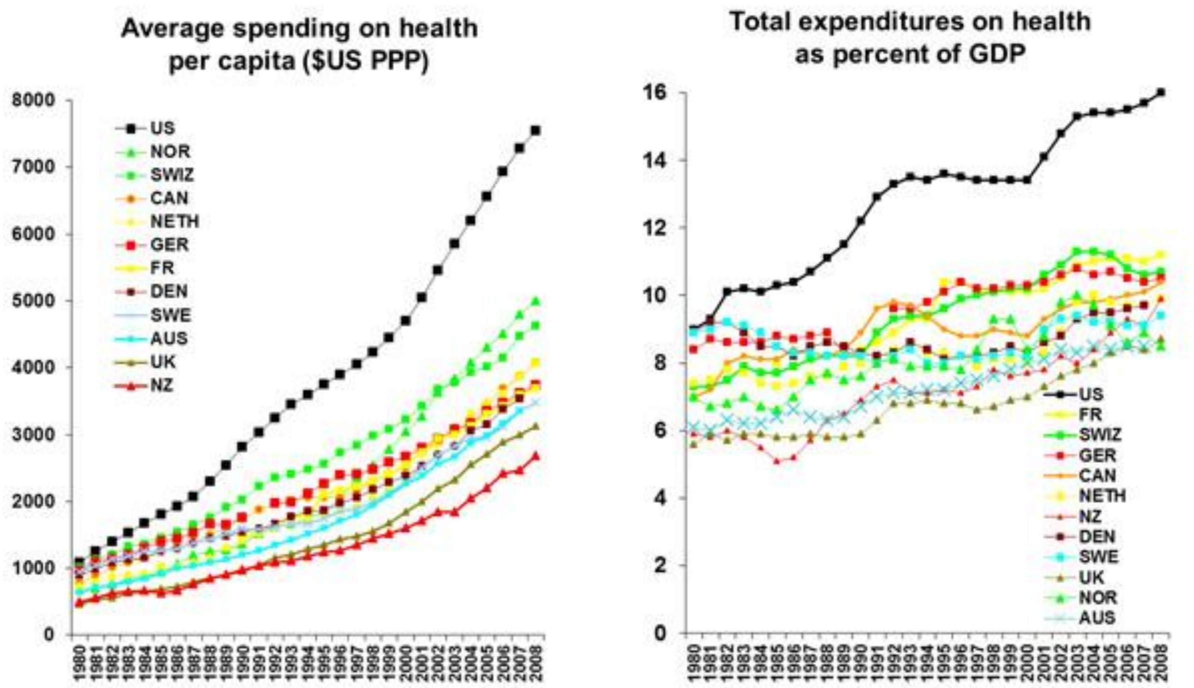
Motivation

International Comparison of Spending on Health, 1980–2008



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

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Motivation

- Quality trailing all other developed nation

Overall Ranking

Country Rankings	
Green	1.00–2.33
Yellow	2.34–4.66
Red	4.67–7.00

	AUS	CAN	GER	NETH	NZ	UK	US
OVERALL RANKING (2010)	3	6	4	1	5	2	7
Quality Care	4	7	5	2	1	3	6
Effective Care	2	7	6	3	5	1	4
Safe Care	6	5	3	1	4	2	7
Coordinated Care	4	5	7	2	1	3	6
Patient-Centered Care	2	5	3	6	1	7	4
Access	6.5	5	3	1	4	2	6.5
Cost-Related Problem	6	3.5	3.5	2	5	1	7
Timeliness of Care	6	7	2	1	3	4	5
Efficiency	2	6	5	3	4	1	7
Equity	4	5	3	1	6	2	7
Long, Healthy, Productive Lives	1	2	3	4	5	6	7
Health Expenditures/Capita, 2007	$3,357	$3,895	$3,588	$3,837*	$2,454	$2,992	$7,290

Note: * Estimate. Expenditures shown in $US PPP (purchasing power parity).
Source: Calculated by The Commonwealth Fund based on 2007 International Health Policy Survey; 2008 International Health Policy Survey of Sicker Adults; 2009 International Health Policy Survey of Primary Care Physicians; Commonwealth Fund Commission on a High Performance Health System National Scorecard; and Organization for Economic Cooperation and Development, *OECD Health Data, 2009* (Paris: OECD, Nov. 2009).

THE COMMONWEALTH FUND

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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

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Transplant Surgery Training: Merging Scheduled Shifts with Random Surgical Opportunities

Acknowledgements

- Ryan Chen, William Pozehl
- Professor Mark Daskin, Professor Jacob Seagull
- Dr. Rishi Reddy, Dr. Andrea Obi, Dr. Jennifer Chung
- SURE summer team

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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

4 x 10 != 40???

- 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?

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  - 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

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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 27^{th} of the preceding month
  - Pre-assigned vacation time must be respected
  - Continuity clinics/post CC
  - Some shifts are pre-assigned to certain residents/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?

	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
- 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 (eg psych, surgery…)

Questions and Discussion