Nurse Scheduling: From Theoretical Modeling to Practical Resolution

Graduate Student Paper Competition Winner

École Polytechnique de Montréal
February 19th, 2011
Outline

1. Context
2. Methodology
3. Results
4. Conclusion
5. Questions
Quebec’s Healthcare Context

• Universal access to healthcare
• Aging of population
• Ever-increasing costs, demand and workload
• Nurses shortage (absenteism, $$$$)

Nurse scheduling is a complex exercise with multiple and contradictory objectives:
• minimizing total costs
• maximizing the nurses’ preferences and requests
• equally distributing workload between nurses
• ...
Project Context - 1

Resource Optimization in Healthcare, Fall 2010
Masters’ program,
Applied Mathematics and Industrial Engineering Department,
École Polytechnique de Montréal

Objectives:
– Conduct a practical study on nurse scheduling process in 2 hospitals
– Introduce models and heuristics that can be easily implemented at no extra cost
– Use of commercial softwares to generate new schedules and to validate heuristics’ efficiency
Project Context - 2

Notre-Dame Hospital

Sainte-Justine Hospital

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- Two large public and university hospitals
- Standard nurses structure: Regular and float teams
- Decentralized scheduling
Current scheduling process

For both hospitals:

1. Collect preferences
2. Sketch the schedule
3. Correct the schedule
4. Post the schedule
5. Adjust the schedule

- 4 inputs: Constraints related to work agreements, demand coverage, preferences and personal judgment
The mathematical model

\[
\begin{align*}
\min & \sum_{j=1}^{27} \sum_{i \in N} \sum_{k \in K} \gamma_{ik} (x_{ijk} - x_{ij+1,k})^2 + \sum_{j=1}^{28} \sum_{k \in K} \left[ c^+ z_{jk}^+ - c^- z_{jk}^- - \sum_{i \in N} (b_i P_{ij} x_{ijk} + r_i F_{ij} x_{ijk}) \right] \\
\text{s.t.} & \sum_{i \in N} x_{ijD} \geq 1, \quad \forall j = 1, \ldots, 28 \quad (1) \\
& \sum_{k \in K} x_{ijk} = F_{ij}, \quad i \in N, j = 1, 7, 8, 14, 15, 21, 22, 28 \quad (8) \\
& \sum_{k \in K} x_{ijk} \leq 1 - A_{ij}, \quad \forall i \in N, j \in J \quad (2) \\
& x_{ijD} + x_{ij+1N} \leq 1, \quad \forall i \in N, j = 1, \ldots, 27 \quad (9) \\
& \sum_{j=b}^{b+13} \left( A_{ij} + \sum_{k \in K} x_{ijk} \right) \leq T, \quad \forall i \in N, b = 1, 8, 15, 22 \quad (3) \\
& \sum_{j=b}^{b+13} \left( A_{ij} + \sum_{k \in K} x_{ijk} \right) \leq \sum_{j=b}^{b+13} F_{ij}, \forall i \in N, b = 1, 15 \quad (4) \\
& \sum_{j=b}^{b+5-M_i} x_{ijk} \leq T - M_i, \quad \forall i \in N, b = 1, \ldots, 5 \quad (5) \\
& \sum_{j=b}^{b+5} \sum_{k \in K} x_{ijk} \leq T, \quad \forall i \in N, b = 6, \ldots, 23 \quad (6) \\
& x_{ijk} \leq Q_{ik}, \forall i \in N, j = 1, \ldots, 28, k \in K \quad (7) \\
& z_{jk}^+ \geq \sum_{i \in N} x_{ijk} - D_{jk}, \forall j \in J, \forall k \in K \quad (11) \\
& z_{jk}^- \geq D_{jk} - \sum_{i \in N} x_{ijk}, \forall j \in J, \forall k \in K \quad (12) \\
& x_{ijk} \in \{0,1\} \quad (13) \\
& z_{jk}^+, z_{jk}^- \text{ real }, \forall \ j = 1, \ldots, 28, k \in K \quad (14)
\end{align*}
\]
Methodology - 1

Improving the current process:

1. Notre-Dame Hospital:
   – Improve the «Sketch the schedule» step by eliminating back and forth movements between two spreadsheets when adjusting the demand coverage

2. Sainte-Justine Hospital:
   – Reduce time for steps 1 to 3 by defining a clear rule on when the list of preferences is expected and a deadline from which no more changes are accepted
Methodology - 2

Standardizing the current process (1/2):

• Current process is person-based
• Guidelines to help decision-making, considering the different objectives
• 2 heuristics were developed using Excel:
  1. Start with a standard schedule
  2. Use the proposed simple flip movements to improve schedule
  3. End when stop criteria is reached
• Designed to be close to the current process to facilitate adaptation
Methodology - 3

Standardizing the current process (2/2):

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Introducing automated scheduling:

- **Objectives**
  - Show what can be done with available softwares
  - Compare the solutions to evaluate the performance of the proposed heuristics

- **Advantages:**
  - Consider more authorized movements
  - Maximize the objectives while respecting all specified constraints
  - Automatization, standardization & simplification of the process
## Results

### Table 1: Results for Notre-Dame Hospital

<table>
<thead>
<tr>
<th>Rank</th>
<th>Criteria</th>
<th>Clerk</th>
<th>Heuristic</th>
<th>Commercial</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Quota requirement</td>
<td>+</td>
<td>+</td>
<td>++</td>
</tr>
<tr>
<td>2</td>
<td>Time consumption</td>
<td>-</td>
<td>++</td>
<td>++</td>
</tr>
<tr>
<td>3</td>
<td>Cost</td>
<td>+</td>
<td>++</td>
<td>--</td>
</tr>
<tr>
<td>4</td>
<td>Preferences</td>
<td>++</td>
<td>+</td>
<td>++</td>
</tr>
<tr>
<td>5</td>
<td>Seniority</td>
<td>++</td>
<td>+</td>
<td>N/A</td>
</tr>
<tr>
<td>6</td>
<td>Ergonomics</td>
<td>++</td>
<td>-</td>
<td>+</td>
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<tr>
<td>7</td>
<td>Equity</td>
<td>+</td>
<td>-</td>
<td>N/A</td>
</tr>
<tr>
<td>8</td>
<td>Standard</td>
<td>--</td>
<td>++</td>
<td>++</td>
</tr>
<tr>
<td>9</td>
<td>Simple to use</td>
<td>--</td>
<td>+</td>
<td>+</td>
</tr>
</tbody>
</table>

### Table 2: Results for Sainte-Justine Hospital

<table>
<thead>
<tr>
<th>Rank</th>
<th>Criteria</th>
<th>Clerk</th>
<th>Heuristic</th>
<th>Commercial</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Preferences</td>
<td>++</td>
<td>+</td>
<td>++</td>
</tr>
<tr>
<td>2</td>
<td>Time consumption</td>
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<td>++</td>
</tr>
<tr>
<td>3</td>
<td>Cost</td>
<td>+</td>
<td>++</td>
<td>-</td>
</tr>
<tr>
<td>4</td>
<td>Quota requirement</td>
<td>-</td>
<td>+</td>
<td>++</td>
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<td>++</td>
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<tr>
<td>9</td>
<td>Simple to use</td>
<td>--</td>
<td>+</td>
<td>+</td>
</tr>
</tbody>
</table>

### Table 3: Time reduction for both hospitals each month using a standardized approach

<table>
<thead>
<tr>
<th>TIME</th>
<th>N.-D. Hospital</th>
<th>S.-J. Hospital</th>
</tr>
</thead>
<tbody>
<tr>
<td>Actual time</td>
<td>2 to 4 days</td>
<td>4 weeks</td>
</tr>
<tr>
<td>Heuristic time</td>
<td>0.5 day</td>
<td>2 weeks</td>
</tr>
<tr>
<td>REDUCTION:</td>
<td>1.5 to 3.5 days</td>
<td>2 weeks</td>
</tr>
</tbody>
</table>
Conclusion

- Actual scheduling process is long, non-standardized and person-based
- Learnings in operations research and optimizing resources applied to 2 practical cases
- Problems modelled and solved by 2 efficient heuristics and 2 commercial softwares
- Important links between regular and float teams
Acknowledgments

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Questions