# Using Mathematical Programming to Improve Scheduling for Medical Residents

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# Residency

- 3-7 year medical training program after completion of medical school
- Development of specialty skills
- Work supervised by attending physicians
- Responsibilities differ by residency year
  - Intern / Senior

# Resident Responsibilities in the U-M Pediatric Emergency Department

- 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

# 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

# Previous Shift Making Methodology

- Chief Resident built monthly schedule by hand
- Guess and check
- Development required 20 - 25 hours
  - Approximately 15 hours to build
  - 10 hours to fix errors
- Errors
  - Not easy to recognize
  - Start it over

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 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 |

# Mathematical Modeling

- Incorporates many inputs
- Abides all rules / requirements
- Solves for feasible schedule quickly

# Formulation

- **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 |

# Formulation

- **Constraints**
  - 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
    - $1 \leq \sum_{r \in \{\text{PED}\}} \sum_{s \in \text{P}} x_{rsd} \ , \forall \text{d}, \text{P} = \{\{\text{7a,9a}\}, \{\text{4p,5p}\}, \{\text{8p,11p}\}\}$
  - Intern-forbidden shifts
    - $\sum_{r \in \{\text{interns}\}} \sum_{d} x_{rsd} = 0, \forall s \in \{\text{7a}, \text{11p}\}$
  - And others

# Objectives

- Create a good quality schedule with no violations:
  - Total shift equity
  - Night shift equity
  - Minimum bad sleep patterns
  - Minimum post-clinic shifts
- Multi-criteria problem
  - Trade-off

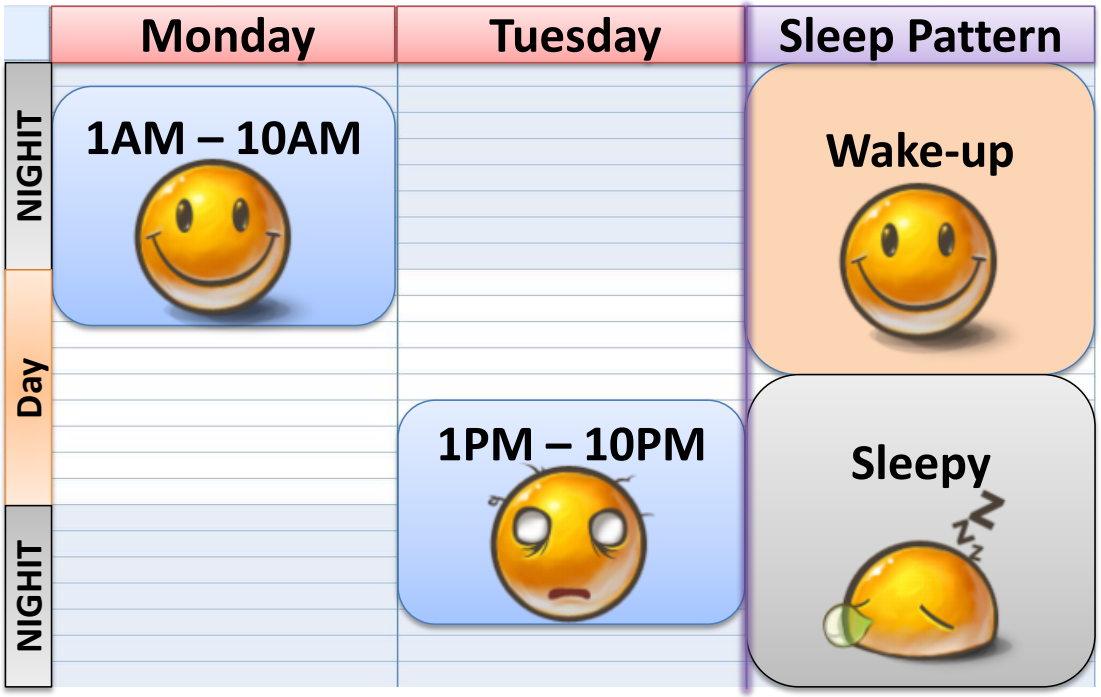
# Metrics: Shift Fairness

- Improving total / night shift equity
  - practice quality in education training
  - poor morale and decreased learning ability

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

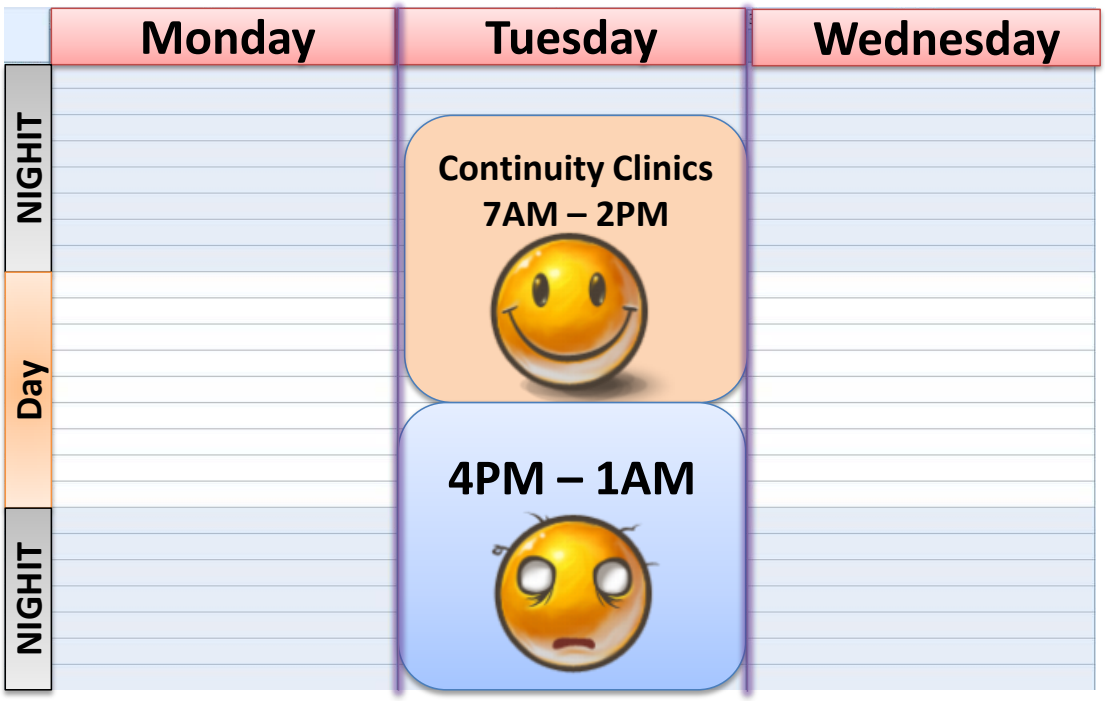
# Metrics: Bad Sleep Patterns

- Work with (not against) circadian rhythm
  - Improves resident quality of life
  - Increases patient safety



# Metrics: Post-Clinic Shifts

- Limit post-clinic shifts
  - Improves resident quality of life
  - Increases patient safety



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# Multi-Criteria Problem : Weighted Sum

$$\textbf{Min}\ w_1(Equity) + w_2(BSPs) + w_3(PostCC) \ldots$$

- Quantifying preferences is difficult
  - No clear way for trade-off
  - Doesn't match your original thought
- Computational time
  - Much slower than feasibility problem
- Chief resident identifies undesirable qualitative characteristics
  - Interactive feedback

# Optimized Residency Scheduling Assistant (ORSA) : Metrics Formulation

- Constraint on metrics

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

$\Rightarrow$

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

- Feasible problem
  - It is enough to know "feasible or infeasible?"
- Benefits of a feasibility problem
  - More flexible
  - Faster to solve : in less than 2 sec.
    - Given : 35 days / 20 PEDs / 8 shifts
    - Phase I only

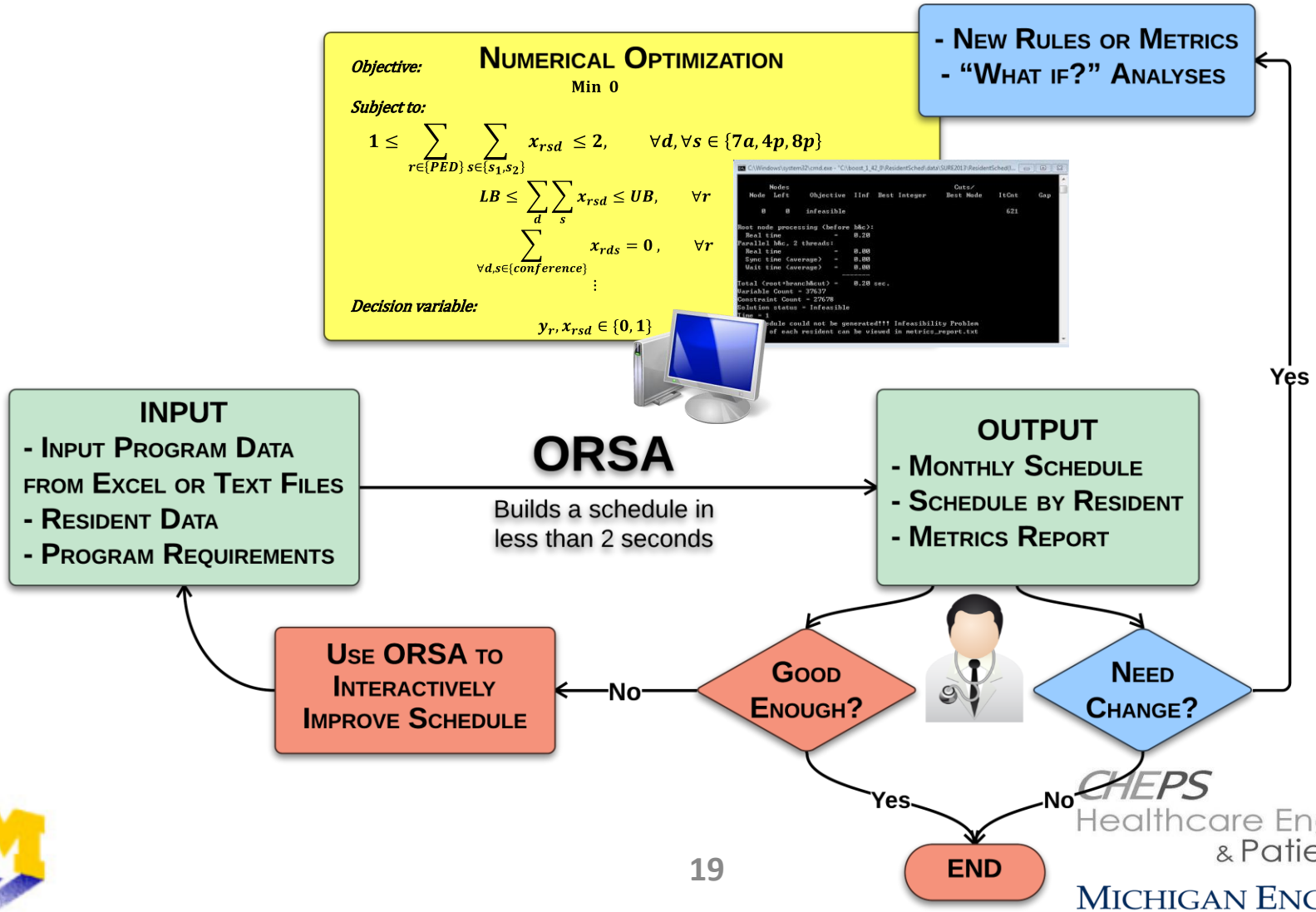
# Optimized Residency Scheduling Assistant (ORSA) : Interactive Improvement

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

| 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
  - High quality schedule built quickly

# Optimized Residency Scheduling Assistant (ORSA)



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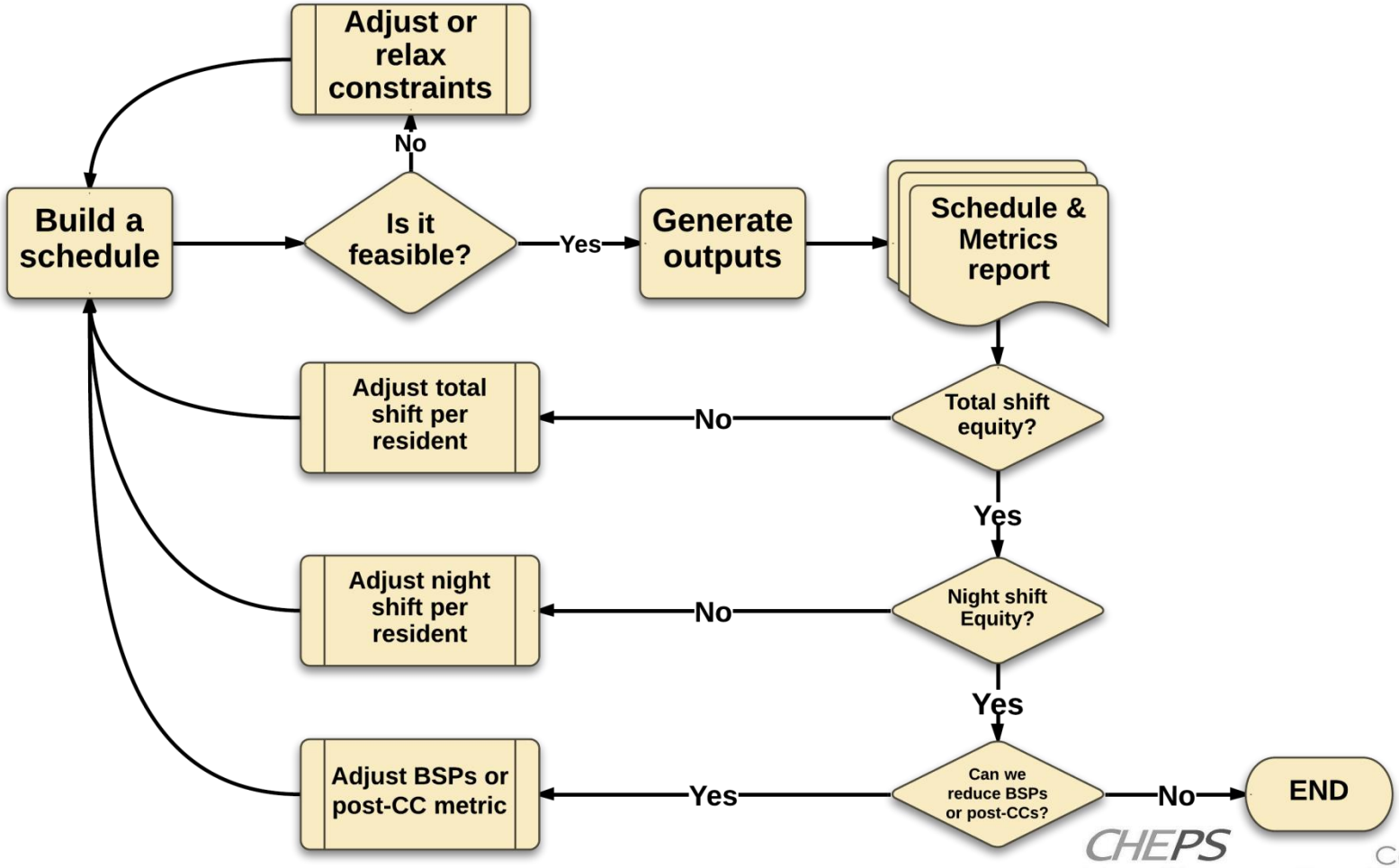
# ORSA Methodology

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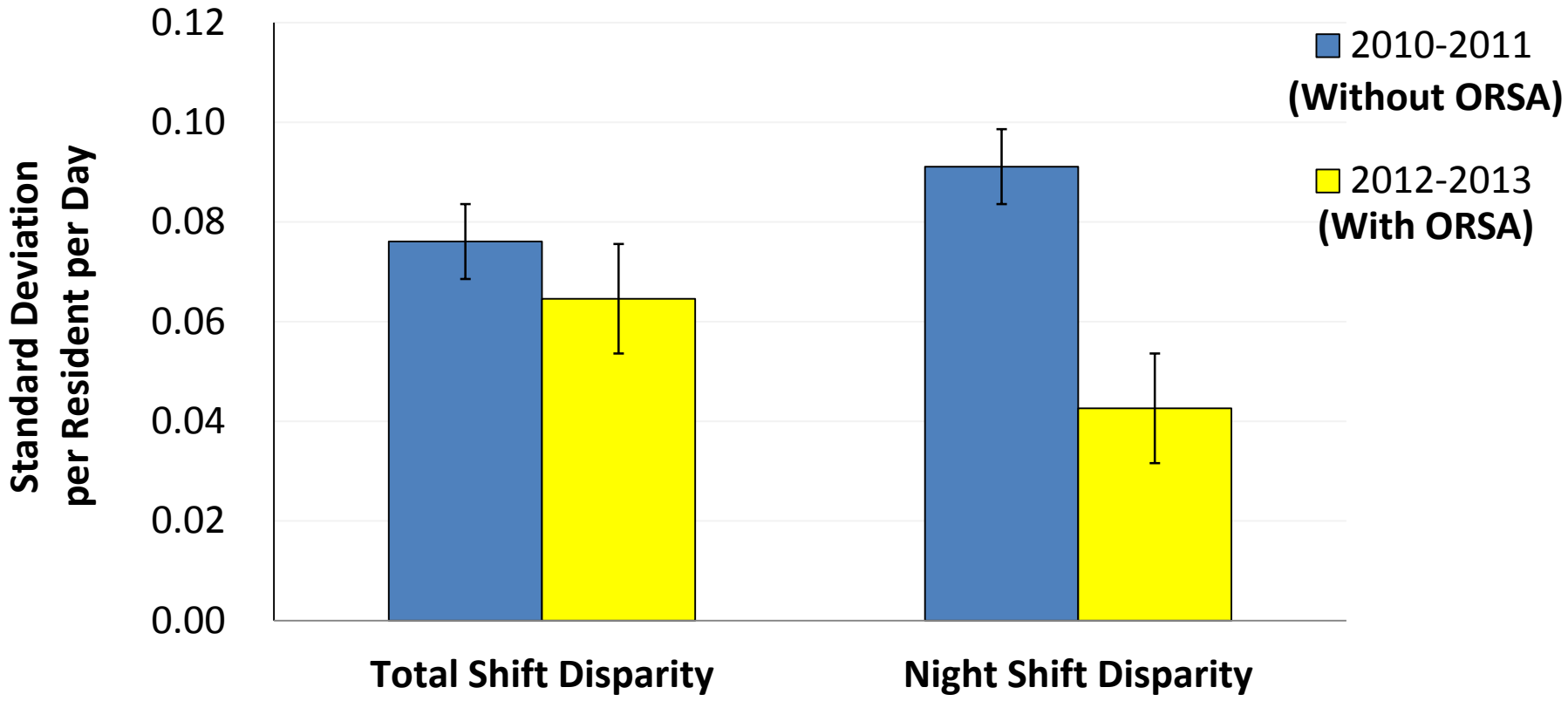
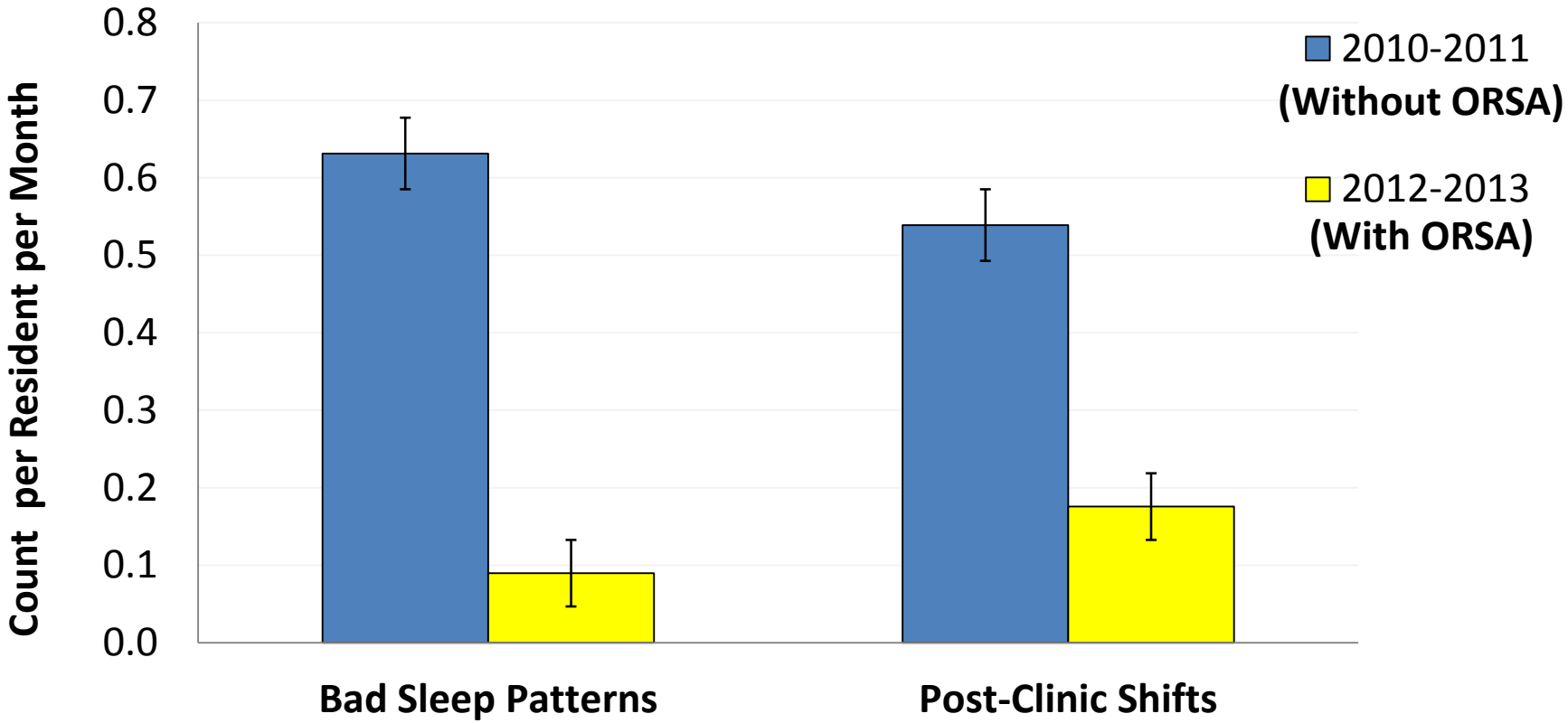
# Results: Shift Equity



# Results: Bad Sleep and Post-Clinic Shifts

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# Conclusions

- Our optimization-based scheduling tool:
  - Solves a multi-criteria scheduling problem
  - Reduces time to create schedule
    - Approximately 24 hour reduction per month
  - Improves measures of schedule quality

# Next Steps

- Create multiple schedules
- Automate trial-and-check
- Apply to other departments/scheduling problems

# Acknowledgements


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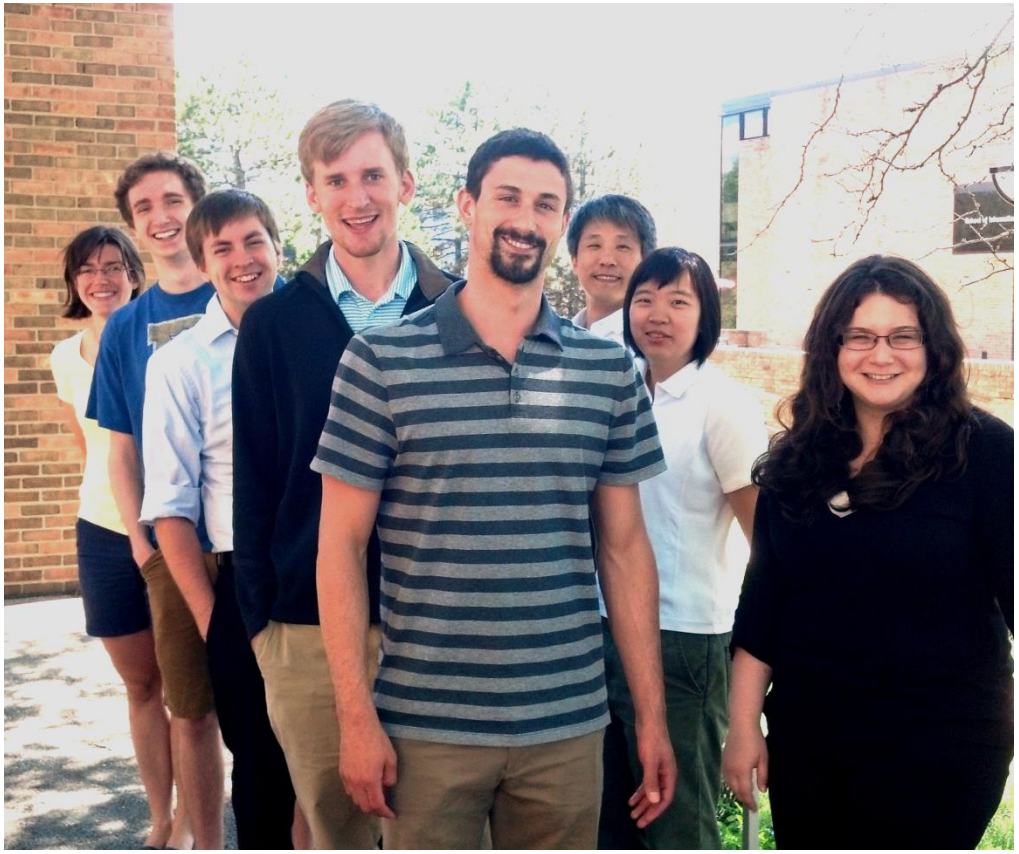
# Thank You!



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