Patient-centered and Personalized Scheduling of Colonoscopy Appointments

Karmel Shehadeh, PhD Candidate
Amy Cohn, Professor

Department of Industrial and Operations Engineering
Center for Healthcare Engineering and Patient Safety
University of Michigan, Ann Arbor

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Research Team

- Systems Concepts for the Optimization and Personalization of Endoscopy Scheduling (SCOPES) Team:
  - Professor Amy Cohn, Industrial and Operations Engineering
  - Dr. Sameer Saini and Dr. Jacob Kurlander, University of Michigan School of Medicine, University of Michigan Health System
  - CHEPS/SCOPES Summer 2017 Team: Bassel Salka, Daniel Huang, Trevor Hoffman, and Stephanie See
Presentation Overview

1. Introduction and Motivation
2. Research Approach
3. Numerical Example
4. Conclusion and Future Directions
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Colonoscopy Procedure

- The most common screening test for Colorectal Cancer (CRC)
  - 2nd leading cause of cancer-related death in the US\(^1\)
  - 4.5 million age-eligible subjects in the US (≥ 50 years)\(^2\)

- Medical procedure, usually performed by a gastroenterologist, allows for direct visual examination of the entire colon and rectum
  - Spot existing cancer, prompting treatment
  - Prevent future cancer (polyps)

- Can help reduce CRC incidence by about 40% and mortality by about 50%\(^1\)

\(^1\) American Cancer Society

\(^2\) Jiang et al. (2015)
Challenges to Daily Colonoscopy Schedule

- **Significant variability** in procedure duration due to the quality of the pre-procedure bowel prep that the patient must undergo.

<table>
<thead>
<tr>
<th>Prep Quality</th>
<th>Type-Duration</th>
</tr>
</thead>
<tbody>
<tr>
<td>Good</td>
<td>Easy-Short</td>
</tr>
<tr>
<td>Poor</td>
<td>Complex-Long</td>
</tr>
</tbody>
</table>

- Patient absenteeism, lack of punctuality, and late cancellations.

- **Multiple** and **conflicting** criteria that affect the quality of the schedule.
  - Waiting, idling, overtime.....
Research Goal

- Develop a decision support tool to optimize colonoscopy appointment scheduling template
  - A list of daily appointments to offer for patients (template)
  - Instructions for scheduling patients (scheduling policies)
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Research Approach

- Observations
  - VA Ann Arbor Healthcare System Endoscopy Unit
  - The University of Michigan Health System Medical Procedures Unit

- Data Analysis Tools

- Optimization and Simulation
  - To design and propose different scheduling templates from which the clinic manager can select the most preferred one based on the associated expectation on the quality of each.
We developed a tool to analyze the colonoscopy appointments data at the University of Michigan Medical Procedure Unit.

Time frame: 1/1/2016 to 1/27/2017

For this talk, ONLY Conscious Sedation Colonoscopies (3,270 procedures)
Do We Really Have a Problem? How Severe?

Table 1: Example of Raw Appointment Data as Queried From the Endoscopy Appointment System

<table>
<thead>
<tr>
<th>Exam Date</th>
<th>Pt Name</th>
<th>Pt Class</th>
<th>Type</th>
<th>Provider</th>
<th>Appt Time</th>
<th>Patient Time</th>
<th>Prep Time</th>
<th>Wait from Arrival</th>
<th>Proj Start</th>
<th>Proc Start</th>
<th>Phase II</th>
<th>Behind</th>
</tr>
</thead>
<tbody>
<tr>
<td>4/15/16</td>
<td>Sam, Amal</td>
<td>Outpatient</td>
<td>Colon</td>
<td>Khan, Bill</td>
<td>9:45</td>
<td>9:22</td>
<td>9:50</td>
<td>5.00</td>
<td>10:15</td>
<td>10:32</td>
<td>11:10</td>
<td>17</td>
</tr>
<tr>
<td>4/15/16</td>
<td>Sour, Zoya</td>
<td>Outpatient</td>
<td>Colon</td>
<td>Gene, Kim</td>
<td>7:30</td>
<td>7:49</td>
<td>7:54</td>
<td>24.00</td>
<td>8:00</td>
<td>8:27</td>
<td>9:18</td>
<td>27</td>
</tr>
</tbody>
</table>

Table 2: Some of the Data Analysis Tool Functionalities/Output

<table>
<thead>
<tr>
<th>Exam Date</th>
<th>Type</th>
<th>Provider</th>
<th>Waiting for Prep</th>
<th>Preparation Duration</th>
<th>Waiting for Procedure</th>
<th>Procedure Duration</th>
<th>Recovery Duration</th>
<th>Time in System</th>
</tr>
</thead>
<tbody>
<tr>
<td>4/15/16</td>
<td>Colon-MGI</td>
<td>Provider 1</td>
<td>28</td>
<td>20</td>
<td>15</td>
<td>38</td>
<td>20</td>
<td>121</td>
</tr>
<tr>
<td>4/15/16</td>
<td>Colon-MGI</td>
<td>Provider 2</td>
<td>5</td>
<td>16</td>
<td>17</td>
<td>51</td>
<td>38</td>
<td>127</td>
</tr>
<tr>
<td>27/1/2017</td>
<td>EGD-MGI</td>
<td>Provider 1</td>
<td>10</td>
<td>17</td>
<td>36</td>
<td>49</td>
<td>42</td>
<td>154</td>
</tr>
</tbody>
</table>

Also, no-show rates, cancellation rates,......

Endoscopy Appointments Data Analysis Tool

For Today
Research Approach

Do We Really Have a Problem? How Severe?

- Colonoscopy duration variability across providers

Figure 1: Minimum, Average, and Maximum Colonoscopy Duration Across the University of Michigan Medical Procedure unit Providers in the Period of 1/1/2016 to 1/27/2017.
Colonoscopy duration variability across providers

“…175 minutes is not a clinically realistic nor observed colonoscopy duration! Said, GI Faculty”

Figure 1: Minimum, Average, and Maximum Colonoscopy Duration Across the University of Michigan Medical Procedure unit Providers in the Period of 1/1/2016 to 1/27/2017.
Do We Really Have a Problem? How Severe?

- A Consensus among UMHS-MPU providers, nurses, and staff:

  "Every day, we observe a range of 10-60 minutes colonoscopies."

**Figure 1:** Observed colonoscopy duration range according to the University of Michigan Medical Procedure unit Staff
10-60 minutes Colonoscopies: 808 out of the 3,270 procedures

<table>
<thead>
<tr>
<th></th>
<th>% of Colonoscopies ≥45 minutes (scheduled time)</th>
<th>48% (390 out of 808)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Waiting time from arrival to prep</td>
<td>18 minutes on average</td>
<td></td>
</tr>
<tr>
<td>Waiting time from prep to procedure</td>
<td>54 on average</td>
<td></td>
</tr>
</tbody>
</table>

Also,

“There is a ~10% chance of a >60-75 colonoscopy due to poor prep.” Said, GI Faculties
Do We Really Have a Problem? How Severe?

- **YES**, a schedule with many outliers, a poor patient and provider experience
- So, what to do?
The Expert and the Data Suggests:

<table>
<thead>
<tr>
<th>Procedure Type</th>
<th>Duration Details</th>
<th>Probability</th>
</tr>
</thead>
<tbody>
<tr>
<td>Short Procedure (s)</td>
<td>Lowest-Highest Observed Duration (LOD-HOD)</td>
<td>10-60 minutes</td>
</tr>
<tr>
<td></td>
<td>Average Observed Duration</td>
<td>51 minutes</td>
</tr>
<tr>
<td>Long Procedure (l)</td>
<td>Observed with 0.1 probability</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Lowest-Highest Observed Duration (LOD-HOD)</td>
<td>&gt;60-75 minutes</td>
</tr>
</tbody>
</table>
The Expert and the Data Suggests:

<table>
<thead>
<tr>
<th>Procedure</th>
<th>Lowest-Highest Observed Duration (LOD-HOD)</th>
<th>Average Observed Duration</th>
</tr>
</thead>
<tbody>
<tr>
<td>Short</td>
<td>10-60 minutes</td>
<td>51 minutes</td>
</tr>
<tr>
<td>Long</td>
<td>&gt;60-75 minutes</td>
<td></td>
</tr>
</tbody>
</table>

One possible mathematical translation:

\[
\begin{align*}
&\star |N(\mu_{l(s)}, \sigma^2_{l(s)})| \\
&\star \sigma_{l(s)} = \frac{HOD - LOD}{6} \\
&\star f_{\text{short}} = |N(51, 8.3^2)|, f_{\text{long}} = |N(68, 5)|
\end{align*}
\]

- e.g., procedure duration is either short \(\sim |N(51, 8.3^2)|\) with 0.9 probability or long with \(|N(68, 5)|\) with 0.1 probability.
Second, Template Optimization Model(s)

- **Setup:**
  - A set of $P$ colonoscopies
  - Colonoscopy duration and patient no-show probability are random
    - Each has a known distribution, is independent of scheduled time and from other patients
    - Observed on the day of services after the appointment decisions are made

- **Goal:** Design an appointment scheduling template for this set of procedures that are adjusted to the observed variability and reflects managerial expectation on patient’s waiting, provider idling, and overtime in the day of service
Second, Template Optimization Model

\[ v_N = \min f_N \]

s.t. \[ \sum_{i=1}^{P} x_{ip} = 1 \quad \forall p \] (every procedure is assigned to one appointment interval only)

\[ \sum_{p=1}^{P} x_{ip} = 1 \quad \forall i \] (every appointment interval is allocated to one procedure only)

\[ s^i_n \geq t_i \quad \forall i, n \] (actual start time = max \{scheduled time, end time of prev procedure\})

\[ s^i_n \geq s^i_{n-1} + \sum_{p=1}^{P} d^p_n \cdot x_{i-1,p} \quad \forall i \geq 2, n \] (actual start time= max \{scheduled time, end time of prev procedure\})

\[ g^i_n = s^i_{n+1} - (s^i_n + \sum_{p=1}^{P} d^p_n \cdot x_{i,p}) \quad \forall i < P, n \] (idle time after the \( i \)th procedure)

\[ o^n \geq (s^P_n + \sum_{j=1}^{j=P} d^j_n \cdot x_{P,j}) - L \quad \forall n \] (overtime incurred to complete the last procedure)

\[ x_{i,p} \in \{0, 1\}, \; (t_i, s^i_n, g^i_n, o^n) \geq 0 \quad \forall i, p, n \]

**Parameters**
- 0 \(-\mathcal{L}\): clinic service hours
- \( N \): number of scenarios
- \( d^p_n \): patient \( p \) duration in scenario \( n \)

**Scheduling variables**
- \( x_{ip} \): 1 if \( p \) is the \( i \)th procedure; 0 otherwise
- \( t_i \): scheduled time of the \( i \)th patient

**Metric variables**
- \( a^n_i \): start time of \( i \)th procedure under scenario \( n \)
- \( g^i_n \): idle time after the \( i \)th procedure under scenario \( n \)
- \( o^n_i \): idle time before the start of the \( i \)th patient under scenario \( n \)
Second, Template Optimization Model

\[ v_N = \min f_N := \sum_{n=1}^{N} \frac{1}{N} \left[ \sum_{i=1}^{P} (s_i^n - t_i) + \sum_{i=1}^{P} g_i^n + o^n \right] \]  
(minimize total expected waiting, idling and overtime)

s.t. \( \sum_{i=1}^{P} x_{ip} = 1 \quad \forall p \)  
(every procedure is assigned to one appointment interval only)

\( \sum_{p=1}^{P} x_{ip} = 1 \quad \forall i \)  
(every appointment interval is allocated to one procedure only)

\( s_i^n \geq t_i \quad \forall i, n \)  
(actual start time = \( \max \{\text{scheduled time, end time of prev procedure}\} \))

\( s_i^n \geq s_{i-1}^n + \sum_{p=1}^{P} d_{ip}^n \cdot x_{i-1,p} \quad \forall i \geq 2, n \)  
(actual start time= \( \max \{\text{scheduled time, end time of prev procedure}\} \))

\( g_i^n = s_{i+1}^n - (s_i^n + \sum_{p=1}^{P} d_{ip}^n \cdot x_{i,p}) \quad \forall i < P, n \)  
(idle time after the \( i \)th procedure)

\( o^n \geq (s_P^n + \sum_{j=1}^{P} d_{ij}^n \cdot x_{P,j}) - L \quad \forall n \)  
(overtime incured to complete the last procedure)

\( x_{ip} \in \{0, 1\}, \ (t_i, s_i^n, g_i^n, o^n) \geq 0 \quad \forall i, p, n \)

---

**Parameters**

- \( 0 - L \) : clinic service hours
- \( N \) : number of scenarios
- \( d_p^n \) : patient \( p \) duration in scenario \( n \)

**Scheduling variables**

- \( x_{ip} \) : 1 if \( p \) is the \( i \)th procedure; 0 otherwise
- \( t_i \) : scheduled time of the \( i \)th patient

**Metric variables**

- \( s_i^n \) : start time of \( i \)th procedure under scenario \( n \)
- \( g_i^n \) : idle time after the \( i \)th procedure under scenario \( n \)
- \( o^n \) : idle time before the start of the \( i \)th patient under scenario \( n \)
Third, Articulation for Managerial Preferences

- Clinic Manager preference toward patient and provider time are typically implicit and indistinct.
- Even when explicitly articulated, hard to arbitrate.

Solution: Optimize the template under different trade-off level ($\lambda$) between patient and provider time.

\[
\text{minimize } f_N = \lambda \cdot (\sum_{n=1}^{N} \sum_{i=1}^{P} (s_{ni} - t_i)) + (1 - \lambda) \cdot (\sum_{n=1}^{N} \sum_{i=1}^{P} (g_{ni} + o_{ni}))
\]

\[
= \lambda \cdot \text{Expected Total Waiting} + (1 - \lambda) \cdot \text{Expected Total idle and overtime}
\]

Results: Accordingly, the manager can select the most preferred template.

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Third, Articulation for Managerial Preferences

- Clinic Manager preference toward patient and provider time are typically implicit and indistinct
- Even when explicitly articulated, hard to arbitrate
- **Solution:** Optimize the template under different trade-off level (λ) between patient and provider time

\[
v_N = \min f_N := \lambda \cdot \left( \frac{1}{N} \sum_{n=1}^{n} \sum_{i=1}^{P} (s^n_i - t_i) \right) + (1 - \lambda) \cdot \left( \frac{1}{N} \sum_{n=1}^{n} \sum_{i=1}^{P} g^n_i + o^n \right)
\]

\[
= \lambda \cdot \text{Expected Total Waiting} + (1 - \lambda) \cdot \text{Expected Total idle and overtime}
\]

\[
= \lambda \cdot E[TW] + (1 - \lambda) \cdot (E[II] + E[O])
\]
Third, Articulation for Managerial Preferences

- Clinic Manager preference toward patient and provider time are typically implicit and indistinct.
- Even when explicitly articulated, hard to arbitrate.

**Solution:** Optimize the template under different trade-off level ($\lambda$) between patient and provider time

\[
v_N = \text{minimize } f_N := \lambda \left( \frac{1}{N} \sum_{n=1}^{N} \sum_{i=1}^{P} (s^n_i - t_i) \right) + (1 - \lambda) \left( \frac{1}{N} \sum_{n=1}^{N} \sum_{i=1}^{P} g^n_i + o^n \right)
\]

\[
= \lambda \cdot \text{Expected Total Waiting} + (1 - \lambda) \cdot \text{Expected Total idle and overtime}
\]

Results:

- A set of optimized templates (Pareto Optimal Templates) each with an expectation on waiting, idling, and overtime.
- Accordingly, the manager can select the most preferred template.
Third, Articulation for Managerial Preferences

- Clinic Manager preference toward patient and provider time are typically implicit and indistinct.
- Even when explicitly articulated, hard to arbitrate.

**Solution:** Optimize the template under different trade-off level ($\lambda$) between patient and provider time

$$v_N = \min f_N := \lambda \cdot \left( \frac{1}{N} \sum_{n=1}^{N} \sum_{i=1}^{P} (s_i^n - t_i) \right) + (1 - \lambda) \cdot \left( \frac{1}{N} \sum_{n=1}^{N} \sum_{i=1}^{P} g_i^n + o^n \right)$$

$$= \lambda \cdot \text{Expected Total Waiting} + (1 - \lambda) \cdot \text{Expected Total idle and overtime}$$

- Results:

**Table 1: Example of Pareto Optimal Templates**

<table>
<thead>
<tr>
<th>$\lambda$</th>
<th>Optimal Template</th>
<th>$E[TW]_\lambda$</th>
<th>$E[TI]_\lambda$</th>
<th>$E[O]_\lambda$</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>$(X, t)_0$</td>
<td>100 min</td>
<td>10 min</td>
<td>5 min</td>
</tr>
<tr>
<td>0.05</td>
<td>$(X, t)_{0.05}$</td>
<td>93 min</td>
<td>15 min</td>
<td>6 min</td>
</tr>
<tr>
<td>.</td>
<td>.</td>
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<tr>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
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Example: A Typical Colonoscopy Scheduling Problem

Table 2: Example of a typical colonoscopy Appt template optimization problem

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Details</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of procedures ((P))</td>
<td>10 Colonoscopies</td>
</tr>
<tr>
<td>Clinic working hours ((0 - \mathcal{L}))</td>
<td>0-expected duration for 10 Colonoscopies</td>
</tr>
<tr>
<td>Poor prep/long procedure-probability</td>
<td>(\alpha = 0.1)</td>
</tr>
<tr>
<td>Colonoscopy duration distribution</td>
<td>(\text{short} \sim</td>
</tr>
<tr>
<td></td>
<td>(\text{long} \sim</td>
</tr>
</tbody>
</table>
Articulation for Managerial Preferences

minimize \( \lambda \cdot E\left[ TW \right] + (1 - \lambda) \cdot (E\left[ TI \right] + E\left[ OT \right]) \)
Articulation for Managerial Preferences

minimize $\lambda \cdot E[TW] + (1 - \lambda) \cdot (E[TI] + E[OT])$

Figure 2: Expected performance of Pareto optimal schedules as function of the trade-off level $\lambda$.

10 Patients
Short $\sim N(51, 8.3^2)$ w.p. 0.9
Long $\sim N(68, 5)$ w.p. 0.1
Articulation for Managerial Preferences

minimize \( 0.25 \cdot E[TW] + 0.75 \cdot (E[TI] + E[OT]) \)

Figure 2: Expected performance of Pareto optimal schedules as function of the trade-off level \( \lambda \).

10 Patients

Short \( \sim N(51, 8.3^2) \) w.p. 0.9

Long \( \sim N(68, 5) \) w.p. 0.1
Numerical Example

Scheduling Templates Adjusted to No-Show

★ No-show rate \( (r) = 0\% \)

Figure 3: Optimal time to schedule for each colonoscopy as the no-shows rate varies from 0 % to 50 %

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University of Michigan
Scheduling Templates Adjusted to No-Show

☆ No-show rate \( (r) = 10\% \)

Figure 3: Optimal time to schedule for each colonoscopy as the no-shows rate varies from 0 % to 50 %

10 Patients
Short \( \sim N(51, 8.3^2) \) w.p. 0.9
Long \( \sim N(68, 5) \) w.p. 0.1
Scheduling Templates Adjusted to No-Show

* No-show rate \((r) = 15\%\)

Figure 3: Optimal time to schedule for each colonoscopy as the no-shows rate varies from 0 % to 50 %
Scheduling Templates Adjusted to No-Show

* No-show rate \( r = 20\% \)

Figure 3: Optimal time to schedule for each colonoscopy as the no-shows rate varies from 0 % to 50 %
Scheduling Templates Adjusted to No-Show

★ No-show rate (r) = 30%

Figure 3: Optimal time to schedule for each colonoscopy as the no-shows rate varies from 0 % to 50 %

10 Patients
Short \( \sim N(51, 8.3^2) \) w.p.0.9
Long \( \sim N(68, 5) \) w.p.0.1
Scheduling Templates Adjusted to No-Show

⭐ No-show rate \( (r) = 50\% \)

**Figure 3:** Optimal time to schedule for each colonoscopy as the no-shows rate varies from 0 % to 50 %
And much more...

We are currently working on (future talks):

- Scheduling policies to mitigate the effect of different levels of poor prep quality and colonoscopy characteristics

- Scheduling policies for different patient mix, e.g., colonoscopy with anesthesia, upper endoscopy+colonoscopy, etc.

- Scheduling policies to mitigate the effect of other sources of observed variability such as patient lack of punctuality
So, Worth the Computational Efforts?

**Figure 4:** Expected performance from 1,000 simulation days of the optimized template using our model (blue), the current UMHS template (red), and the optimal template to the mean value problem (MVP) with one scenario equal to the mean duration (pink).

10 Patients
- Short $\sim N(51, 8.3^2)$ w.p. 0.9
- Long $\sim N(68, 5)$ w.p. 0.1
1,000 Days
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Conclusion

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

- Better scheduling policies can be developed by approximating the uncertainty within these characteristics.

- Properties of the “approximated” schedules can be exploited in designing a fast and easy to use appointment template optimization tool.
Acknowledgment

- Professor Amy Cohn
- The Center for Healthcare Engineering and Patient Safety
- 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”
Q&A

THE QUESTION MARK

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

Karmel Shehadeh
Ksheha@umich.edu

Professor Amy Cohn
amycohn@umich.edu