An effective way to generate multiple solutions for scheduling medical residents

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Content

- Background
  - U-M Pediatric Emergency Department
  - Schedule Quality
- Mathematical Method
  - Weighted Sum
  - Metrics Formulation
- Optimized Residency Scheduling Assistant (ORSA)
- Results
- Conclusion

Resident Responsibilities in the U-M Pediatric Emergency Department

- 3-7 year medical training program
  - Responsibilities differ by residency year
- Balancing patient care and educational requirements
  - In hospital
    - Caring for patients
    - Teaching medical students
    - Learning from attending physicians
  - Out of hospital
    - Community clinics
    - Conferences
    - Other educational requirements

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Pediatric ED: Scheduling Considerations

- All shifts assigned to a resident
- Appropriate coverage
  - e.g. certain shifts require a senior resident
- ACGME rules (similar to ABET for engineering)
  - e.g. 10 hour break rule
- Continuity clinics / Conferences
- Varying start dates
- Time-off requests
- And others

Pediatric ED: Scheduling Objectives

- Create a good quality schedule
  - Total shift equity (TSE)
  - Night shift equity (NSE)
  - Minimum bad sleep patterns (BSP)
  - Minimum post-clinic shifts (PostCC)

Metrics: Shift Fairness

- Improving total / night shift equity
  - Equal opportunities for training
  - Improved morale and learning ability

Resident Name	Smith	Jones	Chen	Joe
Night Shifts / Total Shifts	0 / 7	1 / 7	1 / 7	5 / 7
Fairness				

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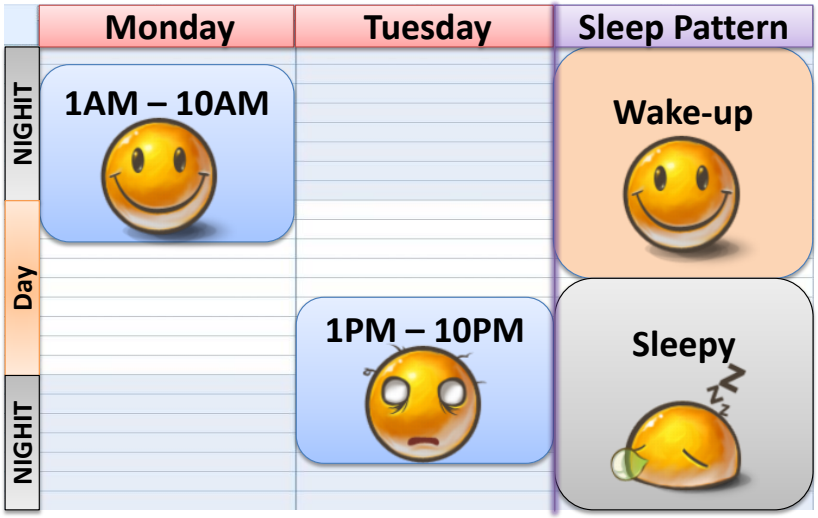
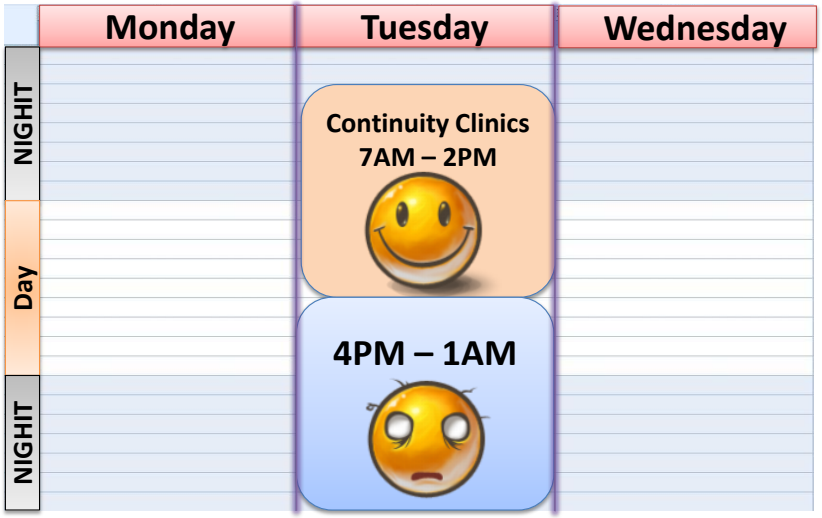
Metrics: Undesired Shift

- Limit bad sleep patterns and post-clinic shifts
  - Improves resident quality of life
  - Increases patient safety



Bad sleep pattern



Post-Clinic shift

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Motivation

- Traditionally, chief resident built monthly schedule by hand
- Guess and check
- Development required 20 - 25 hours / month
  - ~15 hours to build
  - ~10 hours to fix errors
- Errors
  - Difficult to recognize
  - Tedious correction process

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

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Formulation: Multi-Criteria Problem

- **Sets**
  - R: set of residents
    - 15-25 residents
  - D: set of days in the schedule
    - 35 days
  - S: set of shifts
    - 8 shifts

- **Decision Variables**
  - Binary : $x_{rds} \in \{0,1\}$
    - 1 if resident *r* works shift *s* on day *d*
    - 0 otherwise

Residents Name				
Smith	Sanchez	Chen	Shah	…

	27th	…	1st	…	31st
7a-4p	Shah	…		…	
9a-6p	Joe	…		…	Shah
10a-7p		…		…	
12p-9p	Chen	…		…	Chen
4p-1a	Smith	…	Sanchez	…	
5p-2a		…		…	Sanchez
8p-5a	Sanchez	…	Smith	…	Smith
11p-8a		…	Chen	…	Joe

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Formulation: Multi-Criteria Problem

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

- **Objectives**
  - Total shift equity: $(\sum t_{ij}\ , t_{ij} = |D_i - D_j|,\ i > j)$
  - Night shift equity: $(\sum n_{ij}\ ,\ n_{ij} = |N_i - N_j|,\ i > j)$

	R1	R2	R3	R4	R5	R6	AVG	Max|diff$_{ij}$|	∑|diff$_{ij}$|
Schedule A	10	11	12	13	14	15	12.5	5	35
Schedule B	10	10	10	10	10	25	12.5	5	60

  - Minimum bad sleep patterns : $(\sum count)$
  - Minimum post-clinic shifts : $(\sum count\ )$

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Formulation: Multi-Criteria Problem

- **Constraints (rules/requirements)**
  - One resident assigned to each shift in the month
    - $\sum_{r\in\{\text{all}\}} x_{rds} = 1, \quad \forall d, \forall s$
  - Meets shift requests
    - $x_{rds} = 0, \quad \forall r, \forall d, s \in \{\text{day off, conferences, continuity clinic}\}$
  - Ensure resident type appropriate for shift
    - $\sum_{r\in\{\text{PED}\}} \sum_{s\in \text{P}} x_{rsd} \geq 1, \forall \text{d}, \text{P} = \{\{7\text{a},9\text{a}\},\{4\text{p},5\text{p}\},\{8\text{p},11\text{p}\}\}$
  - Intern-forbidden shifts
    - $\sum_{r\in\{\text{interns}\}} \sum_{d} x_{rsd} = 0, \forall s \in \{7\text{a}, 11\text{p}\}$
  - And others

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Weighted Sum Method: Limitations

- Quantifying preferences (w_i) is difficult
  - Resulting schedule does not match your intentions
- Computational time
  - Much slower than feasibility problem
    - 2 – 30 min or more / iteration
    - But only 1 – 2 hours / monthly meeting

Weighted Sum Method: Weights

- Matching Game

STEP 1	Weight
TSE	1.00
NSE	2.00
PostCC	3.00
BSPs	4.00

1

STEP 2	Favorite Schedule
	2

Schedule Number	Measure of TSE	Measure of NSE	Count of PostCC	Count of BSPs
1	2	1	2	0
2	3	0	1	4
3	2	2	0	1
4	4	0	4	0

2

STEP 3	Favorite Schedule	Optimal Schedule (Weight)	Do They Match?
	Schedule 2	Schedule 1	No

3

Result	Success	Fail	%
Chief 1	6	12	33.3%
Chief 2	4	15	21.1%
Chief 3	7	9	43.7%

- Chief residents prefer to examine schedules and choose the best solution

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Weighted Sum Method: Subjective Metrics

- Some criteria are subjective and difficult to quantify
  - Day off requests
- Various measurement units
  - Equity (σ , $\mathrm{Max}|\mathrm{diff_{ij}}|$, $\sum|\mathrm{diff_{ij}}|$, …)
- Chief resident identifies undesirable qualitative characteristics
  - Interactive feedback

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Optimized Residency Scheduling Assistant (ORSA): Metrics Formulation

- Feasibility problem
  - Constraint on metrics

$$\min (\textbf{weighted sum})$$
$$s.t.\ \text{"rules/requirements"}$$
$$x_{rds} \in \{0,1\}$$

$$\min \sout{(\textbf{weighted sum})}$$
$$s.t.\ \text{"rules/requirements"}$$
$$x_{rds} \in \{0,1\}$$
$$\textbf{Lb} \leq (\boldsymbol{Equity}) \leq \textbf{Ub}$$
$$\textbf{Lb} \leq (\boldsymbol{BSPs}) \leq \textbf{Ub}$$
$$\textbf{Lb} \leq (\boldsymbol{PostCC}) \leq \textbf{Ub}$$
$$\vdots$$

- Benefits of a feasibility problem
  - More flexible
  - Faster to solve: < 2 sec.
    - Given: 35 days / 20 PEDs / 8 shifts

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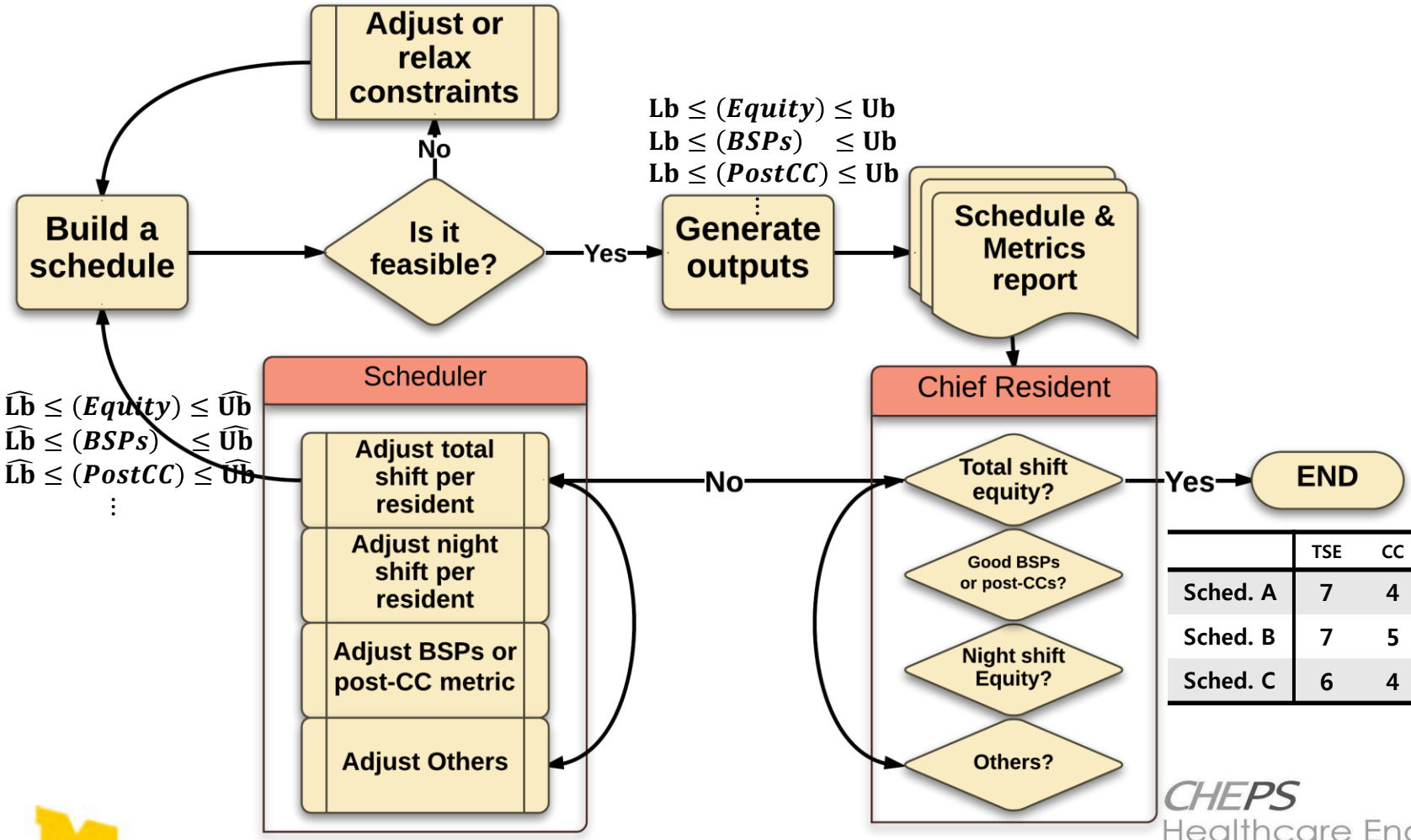
Optimized Residency Scheduling Assistant (ORSA) : Interactive Improvement

- Example output of metrics
  - Value (Lower bound, Upper bound)

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

- Interactive approach engaging chief resident
  - Iteratively adjust bounds on metric constraints
  - Quickly build high quality schedule

ORSA Methodology



	TSE	CC	BSPs	...
Sched. A	7	4	2	...
Sched. B	7	5	1	...
Sched. C	6	4	3	...

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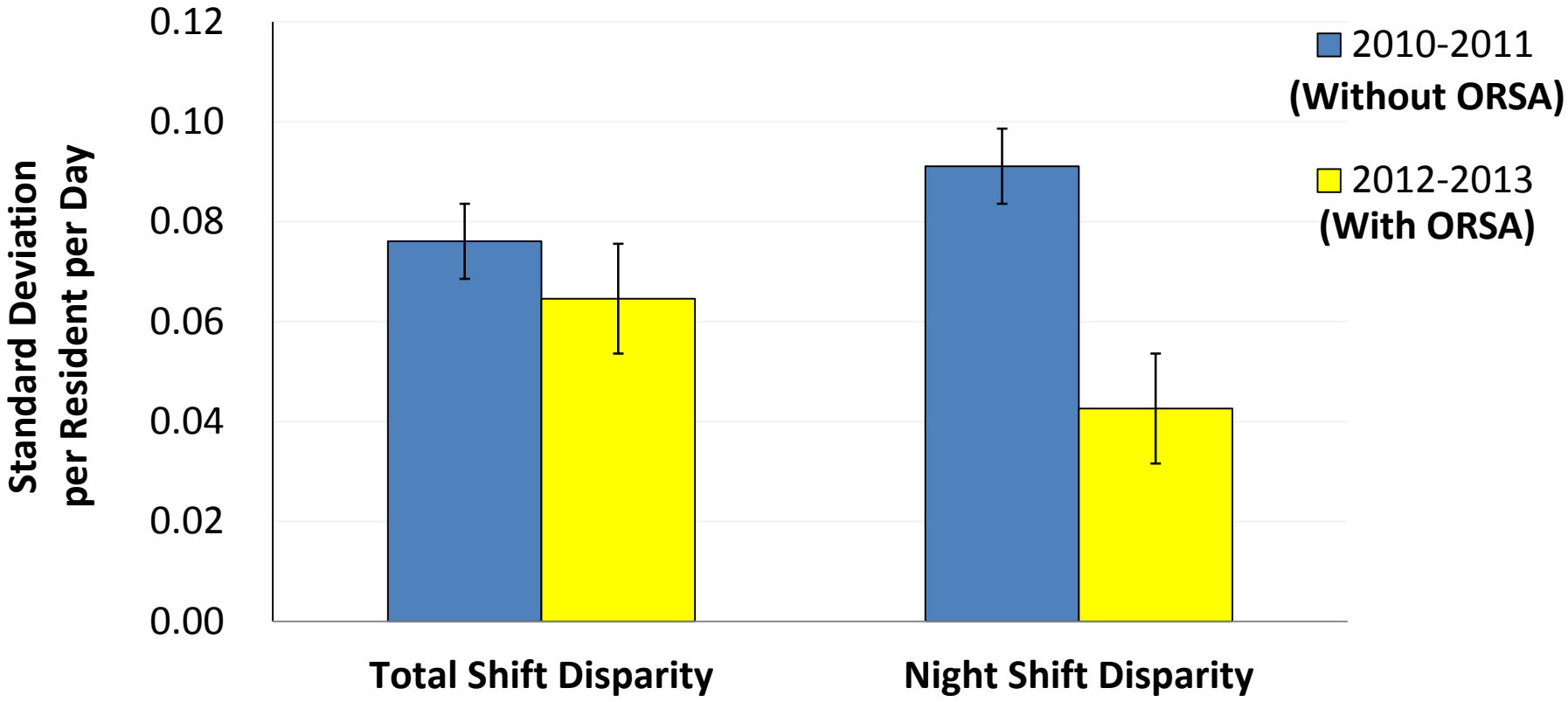
Results: Shift Equity



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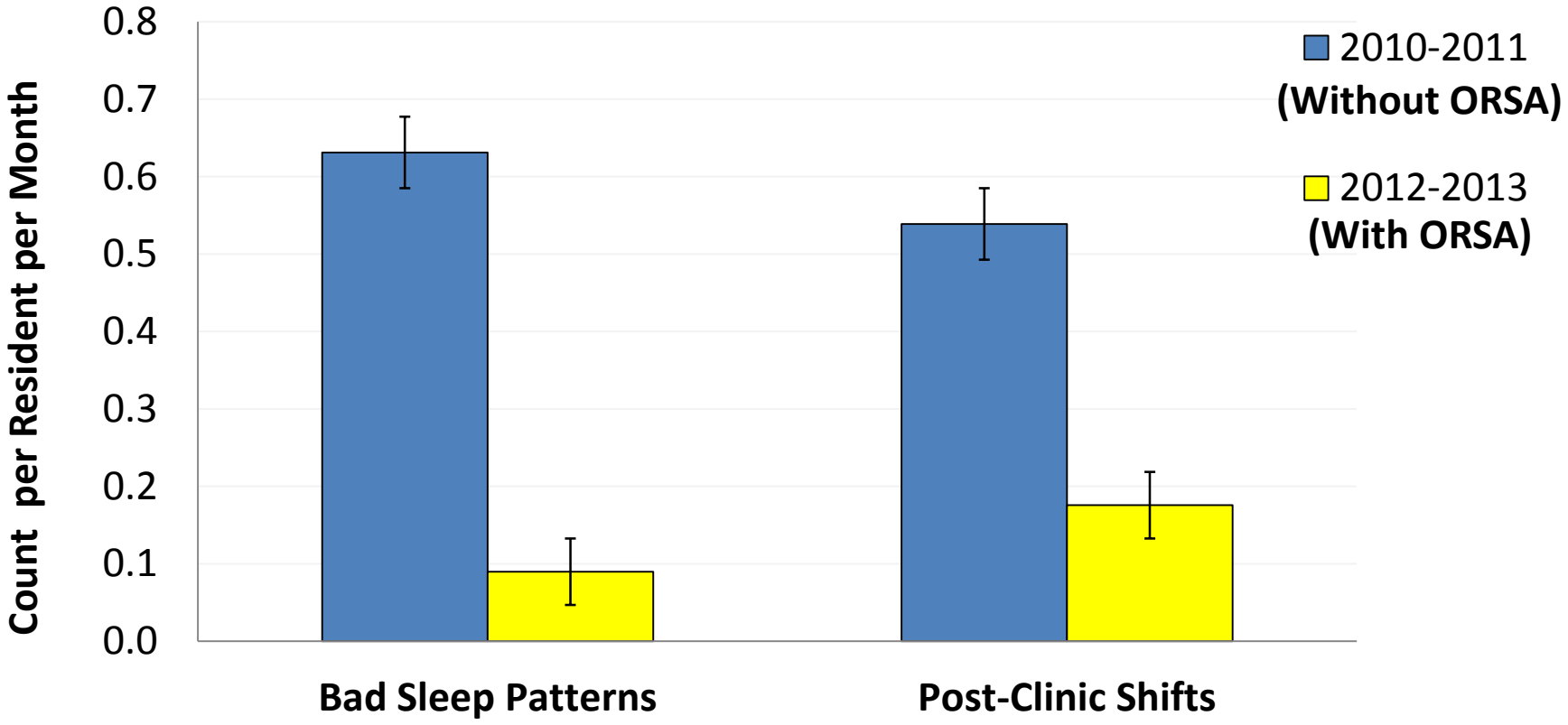
Results: Bad Sleep and Post-Clinic Shifts



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Conclusions

- Our metrics-based scheduling tool:
  - Reduces time to create schedules
    - ~ 24 hour reduction per month
  - Solves a multi-criteria scheduling problem
  - Improves measures of schedule quality by generating multiple candidate schedules

Next Steps

- Automate trial-and-check
- Eliminate equivalent symmetric schedules

Shifts	Mon	Tue	Wed	…
7AM	A ⟺	B	xx	…
⋮	⋮	⋮	⋮	⋮
11PM	xx	A ⟺	B	…

- Eliminate dominated schedules

	TSE	NSE	BSPs	PostCC	Dominance
Schedule A	4	4	1	1	O
Schedule B	5	4	2	1	X

- Apply to other departments

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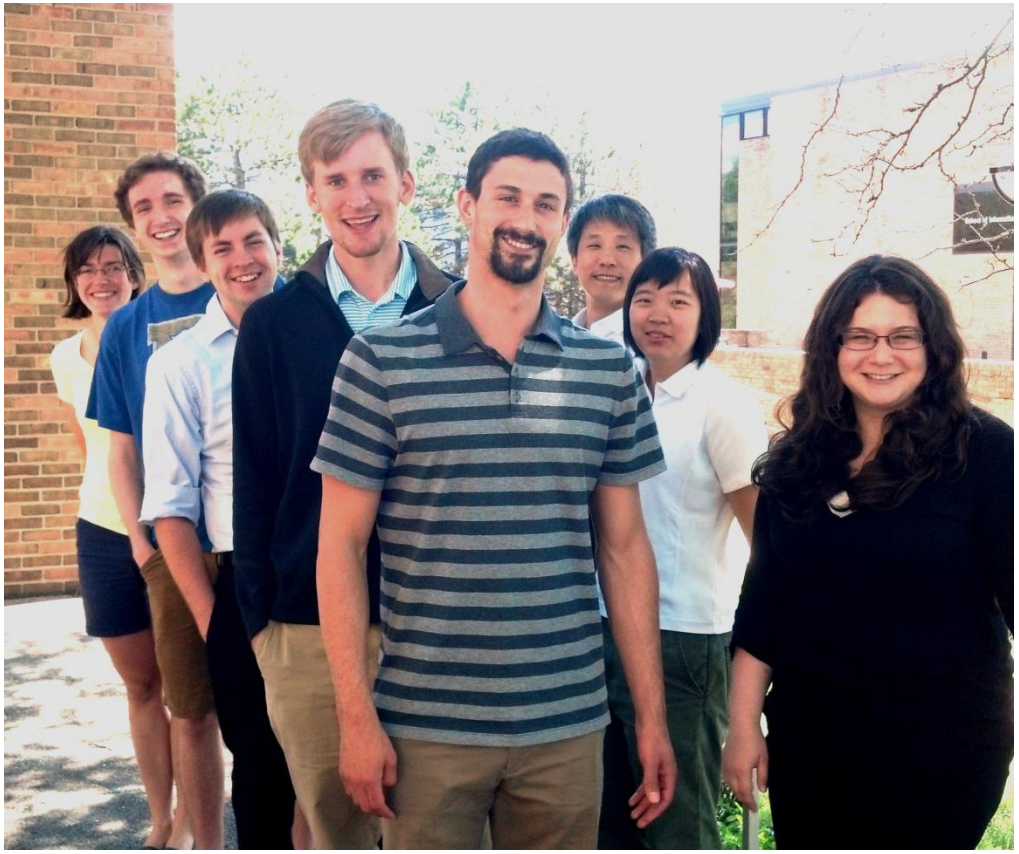
Thank You!