Scheduling Colonoscopy Patients Under Uncertainty

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University of Michigan

May 23, 2017
Research Team

• Systems Concepts for the Optimization and Personalization of Endoscopy Scheduling (SCOPES) Team:

  • Dr. Amy Cohn, Associate Professor, Industrial and Operations Engineering
  • Dr. Sameer Saini and Dr. Jacob Kurlander, The University of Michigan Health System (UMHS) and the Veterans Ann Arbor Healthcare System (VAAHS)
  • All CHEPS students who contribute to SCOPES
Presentation Outline

• Motivation and Overview
• The Offline Stochastic Colonoscopy Appointment Problem (OSSP)
• Properties of Approximated Scheduling Policies
• Conclusion and Future Directions
Presentation Outline

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Colonoscopy Procedure

• Gold standard for **Colorectal Cancer** (CRC) screening
  – 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}

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

• Gold standard for Colorectal Cancer (CRC) screening
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• Carried out by a gastroenterologist in an Endoscopy clinic

• Allows for direct visual examination of the entire colon and rectum
  – Spot existing cancer, prompting treatment
  – Prevent future cancer (polyps)
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  - Spot existing cancer, prompting treatment
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- Can help reduce CRC incidence by about 40% and mortality by about 50\(^1\)
Colonoscopy Appointment Scheduling

• One **special** characteristic of colonoscopy scheduling is the **unique bimodal duration** structure.

<table>
<thead>
<tr>
<th>Type-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>Easy-Short</td>
<td>Good</td>
<td>Good</td>
<td>Low</td>
<td>Conscious</td>
</tr>
<tr>
<td>Complex-Long</td>
<td>Poor</td>
<td>Poor</td>
<td>High</td>
<td>Anesthesia</td>
</tr>
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*Note: also for some cases procedure is not performed*
Colonoscopy Appointment Scheduling

- One **special** characteristic of colonoscopy scheduling is the **unique bimodal duration** structure

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- Extra time flushing out colon
Colonoscopy Appointment Scheduling

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- Significant **variability** in attendance, arrival patterns, and cancellations.
One special characteristic of colonoscopy scheduling is the **unique bimodal duration structure** of attendance, arrival patterns, and cancellations.
One special characteristic of colonoscopy scheduling is the unique bimodal duration structure. A schedule with many outliers in attendance, arrival patterns, and cancellations.
Colonoscopy Appointment Scheduling

- **Multiple conflicting** criteria that affect the quality of schedule
  - Waiting, idling, overtime (*this talk*)
  - Appointment Time Preferences (*future talk*)
  - Procedure quality and Polyps detection (*future talk*)
Research Goal

• Needs a decision support tool:
  • Allocation of available slots to patient groups (resource allocation)
  • A list of daily appointment slots to offer for patients (template)
  • Instructions that tells how to assign individual patient requests to a slot in the daily appointment template (scheduling policies)
Research Goal

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• Things to consider:
  • Provider availability
  • Duration, arrival time, and attendance
  • Multiple criteria
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• Motivation and Problem Overview
• The Offline Stochastic Colonoscopy Appointment Problem (OSSP)
  • Properties of Approximated Scheduling Policies
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The Offline Stochastic Colonoscopy Problem (OSSP)

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)
The Offline Stochastic Colonoscopy Problem (OSSP)

• **First stage decisions (generate a schedule)**
  - Patient order
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The Offline Stochastic Colonoscopy Problem (OSSP)

- **Objective:**
  Optimal scheduling decisions for a set of \( P \) patients, that minimizes the 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)
\[ v = \min_{\omega} f = \sum_{\omega \in \Omega} \phi(\omega) \left[ \lambda^W \sum_{i=1}^{P} (s_i^\omega - a_i^\omega) + \lambda^T \sum_{i=1}^{P} g_i^\omega + \lambda^O o^\omega \right] \]

s.t. \[ \sum_{i \in P} x_{ip} = 1 \]
\[ \sum_{p \in P} x_{ip} = 1 \]
\[ t_1 \geq 0 \]
\[ t_i \geq t_{i-1} \]
\[ t_i \leq \mathcal{L} \]
\[ a_i^\omega = t_i + \sum_{p=1}^{P} u_p^\omega \cdot x_{ip} \]
\[ s_i^\omega \geq t_1 \]
\[ s_i^\omega \geq a_i^\omega \]
\[ s_i^\omega \geq s_{i-1}^\omega + \sum_{p=1}^{P} \tau_p^\omega \cdot x_{i-1p} \]
\[ g_i^\omega \geq a_i^\omega - t_1 \]
\[ g_i^\omega \geq a_i^\omega - (s_{i-1}^\omega + \sum_{p=1}^{P} \tau_p^\omega \cdot x_{i-1p}) \]
\[ o^\omega \geq a_p^\omega + \sum_{j=1}^{P} \tau_j^\omega \cdot x_{pj} - \mathcal{L} \]
\[ g_i^\omega, o^\omega \geq 0 \]
\[ x_{ip} \in \{0, 1\} \]

Each patient is assigned to one position in the sequence
for \( p = 1, \ldots, P \)
for \( i = 1, \ldots, P \)

Appointment times:
- obey the sequence
- within the clinic service hours
for \( i = 2, \ldots, P \)
for \( i = 1, \ldots, P \)

Arrival time= scheduled±unpunctuality

\[ \forall \omega \in \Omega \]
for \( i = 1, \ldots, P, \omega \in \Omega \)

\[ \forall \omega \in \Omega \]
for \( i = 2, \ldots, P, \omega \in \Omega \)

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\[ \forall \omega \in \Omega \]
\[ \forall (i, p) \in \{1, \ldots, P\} \]

Idle time before the \( i \)th patient

Overtime

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Sequencing and scheduling variables</th>
<th>Actual schedule variables</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 - ( \mathcal{L} ): clinic service hours</td>
<td>( x_{ip} ): 1 if ( p ) is the ( i )th patient; 0 otherwise</td>
<td>( a_i^\omega ): arrival time of the ( i )th patient under ( \omega )</td>
</tr>
<tr>
<td>( \tau_p^\omega ): patient ( p ) duration in ( \omega )</td>
<td>( t_i ): scheduled time of the ( i )th patient</td>
<td>( s_i^\omega ): start time of ( i )th patient under ( \omega )</td>
</tr>
<tr>
<td>( u_p^\omega ): patient ( p ) unpunctuality in ( \omega )</td>
<td></td>
<td>( g_i^\omega ): idle time before the start of the ( i )th patient under ( \omega )</td>
</tr>
<tr>
<td>( \phi(\omega) ): probability of scenario ( \omega )</td>
<td></td>
<td>( o^\omega ): idle time before the start of the ( i )th patient under ( \omega )</td>
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Parameters?!
OSSP Parameters: Type-based Duration Model

<table>
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<tr>
<th>Type</th>
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<td>Easy-Short</td>
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So, I have some data and domain knowledge.
OSSP Parameters: Type-based Duration Model

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- **Type-duration likelihood 0.75**
OSSP Parameters: Type-based Duration Model

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<th>Type</th>
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<tr>
<td>Easy-Short</td>
<td>$\sim f(\cdot)^{\text{short}}$</td>
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- Type-duration likelihood 0.75
- Continuous
  - e.g., if easy, then duration $\sim f(\cdot)^{\text{short}}$ with 0.75 probability or $\sim g(\cdot)^{\text{long}}$ with 0.25 probability
OSSP Parameters: Type-based Duration Model

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<td>30</td>
</tr>
<tr>
<td>Complex-Long</td>
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OSSP Parameters: Type-based Duration Model

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<th>Type</th>
<th>Lowest conceivable value (LCV)</th>
<th>Mode</th>
<th>Highest conceivable value (HCV)</th>
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<td>Easy-Short</td>
<td>20</td>
<td>30</td>
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</tr>
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\[
\mathcal{N}\left(\mu_{s(l)}, \sigma^2_s(l)\right)
\]
## OSSP Parameters: Type-based Duration Model

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- **Three Sigma Rule**
  \[
  \sigma_s(l) = \frac{HCV - LCV}{6}
  \]

- \(f(\cdot)^{\text{short}} = |N(30, 6.67^2)|\)
- \(g(\cdot)^{\text{long}} = |N(90, 10^2)|\)
Solution Approach?
Constructive Monte Carlo Optimization Approach

See you at IFOR17, INFORMS17, POMS17, IISE18,.....
for $m=1:M$ do

Step 1. Generate a sample of size $N$
- Generate $N$ scenarios of $\eta_p(\eta^1_p,...,\eta^N_p)$, $\forall p \in P$
- Generate $N$ scenarios of $\tau_p(\tau^1_p,...,\tau^N_p)$, $\forall p \in P$
- Generate $N$ scenarios of $u_p(u^1_p,...,u^N_p)$, $\forall p \in P$

Step 2. Solve Sample Average Problem (OSSP($N$))
Let $v^m_N$ be the corresponding optimal objective value

Step 3. Evaluation of the true objective function using Monte Carlo simulation

3.1 Generate $N$ scenarios, solve OSSP($N$), and obtain $(\hat{X}^m, \hat{t}^m)$
3.2 Generate $N' >> N$ scenarios
3.2 Estimate the true value of the objective function ($\hat{v}^m_{N'}$) using the schedule $(\hat{X}^m, \hat{t}^m)$:

$$\hat{v}^m_{N'}(\hat{X}^m, \hat{t}^m) = \frac{1}{N'} \sum_{n=1}^{N'} \left[ \sum_{i=1}^{P} \left( s^n_i(\hat{X}^m, \hat{t}^m) - a^n_i(\hat{X}^m, \hat{t}^m) \right) + g^n_i(\hat{X}^m, \hat{t}^m) + c^n(\hat{X}^m, \hat{t}^m) \right]$$

end

Compute the average of $v^m_N$ and $\hat{v}^m_{N'}$, overall replication:

$$\bar{v}_N = \frac{1}{M} \sum_{m=1}^{M} v^m_N \quad \bar{v}_{N'} = \frac{1}{M} \sum_{m=1}^{M} \hat{v}^m_{N'}(\hat{X}^m, \hat{t}^m)$$

Compute (Approximate) optimality indices

$$AOI_1 = \frac{\min_{m \in M} (\hat{v}^m_{N'}) - \bar{v}_N}{\min_{m \in M} (\hat{v}^m_{N'})} \quad AOI_2 = \frac{\bar{v}_{N'} - \bar{v}_N}{\bar{v}_{N'}}$$

Algorithm 1: OSSP Monte Carlo Optimization (OSSP-MCO)
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• **Properties of Approximated Scheduling Policies**
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Approximated Scheduling Policy as a Function of Patient Mix

P=8 patients

$\tau^E \sim N(30, 3.36)$

$\tau^C \sim N(90, 6.67)$

Punctual
Approximated Scheduling Policy as a Function of Patient Mix

Patient Mix

(#E, #C)

Appointment slot and slot length (minutes)

1 2 3 4 5 6 7 8

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Patient Mix

(#E, #C)

(8,0)

(0, 8)

Time allowances (slot length) \(\sim\) “dome-shape”

Appointment slot and slot length (minutes)

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Approximated Scheduling Policy as a Function of Patient Mix

One Type

Time allowances ~ “dome-shape”

Patient Mix

(#E, #C)

(4, 4)

Appointment slot and slot length (minutes)

P = 8 patients

$\tau^E \sim N(30, 3.36)$

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Punctual
Approximated Scheduling Policy as a Function of Patient Mix

Patient Mix

(4, 4)

One Type

Time allowances ~"dome-shape"

25  33

Appointment slot and set length (minutes)

P=8 patients
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Punctual
Approximated Scheduling Policy as a Function of Patient Mix

P=8 patients
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Punctual

Patient Mix

(4, 4)

One Type
Time allowances \( \sim \text{“dome-shape”} \)

\[
\begin{align*}
25 & & 33 & & 86 & & 82 \\
\end{align*}
\]

Appointment slot and slot length (minutes)
Approximated Scheduling Policy as a Function of Patient Mix

Patient Mix

(4, 4)

One Type

Time allowances ~“dome-shape”

25 33 86 82 37 62 80 75

Appointments slot and slot length (minutes)

P=8 patients

$T^E \sim N(30, 3.36)$

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Punctual
## Approximated Scheduling Policy as a Function of Patient Mix

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<td>Sequence ~ “Alternating Buckets” of Easy → Complex</td>
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<td>Time allowances ~ “Bucket-based-Dome”</td>
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\[ \tau^E \sim N(30, 3.36) \]
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<tbody>
<tr>
<td>One Type</td>
<td>(6, 2)</td>
<td>Sequence (~) “Alternating Buckets” of Easy (\rightarrow) Complex</td>
</tr>
<tr>
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<td></td>
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\( \tau^E \sim N(30, 3.36) \)
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Punctual

Appointment slot and slot length (minutes)
Approximated Scheduling Policy as a Function of Patient Mix

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<th>8</th>
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<tr>
<td>25</td>
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<td>35</td>
<td>83</td>
<td></td>
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- **Patient Mix**
  - #E, #C
  - (6, 2)

- **Approximation**
  - \( P = 8 \) patients
  - \( \tau^E \sim N(30, 3.36) \)
  - \( \tau^C \sim N(90, 6.67) \)

- **Punctual**
Approximated Scheduling Policy as a Function of Patient Mix

Patient Mix

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- Appointment slot and sot length (minutes)

P=8 patients
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Punctual
Approximated Scheduling Policy as a Function of Patient Mix

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<td>42</td>
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- P=8 patients
  - $\tau^E \sim N(30, 3.36)$
  - $\tau^C \sim N(90, 6.67)$

Punctual
**Natural Question**: how to leverage OSSP sub-problems properties in solving the more challenging OSSP versions?

<table>
<thead>
<tr>
<th>Appointment slot</th>
<th>1</th>
<th>2</th>
<th>3</th>
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<th>…</th>
<th>…</th>
<th>…</th>
<th>P-1</th>
<th>P</th>
</tr>
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<tbody>
<tr>
<td><strong>Patient Mix</strong></td>
<td>$P = #\text{Easy} + #\text{Complex}$</td>
<td></td>
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</tr>
</tbody>
</table>

Approximated Scheduling Policy as a Function of Patient Mix
Approximated Scheduling Policy as a Function of Patient Mix

Natural Question: how to leverage OSSP sub-problems properties in solving the more challenging OSSP versions?
Natural Question: how to leverage OSSP sub-problems properties in solving the more challenging OSSP versions?

\[ P = 10, \text{ intractable} \]
Natural Question: how to leverage OSSP sub-problems properties in solving the more challenging OSSP versions?

\[ P=10, 5E:5C > \text{intractable} \]
**Natural Question**: how to leverage OSSP sub-problems properties in solving the more challenging OSSP versions?
Figure 1. Sensitivity of the approximated scheduling policy to arrivals pattern. Patients are on average punctual, with a mean earliness of 0 minutes and a standard deviation of $\sigma$ minutes.
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Figure 1. Sensitivity of the approximated scheduling policy to arrivals pattern. Patients are on average punctual, with a mean earliness of 0 minutes and a standard deviation of $\sigma$ minutes.
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Figure 2. Sensitivity of the approximated scheduling policy to arrivals pattern. Patients are on average early, with a mean earliness of $\mu$ minutes and a standard deviation of $\sigma$ minutes.
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Sensitivity of Approximated Scheduling Policy to Arrival Patterns

Figure 2. Sensitivity of the approximated scheduling policy to arrivals pattern. Patients are on average early, with a mean earliness of $\mu$ minutes and a standard deviation of $\sigma$ minutes.
Sensitivity of Approximated Scheduling Policy to Arrival Patterns

- Bimodality
- No-show
- Patient Risk and Preference
Sensitivity of Approximated Scheduling Policy to Arrival Patterns

- Bimodality
- No-show
- Patient Risk and Preference
How to Apply in Practice?
TEMPLATE REQUIREMENTS FORM

To determine which template to use, view this provider's visit type lengths and select the lowest common denominator. These lengths must match your service level standards to ensure departments across a service are constant. Click here to locate your department's service level standards.

Your Contact Information

Form Completed By: Karmel Shehadeh

Phone #: 607-744-1945

Uniqname/Email: ksheha@umich.edu
<table>
<thead>
<tr>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
<th>E</th>
<th>F</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>TEMPLATE REQUIREMENTS FORM</strong></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>To determine which template to use, view this provider's visit type lengths and select the lowest common denominator. These lengths must match your service level standards to ensure departments across a service are constant. <a href="#">Click here to locate your department's service level standards.</a></td>
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<tr>
<td><strong>Your Contact Information</strong></td>
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<tr>
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<tr>
<td>Phone #:</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Uniqname/Email:</td>
<td><a href="mailto:ksheha@umich.edu">ksheha@umich.edu</a></td>
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<td></td>
</tr>
<tr>
<td><strong>Department Information</strong></td>
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<td></td>
</tr>
<tr>
<td>MiChart Department Name:</td>
<td>Medical Procedure Unit</td>
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<td></td>
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<tr>
<td>MiChart Department Number:</td>
<td>101021602</td>
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</tbody>
</table>
# TEMPLATE REQUIREMENTS FORM

To determine which template to use, view this provider's visit type lengths and select the lowest common denominator. These lengths must match your service level standards to ensure departments across a service are constant. Click here to locate your department's service level standards.

## Your Contact Information

<table>
<thead>
<tr>
<th>Field</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Form Completed By</td>
<td>Karmel Shehadeh</td>
</tr>
<tr>
<td>Phone #</td>
<td>607-744-1945</td>
</tr>
<tr>
<td>Uniqname/Email</td>
<td><a href="mailto:ksheha@umich.edu">ksheha@umich.edu</a></td>
</tr>
</tbody>
</table>

## Department Information

<table>
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<tr>
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<th>Value</th>
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<tbody>
<tr>
<td>MiChart Department Name</td>
<td>Medical Procedure Unit</td>
</tr>
<tr>
<td>MiChart Department Number</td>
<td>101021602</td>
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</table>

## Provider/Resource Information

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<th>Field</th>
<th>Value</th>
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<tbody>
<tr>
<td>Provider/Resource Full Name</td>
<td>Donald Richardson</td>
</tr>
<tr>
<td>Provider/Resource MiChart ID</td>
<td>100027</td>
</tr>
<tr>
<td>Provider Uniqname</td>
<td>Donalric</td>
</tr>
<tr>
<td>Subgroup</td>
<td>GI</td>
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</tbody>
</table>
TEMPLATE REQUIREMENTS FORM

To determine which template to use, view this provider's visit type lengths and select the lowest common denominator. These lengths must match your service level standards to ensure departments across a service are constant. Click here to locate your department's service level standards.

Your Contact Information

Form Completed By: Karmel Shehadeh

Phone #: 607-744-1945

Uniqname/Email: ksheha@umich.edu

Department Information

MiChart Department Name: Medical Procedure Unit

MiChart Department Number: 101021602

Provider/Resource Information

Provider/Resource Full Name: Donald Richardson

Provider/Resource MiChart ID #: 100127

Provider Uniqname: Donalric

Subgroup: GI

Effective Dates

From: 5/23/17

To: 8/23/17
To determine which template to use, view this provider's visit type lengths and select the lowest common denominator. These lengths must match your service level standards to ensure departments across a service are consistent. Click here to locate your department's service level standards.

**Your Contact Information**

- **Form Completed By:** Karmel Shehadeh
- **Phone #:** 607-744-1945
- **Uniqname/Email:** ksheha@umich.edu

**Department Information**

- **MiChart Department Name:** Medical Procedure Unit
- **MiChart Department Number:** 101021602

**Provider/Resource Information**

- **Provider/Resource Full Name:** Donald Richardson
- **Provider/Resource MiChart ID #:** 100127
- **Provider Uniqname:** Donalric
- **Subgroup:** GI

**Effective Dates**

- **From:** 5/23/17
- **To:** 8/23/17

<table>
<thead>
<tr>
<th>Day</th>
<th>Start Time</th>
<th>Stop Time</th>
<th>Start Time</th>
<th>Stop Time</th>
</tr>
</thead>
<tbody>
<tr>
<td>Monday</td>
<td>7:00 AM to 1:00 PM</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>7:00 AM to 1:00 PM</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>7:20 AM to 1:00 PM</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>8:20 AM to 1:00 PM</td>
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<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>8:50 AM to 1:00 PM</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>10:15 AM to 1:00 PM</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>10:55 AM to 1:00 PM</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>11:30 AM to 1:00 PM</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Submit the form to Cadence-IT folks.
Example for Practical and Optimal Template

Duration + No-show + 50% late

<table>
<thead>
<tr>
<th>Time</th>
<th># Open</th>
<th># Ovbk</th>
<th>Block</th>
</tr>
</thead>
<tbody>
<tr>
<td>7:00 AM</td>
<td>1</td>
<td>0</td>
<td>Easy-Colon</td>
</tr>
<tr>
<td>7:20 AM</td>
<td>1</td>
<td>0</td>
<td>Complex-Colon</td>
</tr>
<tr>
<td>8:20 AM</td>
<td>1</td>
<td>0</td>
<td>Easy-Colon</td>
</tr>
<tr>
<td>8:50 AM</td>
<td>1</td>
<td>0</td>
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</tr>
<tr>
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<td>1</td>
<td>0</td>
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</tr>
<tr>
<td>10:55 AM</td>
<td>1</td>
<td>0</td>
<td>Easy-Colon</td>
</tr>
<tr>
<td>11:30 AM</td>
<td>1</td>
<td>0</td>
<td>Complex-Colon</td>
</tr>
</tbody>
</table>
Worth the computational effort??
3Easy: 4Complex
18% no-show rate
+/- 20 min early/late
Values of Stochastic Optimization in Colonoscopy Scheduling

3Eeasy: 4Complex
18% no-show rate
+/− 20 min early/late
1,000 Days

Figure 3. Expected performance of OSSP and some traditional scheduling rules under different levels of no-show and arrivals uncertainties. The case of $r = 18\%$ and $u \sim N(0, 20)$
Figure 3. Expected performance of OSSP and some traditional scheduling rules under different levels of no-show and arrivals uncertainties. The case of \( r = 18\% \) and \( u \sim N(0, 20) \).
Presentation Outline

- Motivation and Problem Overview
- The Offline Stochastic Colonoscopy Appointment Problem (OSSP)
- Properties of Approximated Scheduling Policies
- **Conclusion and Future Directions**
Conclusion

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

• Scheduling polices depends on the **uncertainty** within these **characteristics**

• **Properties** of the “Approximated” schedules can be exploited in designing appointment scheduling **tool (system)**
Importance?

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

• Less Waiting
  – Better experience
  – Fewer cancelation

• More appointments

• Better Outcome!
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
  – Bowel prep interventions
  – Universal template and scheduling polices
Acknowledgement

• My STAR Professor Amy Cohn

• Committee:
  – Professor Henry Lam
  – Professor Marina Epelman
  – Professor Ruiwei Jiang

• Center for Healthcare Engineering and Patient Safety, SCOPES team

• 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

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Questions and Discussions

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