Scheduling Colonoscopy Patients in an Outpatient Endoscopy Clinic

Karmel Shehadeh
PhD Pre-Candidate
Industrial and Operations Engineering
University of Michigan

HSPIC, Orlando
March 3, 2017
Team Recognition

- Systems Concepts for the Optimization and Personalization of Endoscopy Scheduling (SCOPES) team
  - Dr. Amy Cohn, Dr. Kurlander and Dr. Saini
  - All CHEPS students who support SCOPES
• **Background**
  - Stochastic Colonoscopy Appointment Problem (SCAp)
  - Numerical Experiment
  - General Scheduling Policy
  - Future Directions
Endoscopy Unit

- Outpatient Procedure Center (OPC)

- Conducting screening and surveillance procedures for diseases affecting the digestive system
  - abdominal pain, colitis, constipation, etc.

- Encountering exponentially increasing demand in a resource-constrained setting
  - 7.25 million procedures in 2010

Colonoscopy Procedure

• Screening test for Colorectal Cancer (CRC)
  – 2\textsuperscript{nd} leading cause of cancer-related death in the US\textsuperscript{2}
  – 4.5 million age-eligible subjects in the US (≥50 years)\textsuperscript{3}

• Enables a gastroenterologist to evaluate the inside of the large intestine (rectum and colon)
  – \textbf{Spot} existing cancer, prompting treatment
  – \textbf{Prevent} future cancer (\textit{polyps})

\textsuperscript{2} American Cancer Society
\textsuperscript{3} Jain et al (2015)
Colonoscopy Scheduling

- Rich literature about outpatient scheduling
- One unique characteristic of colonoscopy scheduling, however, is unique bimodal duration structure

<table>
<thead>
<tr>
<th>Duration</th>
<th>Prep Quality</th>
<th>Health Conditions</th>
<th>No. of Polyps</th>
<th>Type of Sedation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Short</td>
<td>Adequate</td>
<td>Good</td>
<td>Low</td>
<td>Conscious</td>
</tr>
<tr>
<td>Long</td>
<td>Poor</td>
<td>Poor</td>
<td>High</td>
<td>Anesthesia</td>
</tr>
</tbody>
</table>

* Note: also for some cases procedure is not performed

- Multiple, unique and conflicting criteria that affect the quality of colonoscopy schedule
  - Number of appointments (access to screening), patient outcome and risk of CRC, patient and provider preferences, delays, idling, overtime
Importance?

• On-time Schedule
  – Less provider fatigue
  – More efficient performance

• Less Waiting
  – Better experience
  – Fewer cancelation

• More appointments

• Better Outcome!
Presentation Outline

- Background
- **Stochastic Colonoscopy Appointment Problem (SCAp)**
  - Numerical Experiment
  - General Scheduling Policy
  - Future Directions
SCAp: Goals

- Develop a **Decision Support Tool** to decide the order (sequence) and the appointment time for a set of patients while considering

  1. The **unique and bimodal** duration structure
  2. Patient **absenteeism** and **un-punctuality**
  3. Multiple and **conflicting** criteria that affect the quality of schedule
     - Waiting, idling and overtime
     - Patient **outcomes** and **preferences** (future talk)
SCAp Formulation

• **Objective:**
  Optimal schedule that minimize total expected waiting, idling and overtime

• **First stage decisions (generate a schedule)**
  Patient order
  Appointment times

• **Second stage decisions (actual schedule)**
  Arrival time
  Actual start time
  Waiting, idling, overtime (metrics)
Presentation Outline

- Background
- Stochastic Colonoscopy Appointment Problem
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Questions

• How the performance of optimal schedule changes as a function of variation in the prep?

• How the performance of optimal schedule changes as a function of no-show?

• How the performance of optimal schedule changes as a function of arrival uncertainty?
Model Parameters: Duration

<table>
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<td>Poor</td>
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- Type likelihood $\gamma = 0.75$
- Simplest model
  - Short: 30 minutes with 0.75 probability
  - Long: 90 minutes with 0.25 probability
- Complex model
  - Short: $\text{Normal}(30, \sigma_s^2)$ with 0.75 probability
  - Long: $\text{Normal}(90, \sigma_l^2)$ with 0.25 probability
Model Parameters: no-show & arrivals

- **Unpunctuality**: $N(\mu, \sigma^2)$
  - Punctual
  - Early/Late

- **No-show**: Uniform[0, 1]
  - Homogenous; once-class
  - Heterogeneous: multiple class
Monte Carlo Optimization

Figure 1: Steps of Monte Carlo Optimization
Impact of Duration Uncertainty

Observations:

- **Variability** in procedure duration makes it **challenging** to control the schedule
- Adjusting the schedule to account for **changes** in the mean duration is much way easier than for duration variability
  - It would be possible to account for average bowel prep behavior but **more challenging** to account for **variability in prep quality** among patients

Figure 2: Effect of duration uncertainty on schedule performance
Impact of procedure type

• Balanced (5 short: 5 long):

![Graph showing impact of procedure type on optimal scheduling policy]

Figure 3: Effect of procedure type on optimal scheduling policy

**Short**: e.g. good prep, conscious sedation colonoscopy, etc.

**Long**: e.g. poor prep, monitored anesthesia colonoscopy, etc.
Impact of procedure type

- Unbalanced (8 short:2 long)

Figure 4: Effect of procedure type on optimal scheduling policy

- **Short**: e.g. good prep, conscious sedation colonoscopy, etc.
- **Long**: e.g. poor prep, monitored anesthesia colonoscopy, etc.
Impact of Arrivals Uncertainty

Observations:
- Variability in arrivals makes it challenging to control the schedule
- Adjusting the schedule to account for changes in the average earliness/lateness behavior is much way easier than for the variability in earliness/lateness behavior

Figure 3: Effect of arrivals uncertainty on schedule performance
**Impact of No-Show**

Observations:
- **One class**: higher rates resulted in performance improvement
- **Two classes**: performance fluctuates between improvement and deterioration
- It would be challenging to account for the variability of no-show behavior among patients

Figure 6: changes in optimal schedule performance for one classes of no-show (blue) as the rate changes from 0% to 35% and for two patient classes (red) where the rate is 18% for one class and ranges from 0% to 35% for the other class.
Figure 7: Effect of patient no-shows on optimal inter-appointment time for the case of one class of no-shows
Figure 8: Effect of patient no-shows on optimal inter-appointment time for the case of two classes of no-shows
Presentation Outline

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- Numerical Experiment
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- Future Directions
Benchmarks

- **SCAp1**: optimal SCAp sequence with schedule time approximated down to the nearest 5
  - e.g. \([7.27]\) = 7.25

- **SCAp2**: optimal SCAp sequence with schedule time approximated down up to the nearest 5
  - e.g. \([7.27]\) = 30

- **Individual-Block/Fixed-Interval (IBFI)**: schedule patients individually at intervals equal to the mean procedure duration

- **Bailey’s rule (2BEG)**: double book two patients at beginning of day then **IBFI**

- **Universal Dom Rule (DC1F)**: appointment lengths are smaller at the beginning and end of day and longer in the middle of the day
Table 2: Change in average performance from optimal
(0% no-show, punctual)

<table>
<thead>
<tr>
<th>Policy</th>
<th>waiting+idle +overtime</th>
<th>waiting</th>
<th>idling</th>
<th>overtime</th>
</tr>
</thead>
<tbody>
<tr>
<td>IBFI</td>
<td>15.15 %</td>
<td>43.23 %</td>
<td>-34.58 %</td>
<td>-3.16 %</td>
</tr>
<tr>
<td>2BEG</td>
<td>&gt;100 %</td>
<td>&gt;100 %</td>
<td>-96.93 %</td>
<td>-25.73 %</td>
</tr>
<tr>
<td>DC1F</td>
<td>27.5 %</td>
<td>-39.54 %</td>
<td>85.84 %</td>
<td>&gt;100 %</td>
</tr>
<tr>
<td>SCAp1</td>
<td>4.90 %</td>
<td>16.99 %</td>
<td>-12.9 %</td>
<td>-7.37 %</td>
</tr>
<tr>
<td>SCAp2</td>
<td>0 %</td>
<td>-9.92 %</td>
<td>10.68 %</td>
<td>14.87 %</td>
</tr>
</tbody>
</table>
Table 3: Change in average performance from optimal  
(18% no-show, early on average)

<table>
<thead>
<tr>
<th>Policy</th>
<th>waiting+idle</th>
<th>waiting</th>
<th>idling</th>
<th>overtime</th>
</tr>
</thead>
<tbody>
<tr>
<td>IBFI</td>
<td>32.11 %</td>
<td>77.38 %</td>
<td>-47.01 %</td>
<td>-47.01 %</td>
</tr>
<tr>
<td>2BEG</td>
<td>76.56 %</td>
<td>&gt;100 %</td>
<td>-65.84 %</td>
<td>-65.84 %</td>
</tr>
<tr>
<td>DC1F</td>
<td>&gt;100 %</td>
<td>&gt;100 %</td>
<td>&gt;100 %</td>
<td>&gt;100 %</td>
</tr>
<tr>
<td>SCAp1</td>
<td>0.70 %</td>
<td>2.88 %</td>
<td>-6.36 %</td>
<td>-6.36 %</td>
</tr>
<tr>
<td>SCAp2</td>
<td>0.08 %</td>
<td>-2.91 %</td>
<td>10.74 %</td>
<td>10.74 %</td>
</tr>
</tbody>
</table>
Table 4: Change in average performance from optimal 
(18% no-show, 50% early and 50% late on average)

<table>
<thead>
<tr>
<th>Policy</th>
<th>waiting+idle +overtime</th>
<th>waiting</th>
<th>idling</th>
<th>overtime</th>
</tr>
</thead>
<tbody>
<tr>
<td>IBFI</td>
<td>30.12%</td>
<td>56.31%</td>
<td>-24.06%</td>
<td>7.24%</td>
</tr>
<tr>
<td>2BEG</td>
<td>75.13%</td>
<td>&gt;100%</td>
<td>-58.02%</td>
<td>-60.70%</td>
</tr>
<tr>
<td>DC1F</td>
<td>&gt;100%</td>
<td>&gt;100%</td>
<td>-73.22%</td>
<td>-59.20%</td>
</tr>
<tr>
<td>SCAp1</td>
<td>2.50%</td>
<td>4.39%</td>
<td>-4.15%</td>
<td>-3.49%</td>
</tr>
<tr>
<td>SCAp2</td>
<td>1.48%</td>
<td>-3.73%</td>
<td>6.53%</td>
<td>36.61%</td>
</tr>
</tbody>
</table>
Example for Practical and Optimal Template
### Table 5: Duration Variability Only

<table>
<thead>
<tr>
<th>Slot</th>
<th>Type</th>
<th>Time</th>
<th>Length</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>C1</td>
<td>7.30</td>
<td>30</td>
</tr>
<tr>
<td>2</td>
<td>C1</td>
<td>8.00</td>
<td>30</td>
</tr>
<tr>
<td>3</td>
<td>C2</td>
<td>8.30</td>
<td>95</td>
</tr>
<tr>
<td>4</td>
<td>C2</td>
<td>10.05</td>
<td>90</td>
</tr>
<tr>
<td>5</td>
<td>C1</td>
<td>11.35</td>
<td>35</td>
</tr>
<tr>
<td>6</td>
<td>C1</td>
<td>12.05</td>
<td>35</td>
</tr>
<tr>
<td>7</td>
<td>C2</td>
<td>12.40</td>
<td>45</td>
</tr>
</tbody>
</table>

### Table 8: Duration + **No-show** + 50% late

<table>
<thead>
<tr>
<th>Slot</th>
<th>Type</th>
<th>Time</th>
<th>Length</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>C1</td>
<td>7.00</td>
<td>20</td>
</tr>
<tr>
<td>2</td>
<td>C2</td>
<td>7.20</td>
<td>85</td>
</tr>
<tr>
<td>3</td>
<td>C1</td>
<td>8.45</td>
<td>25</td>
</tr>
<tr>
<td>4</td>
<td>C2</td>
<td>9.10</td>
<td>85</td>
</tr>
<tr>
<td>5</td>
<td>C1</td>
<td>10.30</td>
<td>40</td>
</tr>
<tr>
<td>6</td>
<td>C1</td>
<td>11.10</td>
<td>35</td>
</tr>
<tr>
<td>7</td>
<td>C2</td>
<td>11.45</td>
<td>70</td>
</tr>
</tbody>
</table>

C1: short procedure (e.g. conscious sedation colonoscopy)
C2: long procedure (e.g. monitored anesthesia colonoscopy)
Presentation Outline

• Background
• Stochastic Colonoscopy Appointment Problem
• Numerical Experiment
• General Scheduling Policy

• Conclusion and Future Directions
Conclusion

• Colonoscopy scheduling have unique characteristics that are different in nature and potentially different from other OPC

• Optimal schedule quality depends on the uncertainty within these characteristics

• Adjusting the schedule to account for the average changes in each characteristics is less challenging than accounting for their variability
Future directions

• Methodology:
  – Incorporate patient outcomes and preference
  – Probabilistic models for duration, absenteeism and arrivals
  – Incorporate interaction effect of uncertain parameters
  – Tractable and efficient solution methods

• Practice
  – Clinical observation
  – Bowel prep interventions
  – Universal template and scheduling rules
Acknowledgement

• My STAR Professor Amy Cohn

• Center for Healthcare Engineering and Patient Safety, SCOPES family

• The Seth Bonder Foundation

• The IOE Family at the University of Michigan
No one can whistle a symphony. It takes a whole orchestra to play it.

Karmel Shehadeh  
Ksheha@umich.edu

Dr. Amy Cohn  
amycohn@umich.edu

CHEPS  
http://chepts.engin.umich.edu
THE QUESTION

MARK

IS IT ALWAYS SO UNCERTAIN?
I’M SO GLAD YOU ASKED.

RESPECT PUNCTUATION
Notations

Table 1: \textit{S-CAP} sets, indices and variables

<table>
<thead>
<tr>
<th>Indices and sets</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>( p \in P )</td>
<td>Set of patients</td>
</tr>
<tr>
<td>( i \in P )</td>
<td>Set of appointment order</td>
</tr>
<tr>
<td>( \omega \in \Omega )</td>
<td>Set of scenarios</td>
</tr>
</tbody>
</table>

**Fixed model parameters**

- \( \mathcal{L} \) : Planned length of the shift.
- \( \lambda_1 \) : Weight assigned to total patient \textit{waiting} time.
- \( \lambda_2 \) : Weight assigned to total provider \textit{idle} time.
- \( \lambda_3 \) : Weight assigned to \textit{overtime}

**Scenario dependent model parameters**

- \( \tau_p^w \) : Procedure duration for patient \( p \) in scenario \( \omega \)
- \( u_p^w \) : Un-punctuality of patient \( p \) in scenario \( \omega \)
- \( \eta_p^w \) : Probability of no-show for patient \( p \) in scenario \( \omega \)
- \( \phi^\omega \) : Probability of scenario \( \omega \)

**Decision variables**

- \( x_{ip} \) : 1 if patient \( p \) is the \textit{ith} patient; 0 otherwise
- \( t_i \) : Scheduled appointment time of the \textit{ith} patients
- \( a_p^\omega \) : Arrival time of patient \( p \) under scenario \( \omega \)
- \( s_p^\omega \) : Start time of patient \( p \) under scenario \( \omega \)
- \( I_i^\omega \) : Idle time before the \textit{ith} patient under scenario \( \omega \)
- \( o^\omega \) : \textit{overtime} under scenario \( \omega \)
SCAp Formulation

\[
S - \text{CAP} \quad \min \psi = \sum_{\omega \in \Omega} \phi(\omega) \left[ \sum_{i \in P} \lambda_1 (s_1 - a_i) + \lambda_2 I_i + \lambda_3 o_\omega \right]
\]

s.t. \( \sum_{i \in P} x_{ip} = 1 \quad \forall p \in P \)

\( \sum_{p \in P} x_{ip} = 1 \quad \forall i \in P \)

\( t_1 \geq 0 \)

\( t_i \geq t_{i-1} \quad \forall i > 1 \)

\( t_i \leq \mathcal{L} \quad \forall i \in P \)

\( a_i^\omega = t_i + \sum_{p \in P} u_p x_{ip} \quad \forall \omega \in \Omega, i \in P \)

\( s_{1}^\omega \geq t_1 \quad \forall \omega \in \Omega \)

\( s_i^\omega \geq a_i^\omega \quad \forall i \in P \)

\( s_i^\omega \geq s_{i-1}^\omega + \sum_{p \in P} \tau_p x_{ip} \quad \forall \omega \in \Omega, i > 1 \in P \)

\( I_1^\omega \geq a_1^\omega - t_1 \quad \forall \omega \in \Omega \)

\( I_i^\omega \geq a_i^\omega - (s_{i-1}^\omega + \sum_{p \in P} \tau_p x_{ip}) \quad \forall \omega \in \Omega, i > 1 \in P \)

\( o_\omega \geq \tau_j^\omega x_{jp} - \mathcal{L} \quad \forall \omega \in \Omega \)

\( I_o^\omega, o_\omega \geq 0 \quad \forall \omega \in \Omega \)

\( x_{ip} \in \{0, 1\} \quad \forall i, p \in P \)

**Min total expected waiting, idling & overtime**

Every appointment 1 patient and every patient gets 1 appointment

Scheduled time obey the order and within the planned length

Arrival time= scheduled± un-punctuality

Actual start time = max(arrival, end of preceding patient)

Idle btw patients= time that provider wait from end of one procedure to the arrival of next patient

Overtime
Impact of Arrivals Uncertainty