SCHEDULING FOR MEDICAL RESIDENTS

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Presentation outline

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

• **Background**
  • Shift scheduling
  • Analysis of schedule quality
  • Rotation scheduling
  • Conclusions and future work
Medical training at UMHS

- 1,199 trainees
- 105 training programs
- 25 residencies
- 80 fellowships
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
Presentation outline

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- **Shift scheduling**
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Decision variables

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

\[ x_{r,s,d} \in \{0, 1\}, \quad \forall \ r \in R, \ s \in S, \ d \in D \]
Shift coverage

Must provide sufficient shift coverage for every day and shift

\[ \sum_{r \in R} x_{r,s,d} = 1, \forall d \in D, s \in S \setminus \{\text{flex, EOM, EMSr}\} \]

\[ 0 \leq \sum_{r \in R} x_{r,s,d} \leq 1, \forall d \in D, s \in \{\text{flex, EOM}\} \]

\[ \sum_{r \in R} x_{r,s,d} = 0, \forall d \in D, s \in \{\text{EMSr}\} \]
Cannot create work assignments that conflict with outside commitments

\[ x_{r,s,d} = 0, \quad \forall \ r \in R, \ d \in D, \ s \in \{\text{clinic, conference, vacation}\} \]
Pediatric paired shifts

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

\[
\sum_{r \in \{\text{PED}\}} \sum_{s \in \mathcal{P}} x_{rsd} \geq 1,
\]

\[
\forall \ d \in D, \ P = \{\{7a,9a\}, \{4p,5p\}, \{8p,11p\}\}
\]
Senior-only shifts

Certain shifts must be covered by senior-level residents

\[
\sum_{r \in \{\text{interns}\}} \sum_{d \in D} x_{r,s,d} = 0, \quad \forall s \in \{7a, 11p\}
\]
Residents must get at least 10 hours off-duty between ending one shift and beginning another.

\[
x_{rsd} + \sum_{(s',d') \in \{\text{within 10 hrs of (s,d)}\}} x_{rs'd'} \leq 1, \\
\forall r \in R, s \in S, d \in D
\]
Multi-criteria objective

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

Multi-objective Mathematical Programming

Preferences? Weights? Trade-off?
Multi-criteria objective

- **Optimization problem**

\[
\text{Min } w_1(TSE) + w_2(NSE) + w_3(BSP) + w_4(PCC) \\
\text{s.t. } "\text{rules/requirements}"
\]

\[x_{r,s,d} \in \{0,1\}\]

- **Quantifying preferences (}w_i{) is difficult**
  - Subjective weights
  - Alternative measures
  - Non-linearity
Multi-criteria objective

- **Feasibility Optimization problem**
  \[
  \text{Min } w_1(TSE) + w_2(NSE) + w_3(BSP) + w_4(PCC) \\
  \text{s.t. } "\text{rules/requirements}" \\
  x_{rsd} \in \{0,1\} \\
  lb_{TSE} \leq TSE \leq ub_{TSE} \\
  lb_{NSE} \leq NSE \leq ub_{NSE} \\
  lb_{BSP} \leq BSP \leq ub_{BSP} \\
  lb_{PCC} \leq PCC \leq ub_{PCC}
  \]

- **Benefits of a feasibility problem**
  - Flexibility
  - Speed: < 2 seconds per iteration
    - Given: 20 residents / 7 shifts daily / 35 days
<table>
<thead>
<tr>
<th>Resident Name</th>
<th>Number of Shifts</th>
<th>Number of Night Shifts</th>
<th>Number of Post-CC Shifts</th>
<th>Number of Bad Sleep Patterns</th>
</tr>
</thead>
<tbody>
<tr>
<td>Smith</td>
<td>8 (7,9)</td>
<td>2 (2,3)</td>
<td>0 (0,1)</td>
<td>0 (0,0)</td>
</tr>
<tr>
<td>Sanchez</td>
<td>8 (7,10)</td>
<td>2 (2,3)</td>
<td>0 (0,1)</td>
<td>0 (0,0)</td>
</tr>
<tr>
<td>Chen</td>
<td>8 (7,9)</td>
<td>2 (2,3)</td>
<td>1 (0,1)</td>
<td>0 (0,0)</td>
</tr>
<tr>
<td>Shah</td>
<td>14 (13,15)</td>
<td>4 (3,5)</td>
<td>1 (0,1)</td>
<td>0 (0,0)</td>
</tr>
</tbody>
</table>

Iterative improvements
Presentation outline

• Background
• Shift scheduling
• **Analysis of schedule quality**
• Rotation scheduling
• Conclusions and future work
Implementation results

- Reduced time to create schedules

  20 hours per month → 1 hour per month

- Statistically significant improvement in 3 of 4 major metrics
Total shift equity

<table>
<thead>
<tr>
<th>Month</th>
<th>2010-11</th>
<th>2012-13</th>
<th>2013-14</th>
<th>2014-15</th>
</tr>
</thead>
<tbody>
<tr>
<td>2010-11</td>
<td>0.0761 ± 0.0214</td>
<td>0.0665 ± 0.0367</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2013-14</td>
<td>0.0801 ± 0.0231</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2014-15</td>
<td>0.0743 ± 0.0238</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
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

Percentage Feasible (of 2,000 Iterations)

Total Residents

20
19
18
17
16
15
14
13
12
11

10% 20% 30% 40% 50% 60% 70% 80% 90% 100%

Pr(Senior Standing)
Simulation study

Percentage Feasible (of 2,000 Iterations)

Total Residents

11 0.3%
10% 20% 30% 40% 50% 60% 70% 80% 90% 100% 

Pr(Senior Standing)
Simulation study

<table>
<thead>
<tr>
<th>Total Residents</th>
<th>Percentage Feasible (of 2,000 Iterations)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>10%</td>
</tr>
<tr>
<td>20</td>
<td>5.4%</td>
</tr>
<tr>
<td>19</td>
<td>6.2%</td>
</tr>
<tr>
<td>18</td>
<td>4.1%</td>
</tr>
<tr>
<td>17</td>
<td>3.8%</td>
</tr>
<tr>
<td>16</td>
<td>2.2%</td>
</tr>
<tr>
<td>15</td>
<td>2.1%</td>
</tr>
<tr>
<td>14</td>
<td>1.2%</td>
</tr>
<tr>
<td>13</td>
<td>0.7%</td>
</tr>
<tr>
<td>12</td>
<td>0.6%</td>
</tr>
<tr>
<td>11</td>
<td>0.3%</td>
</tr>
</tbody>
</table>

Pr(Senior Standing)
Presentation outline

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

<table>
<thead>
<tr>
<th>Service Pair</th>
<th>July</th>
</tr>
</thead>
<tbody>
<tr>
<td>NICU</td>
<td>General</td>
</tr>
<tr>
<td>1st Half</td>
<td>2nd Half</td>
</tr>
</tbody>
</table>

Hard = 0
**Decision variables**

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

\[ x_{rpm} \in \{0, 1\}, \quad \forall \ r \in R, \ p \in P, \ m \in M \]

<table>
<thead>
<tr>
<th>Month</th>
<th>July</th>
<th>August</th>
<th>September</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1\textsuperscript{st} Half</td>
<td>2\textsuperscript{nd} Half</td>
<td>1\textsuperscript{st} Half</td>
</tr>
<tr>
<td>Paige Mollison</td>
<td>General</td>
<td>General</td>
<td>Heme Onc</td>
</tr>
<tr>
<td></td>
<td>Hard = 0</td>
<td>Hard = 1</td>
<td></td>
</tr>
<tr>
<td>Luke Stumpos</td>
<td>1\textsuperscript{st} Half</td>
<td>2\textsuperscript{nd} Half</td>
<td>1\textsuperscript{st} Half</td>
</tr>
<tr>
<td></td>
<td>Heme Onc</td>
<td>NICU</td>
<td>General</td>
</tr>
<tr>
<td></td>
<td>Hard = 1</td>
<td>Hard = 0</td>
<td></td>
</tr>
</tbody>
</table>
Monthly rotation assignment

Each resident is assigned one service pair per month

\[ \sum_{p \in P} x_{rpm} = 1, \quad \forall r \in R, m \in M \]
Each service must have between a minimum and maximum number of residents at all times

\[ \text{LBRes}_{sm} \leq \sum_{p \in P_{sh}} x_{rpm} \leq \text{UBRes}_{sm} , \]

\[ \forall s \in S, m \in M, h \in \{1, 2\} \]
Educational requirements

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

\[ \text{LBMonths}_{rs} \leq \sum_{p \in P} \sum_{m \in M} q_{ps} x_{rpm} \leq \text{UBMonths}_{rs}, \]

\[ \forall r \in R, s \in S \]
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

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

\[ \sum_{m \in M} Y_{rm} \leq UBHard_r, \quad \forall \ r \in R \]
Implementation results

• Two-phase schedule creation
  – Senior phase
  – Intern phase

• Satisfied 238/242 (98.3%) of time preference requests

• Speed: < 3 minutes per iteration
Presentation outline

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• **Conclusions and future work**
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
• The Doctors Company Foundation
• The Seth Bonder Foundation
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

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

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

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

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

\[
\begin{align*}
\min & \quad \sum_{rsd \in \text{off}} x_{rsd} + \sum_{rsd \in \text{on}} (1 - x_{rsd}) \\
\text{s.t.} & \quad \text{“New Requests”} \\
& \quad \text{On: } \{(r, s, d) \mid \bar{x}_{rsd} = 1\} \\
& \quad \text{Off: } \{(r, s, d) \mid \bar{x}_{rsd} = 0\}
\end{align*}
\]

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

OUTPUT
- Monthly Schedule
- Schedule by Resident
- Metrics Report

Use ORSA to Interactively Improve Schedule

Good Enough?

Need Change?

Yes

No

END
Implementation Process

Sets
- \( R \): residents
- \( C \): resident categories
- \( S \): services
- \( M \): months

Parameters
- \( \alpha_{re} \in \{0, 1\} \): whether resident \( r \) fits category \( e \)
- \( \lambda_{re, m}, \mu_{re, m} \): lower, upper bounds on staff of residents fitting category \( e \) in service \( s \) during month \( m \)

Decision Variables
- \( x_{rem} \in \{0, 1\} \): whether resident \( r \) is assigned to service \( s \) in month \( m \)

Objective Function
- \( \forall r \in R, s \in S, m \in M \)
Total shifts

- Must provide adequate educational experience for every resident

\[ \text{LBShifts}_r \leq \sum_{s \in S} \sum_{d \in D} x_{r,s,d} \leq \text{UBShifts}_r, \quad \forall r \in R \]

\[ \text{LBNites}_r \leq \sum_{s \in S} \sum_{d \in D} x_{r,s,d} \leq \text{UBNites}_r, \quad \forall r \in R \]