Using OR to Improve Healthcare: Challenges and Opportunities

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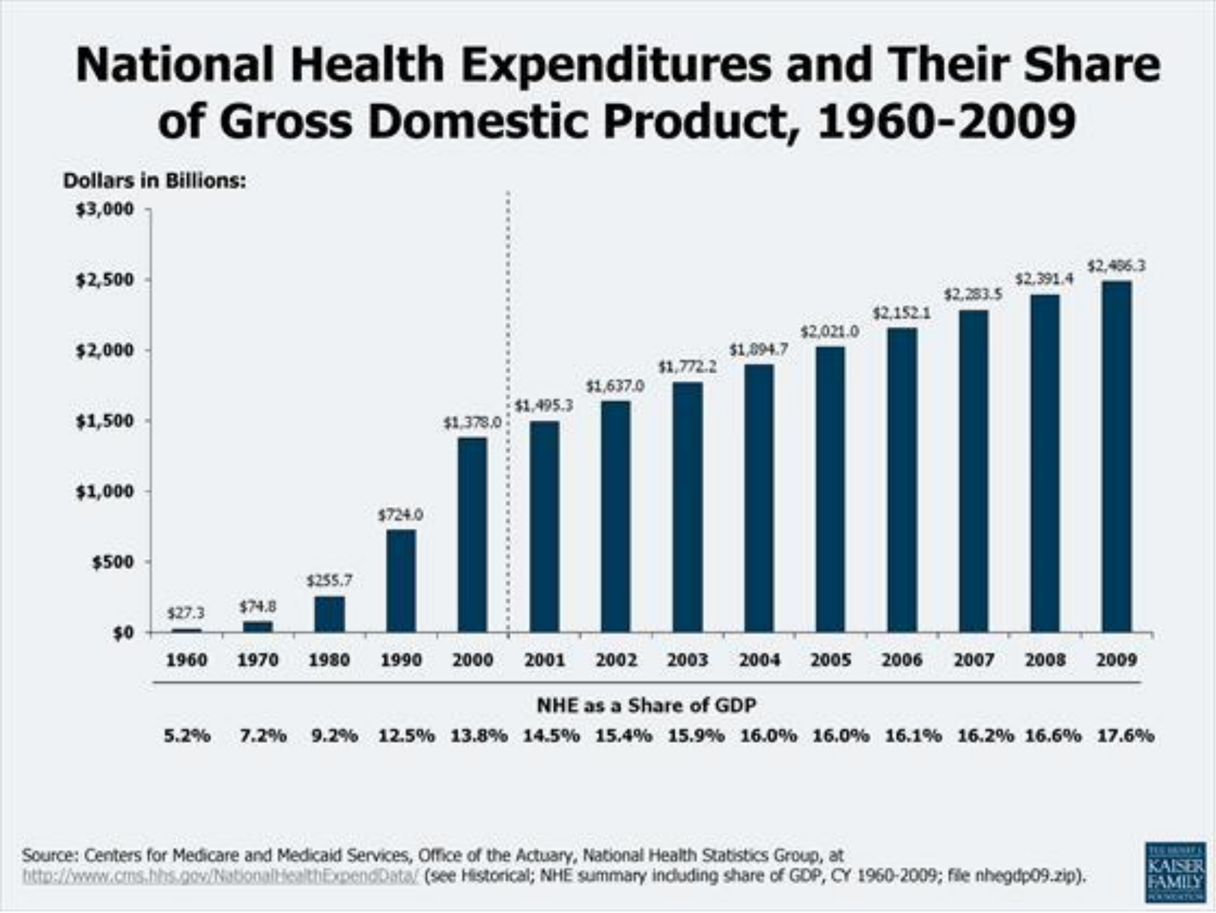
CHEPS Center for Healthcare Engineering & Patient Safety

Background

- Undergrad in applied math
- 5 years in freight transportation consulting
- PhD with Cindy Barnhart – 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

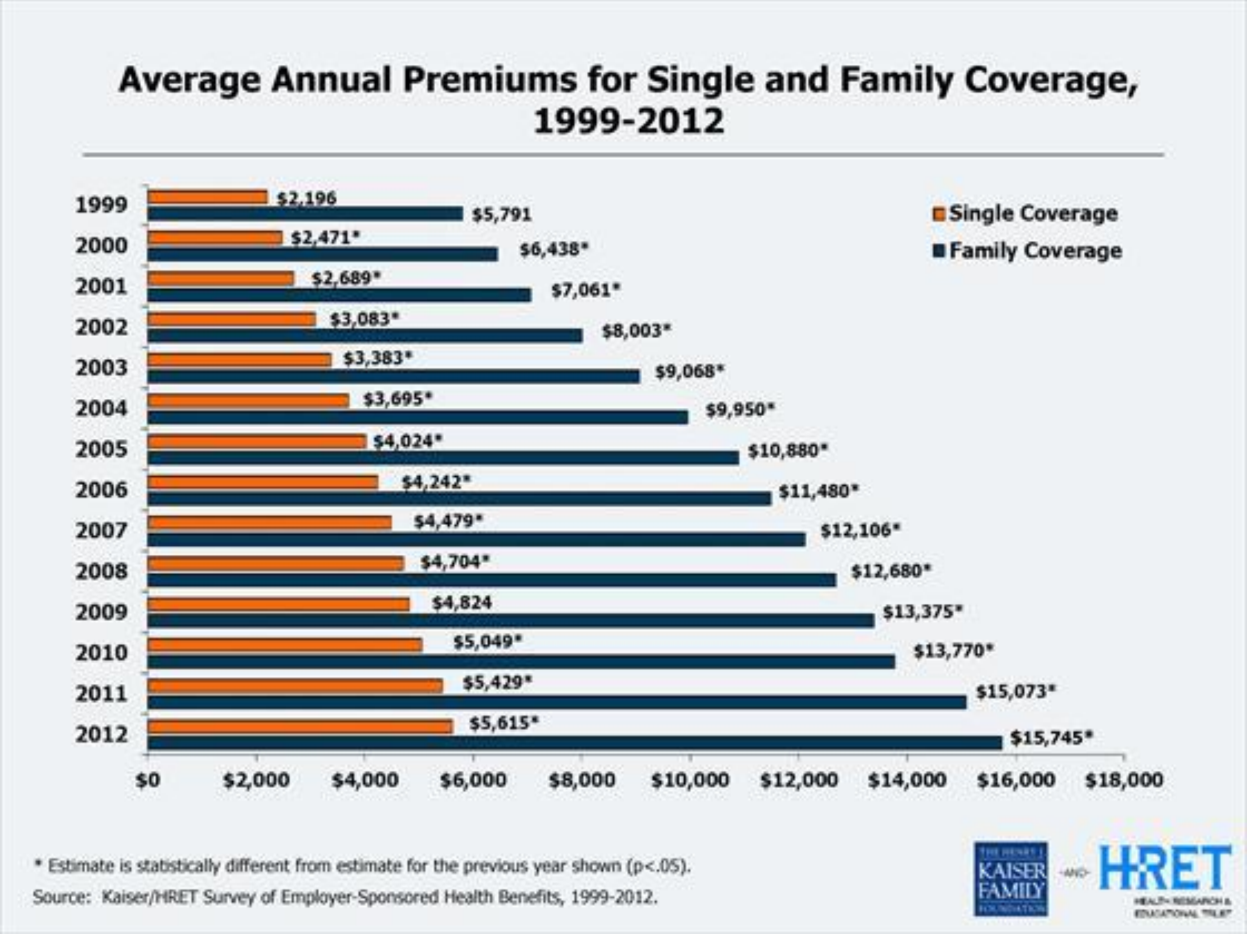
Motivation

- 17% of US GDP



Motivation

- Personal costs are rising rapidly



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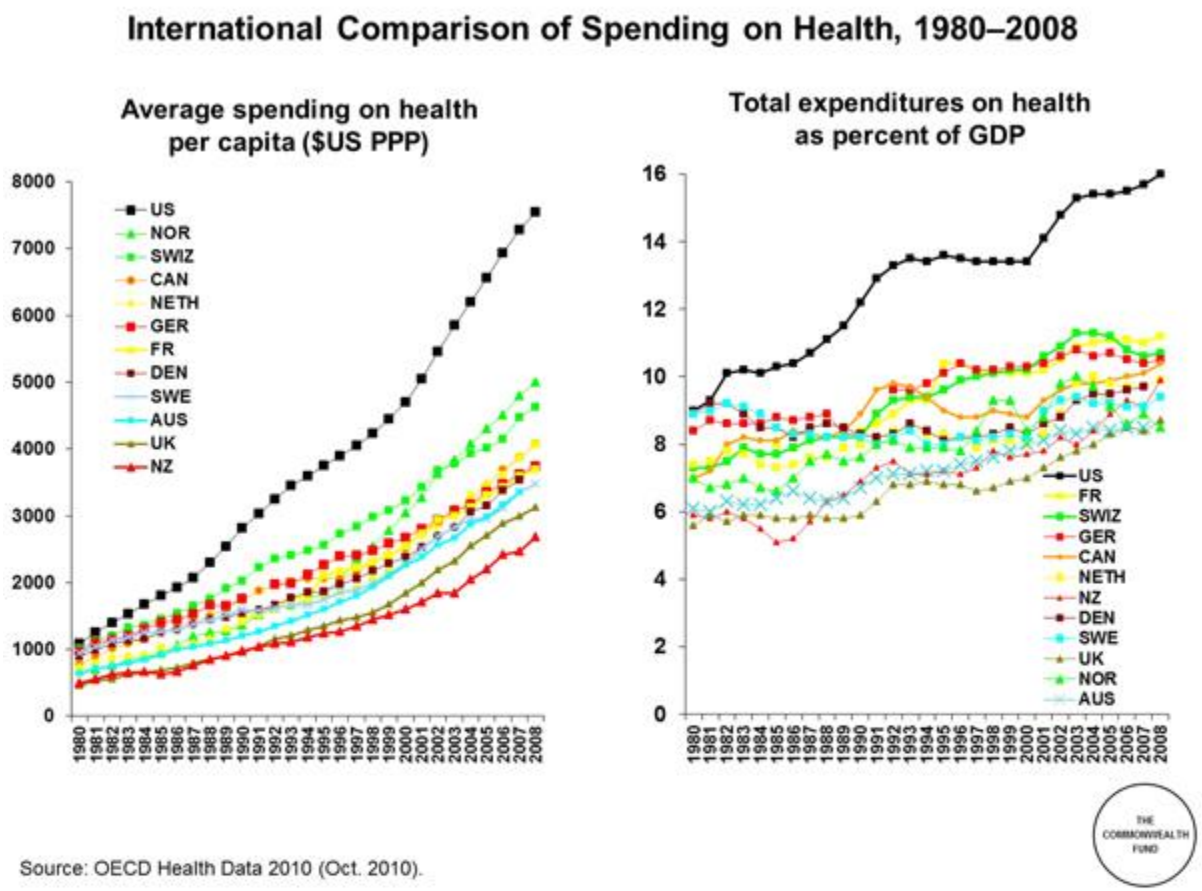
Motivation



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

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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

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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

Our Summer Model

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

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?

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?
  - 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

Pediatric Asthma Patients Presenting at the ED: Patient Flow Issues

Pediatric Asthma in the ED

- What happens to children presenting at the ED with asthma?
- Downside of treating in ED
- Downside of treating in inpatient ward
- Length of stay issues

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Pediatric Asthma in the ED

Relationship between respiratory patient arrival to and discharge from the ED

Total Patients: 5732

Discharge Hour	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	
Total:	282	197	177	141	161	123	119	117	159	210	273	273	293	311	256	240	261	290	320	315	302	334	306	272	
23	0	0	0	0	0	0	0	0	0	2	0	2	3	2	9	2	10	22	38	58	87	89	26	1	351
22	0	0	0	0	0	0	0	0	0	0	0	2	3	5	10	12	16	42	67	73	62	33	0	0	325
21	0	0	0	0	0	0	0	0	0	0	1	5	4	8	10	22	30	63	78	65	9	0	0	0	295
20	0	0	0	0	0	0	0	0	2	2	6	5	9	16	28	41	69	74	60	23	0	0	0	0	335
19	0	0	0	0	1	0	0	2	2	3	4	9	12	28	38	52	54	48	22	0	0	0	1	0	276
18	1	0	0	0	1	0	0	3	1	4	5	17	29	46	68	58	53	16	2	0	0	0	0	1	305
17	0	0	0	2	1	2	2	1	3	5	21	20	38	55	59	32	12	0	0	0	1	0	0	1	255
16	1	0	2	0	0	1	1	3	8	16	23	43	63	74	26	10	0	0	0	0	0	0	1	0	272
15	0	1	0	0	3	0	2	4	12	16	49	62	61	61	6	0	1	0	1	0	0	1	0	0	280
14	1	0	1	1	6	5	4	3	12	23	46	57	59	9	0	0	1	3	1	1	2	1	0	0	236
13	1	0	2	2	4	9	7	6	14	22	62	32	8	1	0	0	0	0	1	1	0	0	1	0	173
12	4	2	2	2	4	3	11	10	16	52	42	18	1	0	0	1	1	1	0	0	1	2	3	3	179
11	1	1	4	3	3	10	14	13	23	41	14	0	0	0	0	0	0	0	1	1	0	1	1	2	133
10	5	1	5	3	10	8	17	27	47	24	0	0	0	0	0	0	0	1	0	2	2	3	5	1	161
9	2	4	2	10	16	17	11	28	19	0	0	0	0	0	0	0	1	0	0	2	1	2	5	1	121
8	10	6	11	15	10	16	27	17	0	0	0	0	0	0	0	1	0	2	2	1	3	2	4	5	132
7	8	11	16	21	31	27	20	0	0	0	0	0	0	0	0	0	0	2	1	1	1	2	7	10	158
6	22	21	32	28	32	23	3	0	0	0	0	0	2	0	0	0	0	2	0	2	2	8	8	11	196
5	30	30	29	35	35	1	0	0	0	0	0	0	0	2	0	0	0	0	1	3	6	9	12	10	203
4	36	46	45	19	4	0	0	0	0	0	0	0	0	0	0	0	0	0	4	5	5	4	18	33	219
3	67	57	23	0	0	1	0	0	0	0	0	0	0	0	0	0	1	0	3	7	11	18	42	41	271
2	58	17	3	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	3	11	17	35	42	66	254
1	34	0	0	0	0	0	0	0	0	0	0	1	1	0	1	2	3	6	9	23	31	58	56	60	285
0	1	0	0	0	0	0	0	0	0	0	0	0	0	4	1	6	9	7	26	36	61	66	74	26	317
	0	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	

Arrival Hour

Pediatric Asthma in the ED

Matrix of Admit (to Inpatient) Hour vs Discharge (from Inpatient) Hour, for Respiratory Patients

Total # of patients 1536

	23	0	1	0	0	1	0	1	0	0	0	0	0	1	0	0	0	1	0	0	0	0	0	1	0
	22	0	1	1	0	0	0	0	0	1	0	0	0	1	0	1	0	1	0	1	0	0	0	0	0
	21	1	3	0	2	0	1	1	0	1	0	0	0	1	0	0	0	0	1	3	0	0	0	1	0
Discharge	**20**	0	3	2	2	0	0	0	1	2	0	0	0	2	0	1	1	0	2	3	1	2	2	4	0
Hour	**19**	4	6	0	4	6	3	1	4	2	1	0	1	1	1	1	2	2	4	6	4	7	6	1	3
of	**18**	7	7	2	3	2	3	3	3	3	1	3	0	0	2	4	1	11	6	1	7	7	3	6	4
Admitted	**17**	8	3	5	9	5	3	4	4	4	2	1	4	5	5	4	4	10	7	11	7	5	12	7	12
Patients	**16**	13	6	9	6	3	1	7	5	3	1	3	1	6	3	6	8	8	7	11	4	18	11	8	11
from	**15**	7	9	7	5	3	4	3	3	3	4	3	2	3	7	7	10	10	5	16	8	7	14	3	12
Hospital	**14**	15	11	7	8	9	3	4	6	2	4	3	3	6	3	9	13	19	15	10	11	12	12	8	16
(JUST	**13**	9	10	9	9	5	6	6	5	5	0	3	3	7	2	7	15	13	14	15	20	19	9	12	8
Respiritory	**12**	10	6	5	6	4	9	5	1	5	4	2	0	3	6	5	12	13	15	11	13	13	13	7	9
Patients)	**11**	9	4	6	7	3	3	3	1	1	3	1	3	1	4	3	8	8	3	8	7	6	3	9	8
	10	3	3	4	1	2	1	3	4	3	1	1	1	1	2	5	6	6	6	2	5	5	1	3	4
	9	1	1	2	2	0	0	1	1	0	0	0	2	1	0	1	3	2	1	1	0	3	2	1	1
	8	1	0	1	0	1	2	1	3	0	0	2	0	2	3	0	2	1	0	1	1	0	1	2	1
	7	0	1	0	0	0	0	0	0	2	0	1	0	0	0	0	0	0	2	1	1	1	2	1	0
	6	0	0	0	1	0	1	1	0	0	0	0	0	0	0	1	0	0	0	0	0	0	1	0	1
	5	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0
	4	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	1	0	0	0	0	0	0	0	0
	3	0	0	0	1	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	2	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
	1	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	0	0	2	0	0	0	0
		0	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**
total patients each hr:		90	76	60	66	44	41	44	41	37	23	23	20	41	38	56	86	106	90	102	91	105	92	74	90

Admit hour of admitted patients to Inpatient (JUST Respiritory Patients)

Short Term Vision for Peds ED Asthma

- How can we reduce length of stay?
  - Benefits for asthma patient
  - Benefits for other patients
- Increased rounding
  - Spreadsheet tool
- Obs unit
  - Lots of opportunity for operational analysis

Long Term Vision for Peds ED Asthma

- Idealized vision: LOS (“length of stay”) is 0 (i.e. don’t ever have to go to the emergency department)
- Innovations in sensor technology, EMR (“electronic medical record”), LHS (“learning health system”) are making data abundant
- How do we convert that data into meaningful decisions?
- Merging of multiple faculty, providers, disciplines to form a continuum of care

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Scheduling Pediatric Emergency Medicine Residents at UMHS

Acknowledgements

- Ongoing collaboration with many talented contributors
  - 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

8

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…)

Conclusions

Applying OR in Healthcare

- Requires new skills not always taught to engineers in school
- Requires deep collaboration between engineers and healthcare providers
- Requires a heavy up-front and on-going investment in learning the problem domain
- Tremendous opportunity to have impact

Questions and Discussion