CENTER FOR
HEALTHCARE ENGINEERING & PATIENT SAFETY
UNIVERSITY OF MICHIGAN

SCHEDULING FOR MEDICAL RESIDENTS

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Presentation outline

- Background
- Shift scheduling
- Analysis of schedule quality
- Rotation scheduling
- Conclusions and future work

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- **Background**
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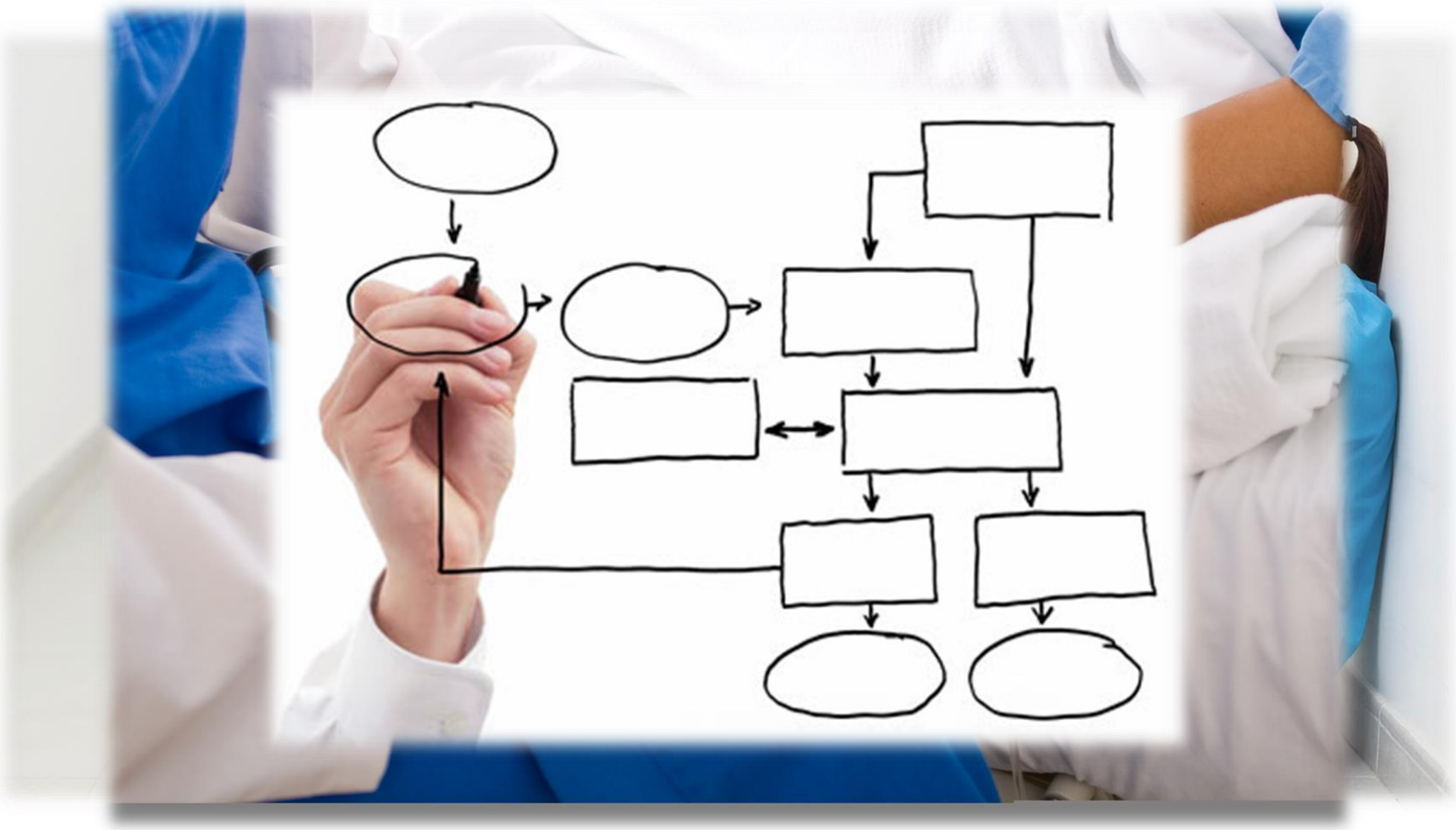
Medical training at UMHS

Mott Pediatric Emergency Room

- Level I Pediatric Trauma Center
- About 25,000 visits per year
- Staffed by residents from 5 programs
  - Pediatrics
  - Medicine-Pediatrics
  - Family Medicine
  - Emergency Medicine
  - Psychology

Importance of scheduling



Traditional approach

- Hand-built by chief resident or administrator
- Benefits
  - Intimate knowledge
  - Administrative consolidation
- Drawbacks
  - Time-consuming
  - Cognitively-demanding

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Decision variables

Whether to assign a certain resident to a certain shift on a certain day

$$\mathbf{x_{rsd}} \in \{\mathbf{0}, \mathbf{1}\}, \qquad \forall\, \mathbf{r} \in \mathbf{R}, \mathbf{s} \in \mathbf{S}, \mathbf{d} \in \mathbf{D}$$

Shift coverage

Must provide sufficient shift coverage for every day and shift

$$\sum_{r \in R} x_{rsd} = 1, \forall\, d \in D, s \in S \backslash \{flex, EOM, EMSr\}$$

$$0 \leq \sum_{r \in R} x_{rsd} \leq 1, \qquad \forall\, d \in D, s \in \{flex, EOM\}$$

$$\sum_{r \in R} x_{rsd} = 0, \qquad \forall\, d \in D, s \in \{EMSr\}$$

External requirements

Cannot create work assignments that conflict with outside commitments

$$\mathbf{x_{rsd} = 0,\ \forall\ r \in R, d \in D,}$$
$$\mathbf{s \in \{clinic, conference, vacation\}}$$

Pediatric paired shifts

Ensure that at least 1 of 2 shifts in a pair is covered by a Pediatric resident each day

$$\sum_{r \in \{PED\}} \sum_{s \in P} x_{rsd} \geq 1,$$

$$\forall\, d \in D, P = \{\{7a,9a\}, \{4p,5p\}, \{8p,11p\}\}$$

Senior-only shifts

Certain shifts must be covered by senior-level residents

$$\sum_{r \in \{interns\}} \sum_{d \in D} x_{rsd} = 0, \qquad \forall\, s \in \{7a, 11p\}$$

Work-rest rules

Residents must get at least 10 hours off-duty between ending one shift and beginning another

$$x_{rsd} + \sum_{\substack{(s',d') \in \\ \{\text{within 10 hrs of } (s,d)\}}} x_{rs'd'} \leq 1, \quad \forall\, r \in R, s \in S, d \in D$$

Multi-criteria objective

- Multi-criteria schedule
  - Total shift equity (TSE)
  - Night shift equity (NSE)
  - Bad sleep patterns (BSP)
  - Post-continuity clinic shifts (PCC)
  - ⋮

Preferences?
Weights?
Trade-off?

Multi-objective Mathematical Programming

Multi-criteria objective

- Optimization problem

$$\textbf{Min } \boldsymbol{w_1}(TSE) + \boldsymbol{w_2}(NSE) + \boldsymbol{w_3}(BSP) + \boldsymbol{w_4}(PCC)$$
$$\textbf{s. t.} \quad \text{"rules/requirements"}$$
$$x_{rsd} \in \{0,1\}$$

- Quantifying preferences (w_i) is difficult
  - Subjective weights
  - Alternative measures
  - Non-linearity

Multi-criteria objective

- Feasibility ~~Optimization~~ problem

$$\textbf{Min } \sout{w_1(TSE) + w_2(NSE) + w_3(BSP) + w_4(PCC)}$$

$$\textbf{s. t.} \quad \text{"rules/requirements"}$$

$$x_{rsd} \in \{0,1\}$$

$$lb_{TSE} \leq (TSE) \leq ub_{TSE}$$

$$lb_{NSE} \leq (NSE) \leq ub_{NSE}$$

$$lb_{BSP} \leq (BSP) \leq ub_{BSP}$$

$$lb_{PCC} \leq (PCC) \leq ub_{PCC}$$

- Benefits of a feasibility problem
  - Flexibility
  - Speed: < 2 seconds per iteration
    - Given: 20 residents / 7 shifts daily / 35 days

Iterative improvements

Resident Name	Number of Shifts	Number of Night Shifts	Number of Post-CC Shifts	Number of Bad Sleep Patterns
Smith	8 (7,9)	2 (2,3)	0 (0,1)	0 (0,0)
Sanchez	8 (7,10)	2 (2,3)	0 (0,1)	0 (0,0)
Chen	8 (7,9)	2 (2,3)	1 (0,1)	0 (0,0)
Shah	14 (13,15)	4 (3,5)	1 (0,1)	0 (0,0)
⋮	⋮	⋮	⋮	⋮

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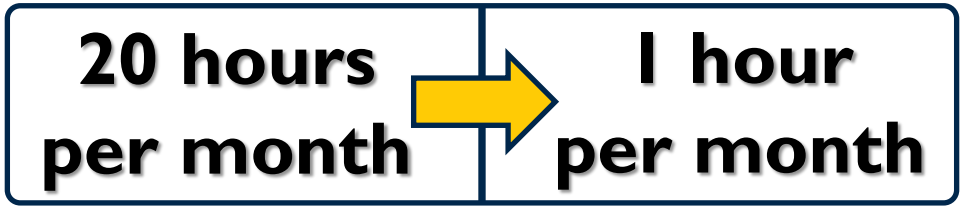
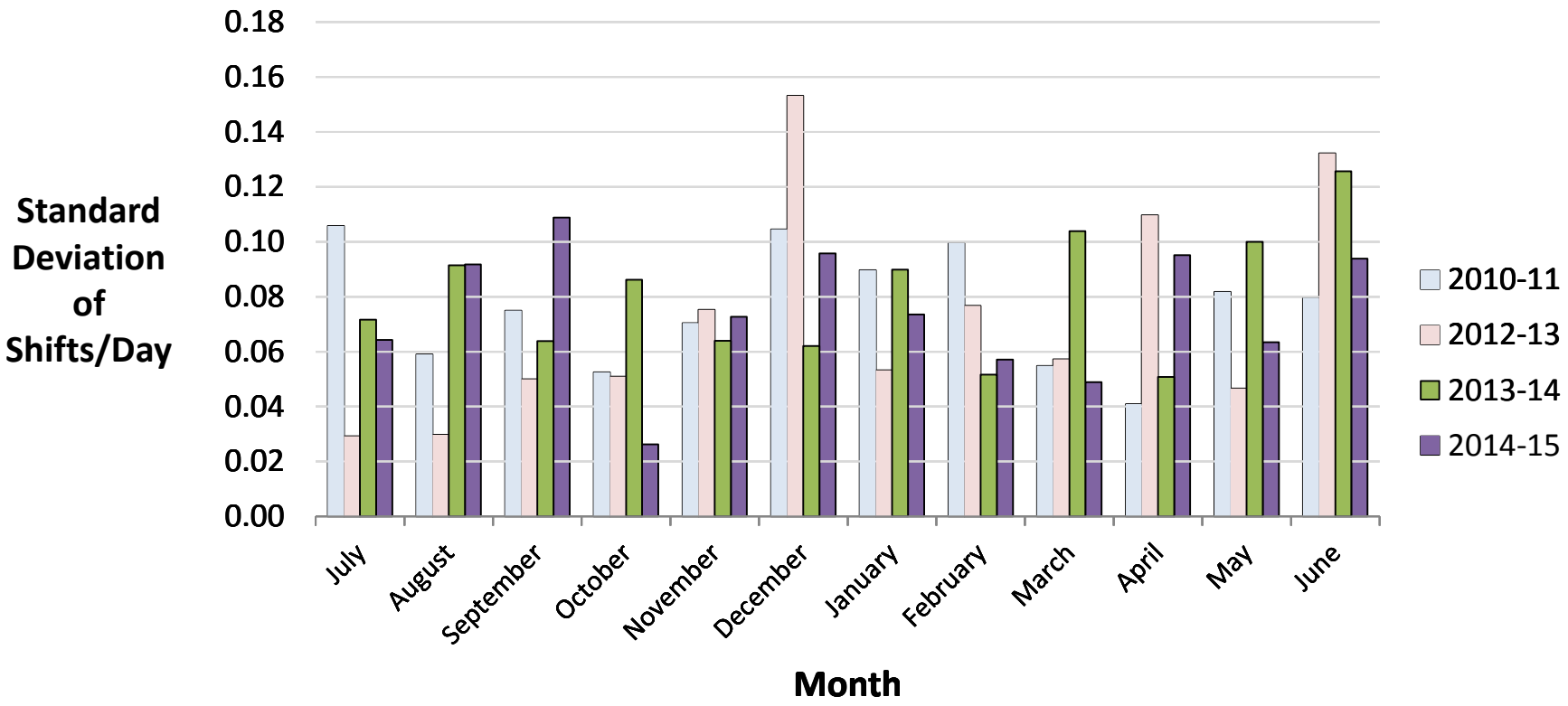
Implementation results

- Reduced time to create schedules



- Statistically significant improvement in 3 of 4 major metrics

Total shift equity



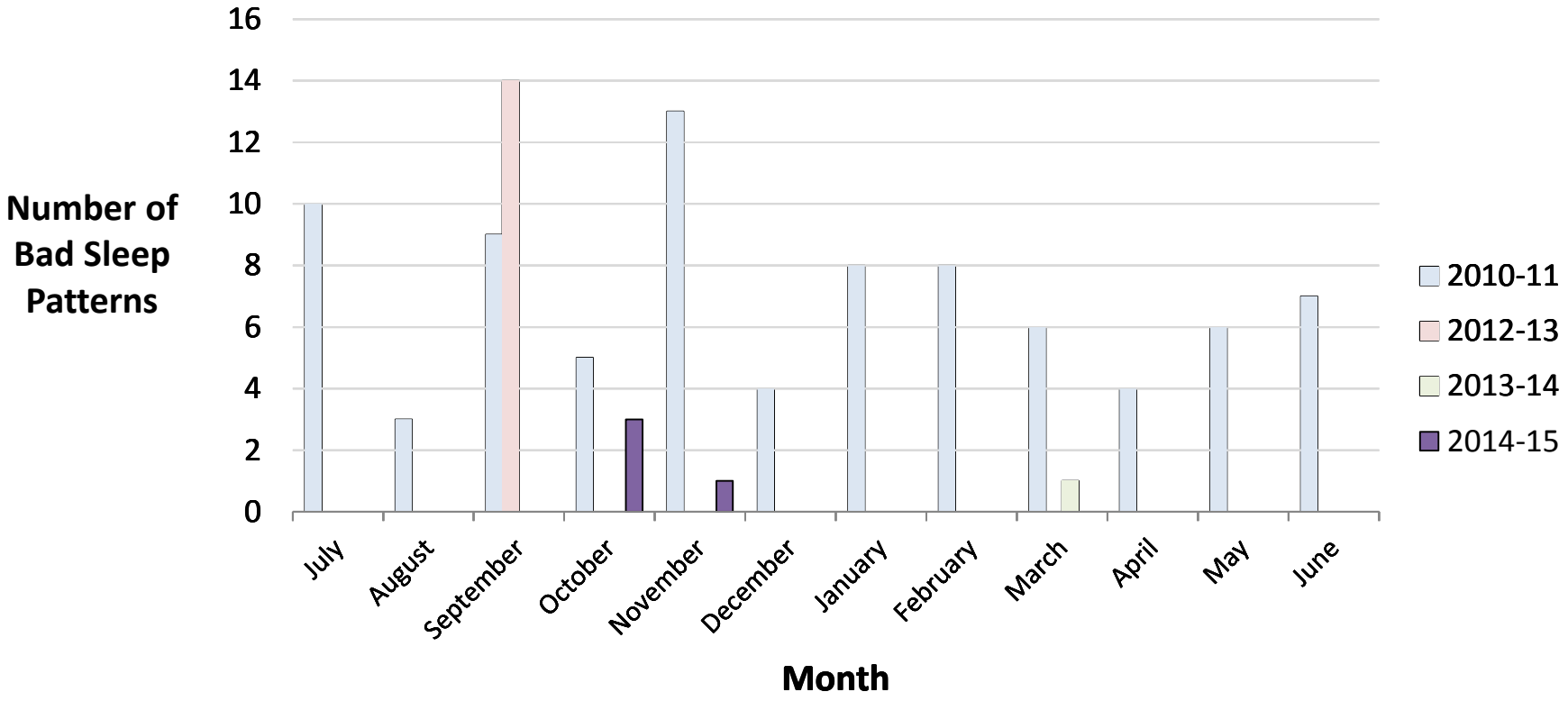
2010-11: 0.0761 ± 0.0214

2012-13: 0.0665 ± 0.0367

2013-14: 0.0801 ± 0.0231

2014-15: 0.0743 ± 0.0238

Bad sleep patterns



2010-11: 6.9167 ± 2.8749

2012-13: 1.1667 ± 4.0415

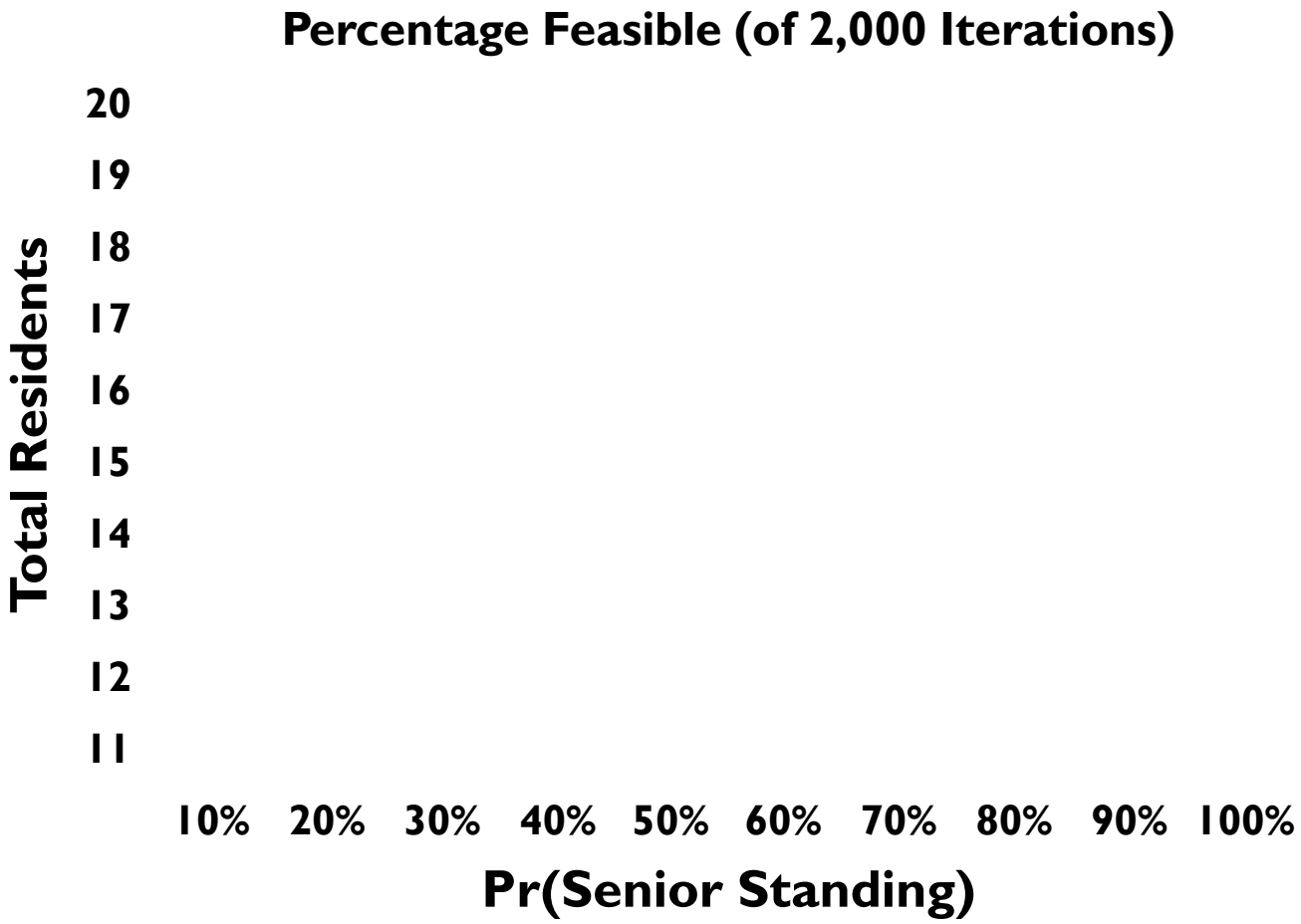
2013-14: 0.0833 ± 0.2887

2014-15: 0.3333 ± 0.8876

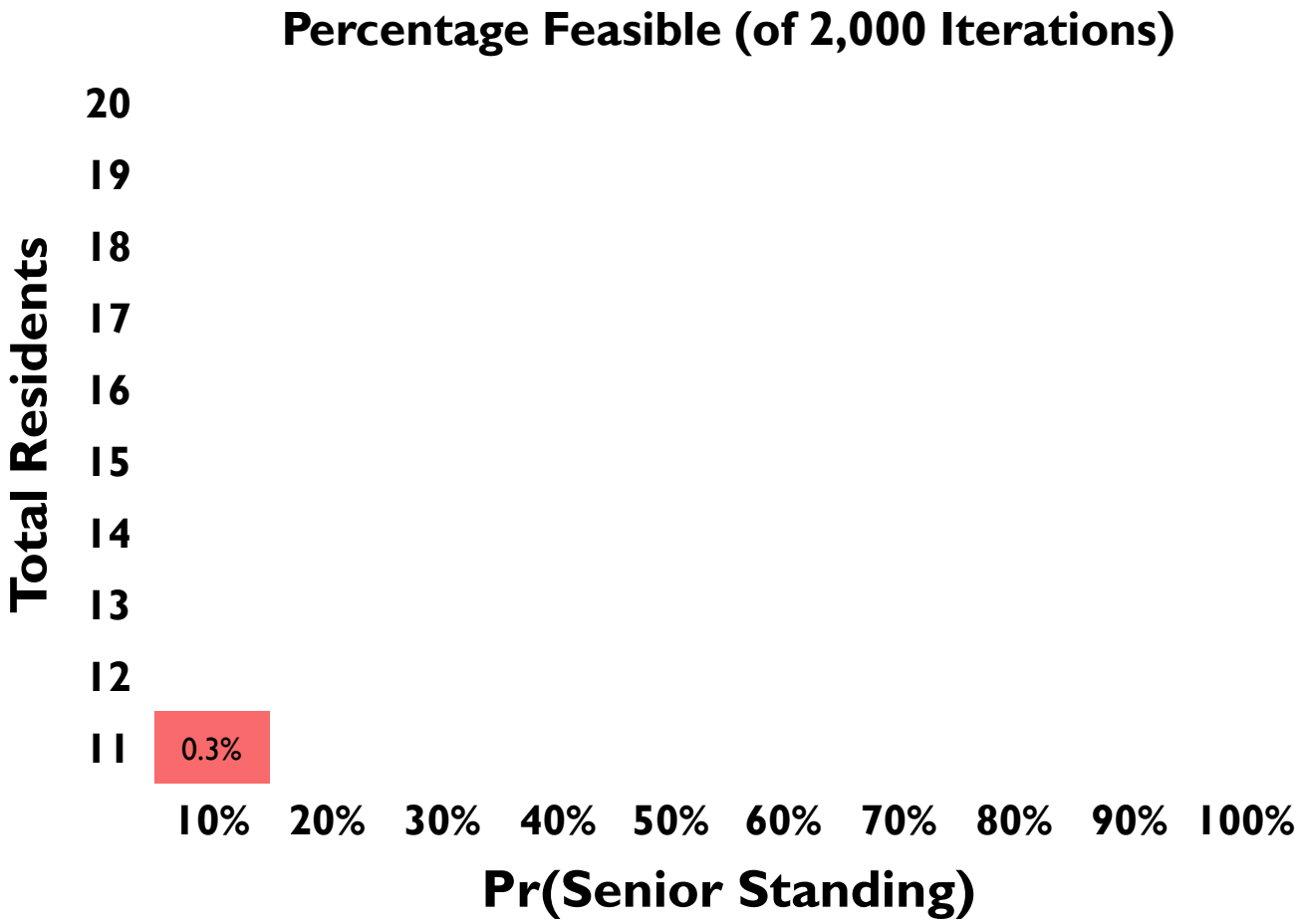
Implementation results

- Months with poor metrics tend to have:
  - Fewer residents overall
  - Fewer senior residents
  - Fewer Pediatrics residents

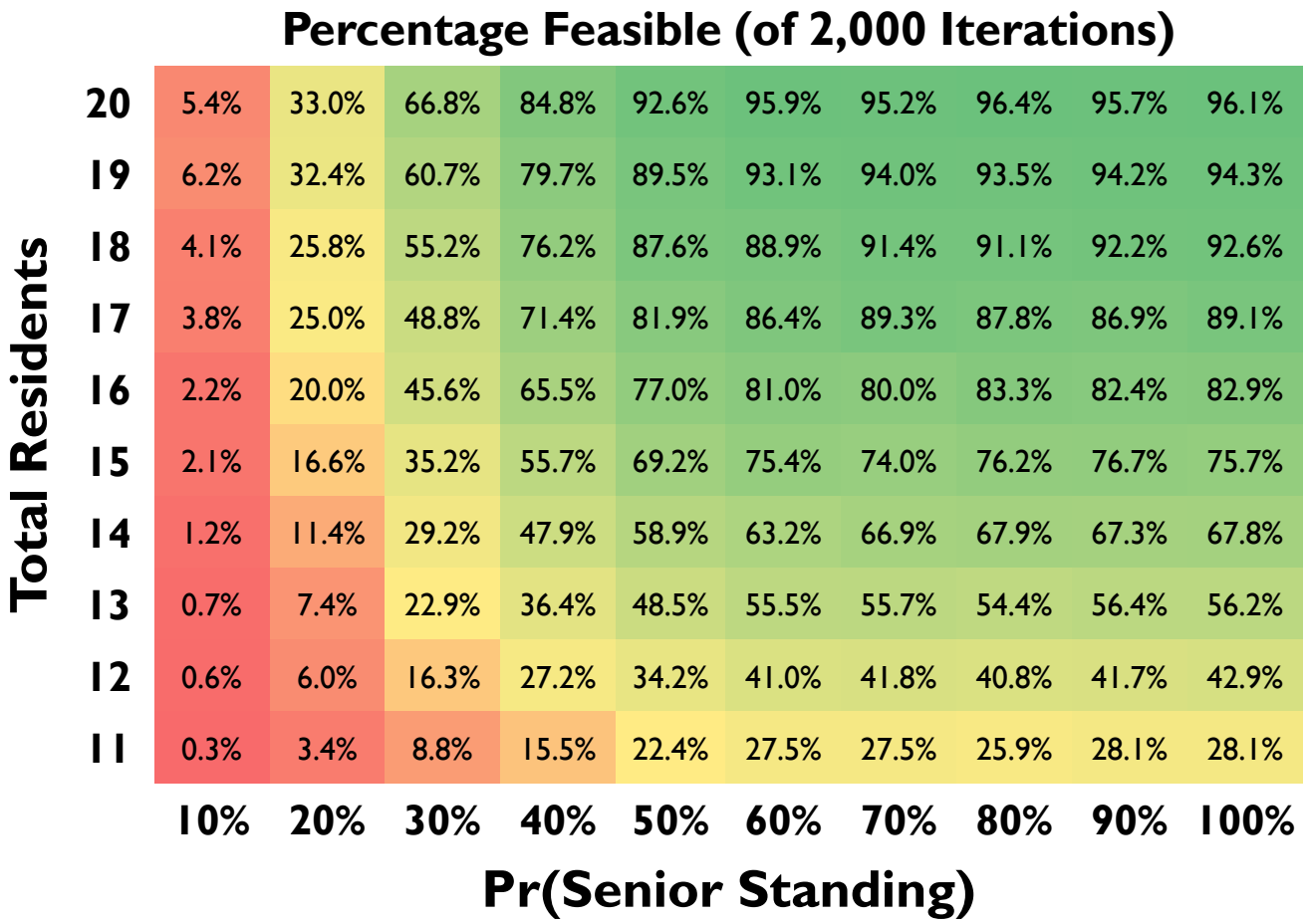
Simulation study



Simulation study



Simulation study



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Rotation scheduling

- Assigning residents to services over the course of the year
- Usually 2- or 4-week-long rotations
- Residents given opportunity to make time preference requests

Service pairs

- An ordered couplet of services that may be worked during the same month
- Combinations of service pairs are classified as "hard" or not

Service Pair	
July	
1st Half	2nd Half
NICU	General
Hard = 0	

Decision variables

Whether to assign a certain resident to a certain service pair on a certain month

$$x_{rpm} \in \{0, 1\}, \qquad \forall\, r \in R, p \in P, m \in M$$

Month	July		August		September	
Paige Mollison	1st Half	2nd Half	1st Half	2nd Half	1st Half	2nd Half
	General	General	Heme Onc	NICU	General	Vacation
	Hard = 0		Hard = 1		Hard = 0	
Luke Stumpos	1st Half	2nd Half	1st Half	2nd Half	1st Half	2nd Half
	Heme Onc	NICU	General	General	PER	Night Team
	Hard = 1		Hard = 0		Hard = 1	

Monthly rotation assignment

Each resident is assigned one service pair per month

$$\sum_{p \in P} x_{rpm} = 1, \qquad \forall r \in R, m \in M$$

Service coverage

Each service must have between a minimum and maximum number of residents at all times

$$\mathbf{LBRes_{sm}} \leq \sum_{\mathbf{p \in P_{sh}}} \mathbf{x_{rpm}} \leq \mathbf{UBRes_{sm}},$$

$$\forall\, \mathbf{s \in S, m \in M, h \in \{1, 2\}}$$

Educational requirements

Each resident must have between a minimum and maximum number of months on each service throughout the year

$$\mathbf{LBMonths_{rs}} \leq \sum_{\mathbf{p} \in \mathbf{P}} \sum_{\mathbf{m} \in \mathbf{M}} \mathbf{q_{ps} x_{rpm}} \leq \mathbf{UBMonths_{rs}},$$

$$\forall\, \mathbf{r} \in \mathbf{R}, \mathbf{s} \in \mathbf{S}$$

Triple-hard sequences

Track when a resident works a sequence of three hard pairs in a row and limit the total triple-hard sequences anyone can work

$$\mathbf{b_t x_{rpm} + b_t x_{rp(m+1)} + b_t x_{rp(m+2)} \leq Y_{rm} + 2} \qquad \forall\, \boldsymbol{r \in R, m \in \{1, \ldots, |M| - 2\}}$$

$$\sum_{\mathbf{m \in M}} \mathbf{Y_{rm} \leq UBHard_{r,}} \qquad \forall\, \mathbf{r \in R}$$

Implementation results

- Two-phase schedule creation
  - Senior phase
  - Intern phase
- Satisfied 238/242 (98.3%) of time preference requests
- Speed: < 3 minutes per iteration

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Conclusions

- Significantly reduced time and improved metrics for ED shift schedules
- Lingering scheduling challenges may derive from the rotation schedule
- Significantly improved satisfaction of time preferences for rotation schedules

Future work

- Pareto frontier of shift schedule options
- Maximally feasible sets of vacations and time preferences
- Extend rotation schedule model to other residencies

Acknowledgements

- Univ. of Michigan Pediatric Residency Program
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Questions [?] & Comments [!]

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For more information on collaborative projects between CHEPS and the C.S. Mott Children's Hospital Emergency Room, please attend:

1. Simulating a Medical Observation Unit for a Pediatric Emergency Dept – Mark Grum
   Today, 12:30 – 2:00 PM session, Emergency Care
2. Patient Flow in a Pediatric Emergency Department – Hassan Abbas & Brooke Szymanski
   Friday, 8:00 – 9:30 AM session, Student Research Projects in Healthcare Operations

Numerical Optimization

Min 0

$$1 \le \sum_{r \in \{PED\}} \sum_{s \in \{s_1, s_2\}} x_{rsd} \le 2, \qquad \forall d, \forall s \in \{7a, 4p, 8p\}$$

$$LB \le \sum_{d} \sum_{s} x_{rsd} \le UB, \qquad \forall r$$

$$\sum_{\forall d, s \in \{conference\}} x_{rds} = 0, \qquad \forall r$$

$$\vdots$$

$$y_r, x_{rsd} \in \{0, 1\}$$

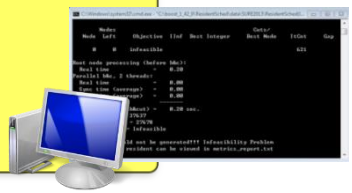
$$\min \sum_{rsd \in Off} x_{rsd} + \sum_{rsd \in On} (1 - x_{rsd})$$

$$s.t. \quad \text{“New Requests”}$$

$$\vdots$$

$$On: \{(r, s, d) \mid \bar{x}_{rsd} = 1\}$$

$$Off: \{(r, s, d) \mid \bar{x}_{rsd} = 0\}$$



INPUT
- Input Program Data from Excel or Text Files
- Resident Data
- Program Requirements

Builds a schedule in less than 2 seconds

OUTPUT
- Monthly Schedule
- Schedule by Resident
- Metrics Report

Good Enough?

No

Use ORSA to Interactively Improve Schedule

Need Change?

Yes

Yes

No

END

Implementation Process

Sets

R: residents
C: resident categories
S: services
M: months

Parameters

$a_{rc} \in \{0,1\}$: whether resident r fits category c

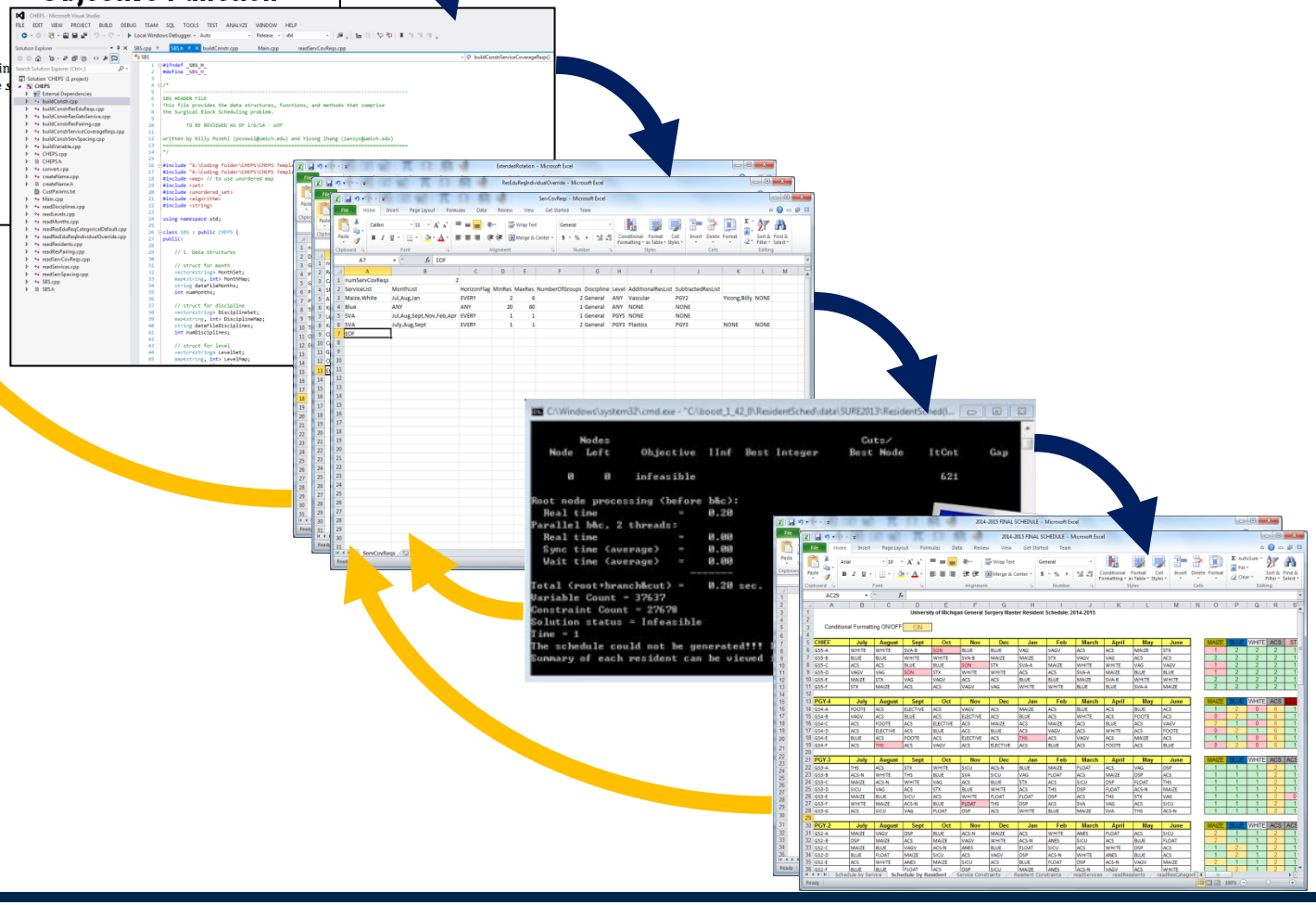
$\mathcal{L}_{csm}, \mathcal{U}_{csm}$: lower, upper bounds on staffin of residents fitting category c in service during month m

λ_{rs}, μ_{rs}: lower, upper bounds on months resident r must spend on service s

Decision Variables

$x_{rsm} \in \{0,1\}$: whether resident r is assigned to service s in month m
$\forall r \in R, s \in S, m \in M$

Objective Function



Total shifts

- Must provide adequate educational experience for every resident

$$\text{LBShifts}_r \leq \sum_{s \in S} \sum_{d \in D} x_{rsd} \leq \text{UBShifts}_r, \qquad \forall\, r \in R$$

$$\text{LBNites}_r \leq \sum_{s \in S} \sum_{d \in D} x_{rsd} \leq \text{UBNites}_r, \qquad \forall\, r \in R$$