Using Mathematical Programming to Improve Scheduling for Medical Residents

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Contents

- Background
- Mathematical Method
- Schedule Quality
- Optimized Residency Scheduling Assistant (ORSA)
- Results
- Conclusion
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
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

<table>
<thead>
<tr>
<th>Residents Name</th>
<th>27th</th>
<th>...</th>
<th>1st</th>
<th>...</th>
<th>31st</th>
</tr>
</thead>
<tbody>
<tr>
<td>Smith</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sanchez</td>
<td>Shah</td>
<td>...</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Chen</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Shah</td>
</tr>
<tr>
<td>Shah</td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Joe</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Shah</td>
</tr>
<tr>
<td>Chen</td>
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<tr>
<td>Chen</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Smith</td>
<td></td>
<td></td>
<td>Sanchez</td>
<td>...</td>
<td></td>
</tr>
<tr>
<td>Sanchez</td>
<td></td>
<td></td>
<td>Smith</td>
<td>...</td>
<td>Smith</td>
</tr>
<tr>
<td>Smith</td>
<td></td>
<td></td>
<td>Chen</td>
<td>...</td>
<td>Joe</td>
</tr>
<tr>
<td>Joe</td>
<td></td>
<td></td>
<td>Smith</td>
<td>...</td>
<td></td>
</tr>
</tbody>
</table>
Formulation

• **Constraints**
  
  – One resident assigned to each shift in the month
    
    \[ \sum_{r \in \text{all}} x_{rds} = 1, \forall d, \forall s \]
  
  – Meets shift requests
    
    \[ x_{rds} = 0, \forall r, \forall d, s \in \{\text{day off, conferences, continuity clinic}\} \]
  
  – Ensure resident type appropriate for shift
    
    \[ 1 \leq \sum_{r \in \text{PED}} \sum_{s \in P} x_{rds}, \forall d, P = \{\{7a, 9a\}, \{4p, 5p\}, \{8p, 11p\}\} \]
  
  – Intern-forbidden shifts
    
    \[ \sum_{r \in \text{interns}} \sum_{d} x_{rds} = 0, \forall s \in \{7a, 11p\} \]
  
  – 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

<table>
<thead>
<tr>
<th>Resident Name</th>
<th>Smith</th>
<th>Jones</th>
<th>Chen</th>
<th>Joe</th>
</tr>
</thead>
<tbody>
<tr>
<td>Night Shifts / Total Shifts</td>
<td>0 / 7</td>
<td>1 / 7</td>
<td>1 / 7</td>
<td>5 / 7</td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th>Day</th>
<th>Monday</th>
<th>Tuesday</th>
<th>Wednesday</th>
</tr>
</thead>
<tbody>
<tr>
<td>NIGHT</td>
<td></td>
<td>Continuity Clinics 7AM – 2PM</td>
<td></td>
</tr>
<tr>
<td>Day</td>
<td></td>
<td>4PM – 1AM</td>
<td></td>
</tr>
<tr>
<td>NIGHT</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Multi-Criteria Problem: Weighted Sum

\[
\text{Min } w_1(\text{Equity}) + w_2(\text{BSPs}) + w_3(\text{PostCC}) \ldots
\]

- 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**

\[
\begin{align*}
\min \, \text{(weighted sum)} \\
\text{s.t. } "\text{rules/ requirements}" \\
x_{rds} \in \{0,1\}
\end{align*}
\]

- **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

\[
\begin{align*}
\min \, \text{(weighted sum)} \\
\text{s.t. } "\text{rules/ requirements}" \\
x_{rds} \in \{0,1\} \\
L_b \leq \text{(Equity)} \leq U_b \\
L_b \leq \text{(BSPs)} \leq U_b \\
L_b \leq \text{(PostCC)} \leq U_b
\end{align*}
\]
Optimized Residency Scheduling Assistant (ORSA) : Interactive Improvement

• Example output
  – Value (Lower bound, Upper bound) of metrics

<table>
<thead>
<tr>
<th>Resident Name</th>
<th>Number of Shifts</th>
<th>Number of Night Shifts</th>
<th>Number of Post CC</th>
<th>Number of Bad Sleep Templates</th>
</tr>
</thead>
<tbody>
<tr>
<td>Smith</td>
<td>8 (7,9)</td>
<td>1 (0,10)</td>
<td>0 (0,1)</td>
<td>1 (0,1)</td>
</tr>
<tr>
<td>Sanchez</td>
<td>8 (7,10)</td>
<td>2 (0,10)</td>
<td>0 (0,1)</td>
<td>1 (0,1)</td>
</tr>
<tr>
<td>Chen</td>
<td>8 (7,9)</td>
<td>3 (0,10)</td>
<td>1 (0,1)</td>
<td>1 (0,1)</td>
</tr>
<tr>
<td>Shah</td>
<td>14 (13,15)</td>
<td>4 (0,10)</td>
<td>1 (0,1)</td>
<td>1 (0,1)</td>
</tr>
</tbody>
</table>

• Interactive approach engaging chief resident
  – Iteratively adjust bounds on metric constraints
  – High quality schedule built quickly
**Objective:**

\[ \text{Minimize } 0 \]

**Subject to:**

\[ 1 \leq \sum_{r \in \{PRD\}} \sum_{s \in \{s_1, s_2\}} x_{rsd} \leq 2, \quad \forall d, \forall s \in \{7a, 4p, 8p\} \]

\[ LB \leq \sum_{d} \sum_{s} x_{rsd} \leq UB, \quad \forall r \]

\[ \sum_{d} x_{rds} = 0, \quad \forall r, \forall d, s \in \text{conference} \]

**Decision variable:**

\[ y_r, x_{rsd} \in \{0, 1\} \]

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**INPUT**

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

**ORSA**

Builds a schedule in less than 2 seconds

**OUTPUT**

- Monthly Schedule
- Schedule by Resident
- Metrics Report

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**Use ORSA to Interactively Improve Schedule**

- **Good Enough?**
- **Need Change?**

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**NEW RULES OR METRICS**

- “WHAT IF?” ANALYSES

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**END**
ORSA Methodology

1. Build a schedule
2. Adjust or relax constraints
   - No
     - Adjust total shift per resident
     - Adjust night shift per resident
     - Adjust BSPs or post-CC metric
   - Yes
     - Is it feasible?
       - Yes
         - Generate outputs
         - Schedule & Metrics report
           - Total shift equity?
             - Yes
               - Night shift equity?
                 - Yes
                   - Can we reduce BSPs or post-CCs?
                     - No
                       - END
                 - No
               - No
             - No
       - No
     - No
   - Yes
     - END
Results: Shift Equity

<table>
<thead>
<tr>
<th></th>
<th>2010-2011 (Without ORSA)</th>
<th>2012-2013 (With ORSA)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Shift Disparity</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Night Shift Disparity</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Results: Bad Sleep and Post-Clinic Shifts

Bad Sleep Patterns

Count per Resident per Month

2010-2011 (Without ORSA)

2012-2013 (With ORSA)

Post-Clinic Shifts
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!