Patient-centered and Personalized Scheduling of Colonoscopy Appointments

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October 22, 2017
INFORMS 2017 | Houston

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

Presentation Overview

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 ($\geq$ 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

Prep Quality	Type-Duration
Good	Easy-Short
Poor	Complex-Long

- 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)

Presentation Overview

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.

Do We Really Have a Problem? How Severe?

- 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

Exam Date	Pt Name	Pt Class	Type	Provider	Appt Time	Patient Time	Prep	Wait from Arrival	Proj Start	Proc Start	Phase II Assigned	Behind
4/15/16	Sam, Amal	Outpatient	Colon	Khan,Bill	9:45	9:22	9:50	5.00	10:15	10:32	11:10	17
4/15/16	Souri, Zoya	Outpatient	Colon	Gene, Kim	7:30	7:49	7:54	24.00	8:00	8:27	9:18	27
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27/1/17	Basha, Ali	Outpatient	EGD	Khan, Bill	8:30	8:28	8.38	32.00	9:00	9:31	10:22	.

Endoscopy Appointments Data Analysis Tool

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

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

For Today

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

Do We Really Have a Problem? How Severe?

- Colonoscopy duration variability across providers

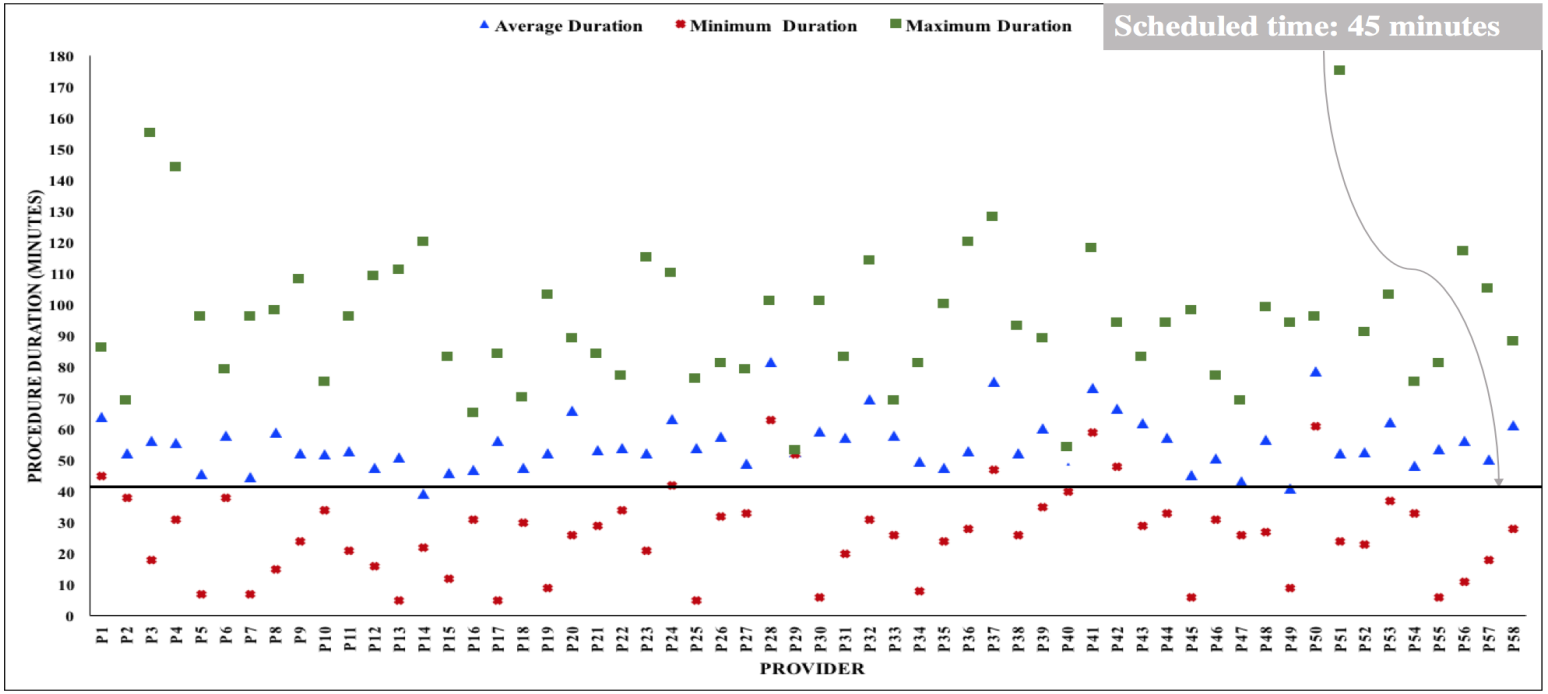

Figure 1: Minimum, Average, and Maximum Colonoscopy Duration Across the University of Michigan Medical Procedure unit Providers in the Period of 1/1/2016 to 1/27/2017.

Do We Really Have a Problem? How Severe?

- Colonoscopy duration variability across providers

  "*...175 minutes is not a clinically realistic nor observed colonoscopy duration! Said, GI Faculty* "

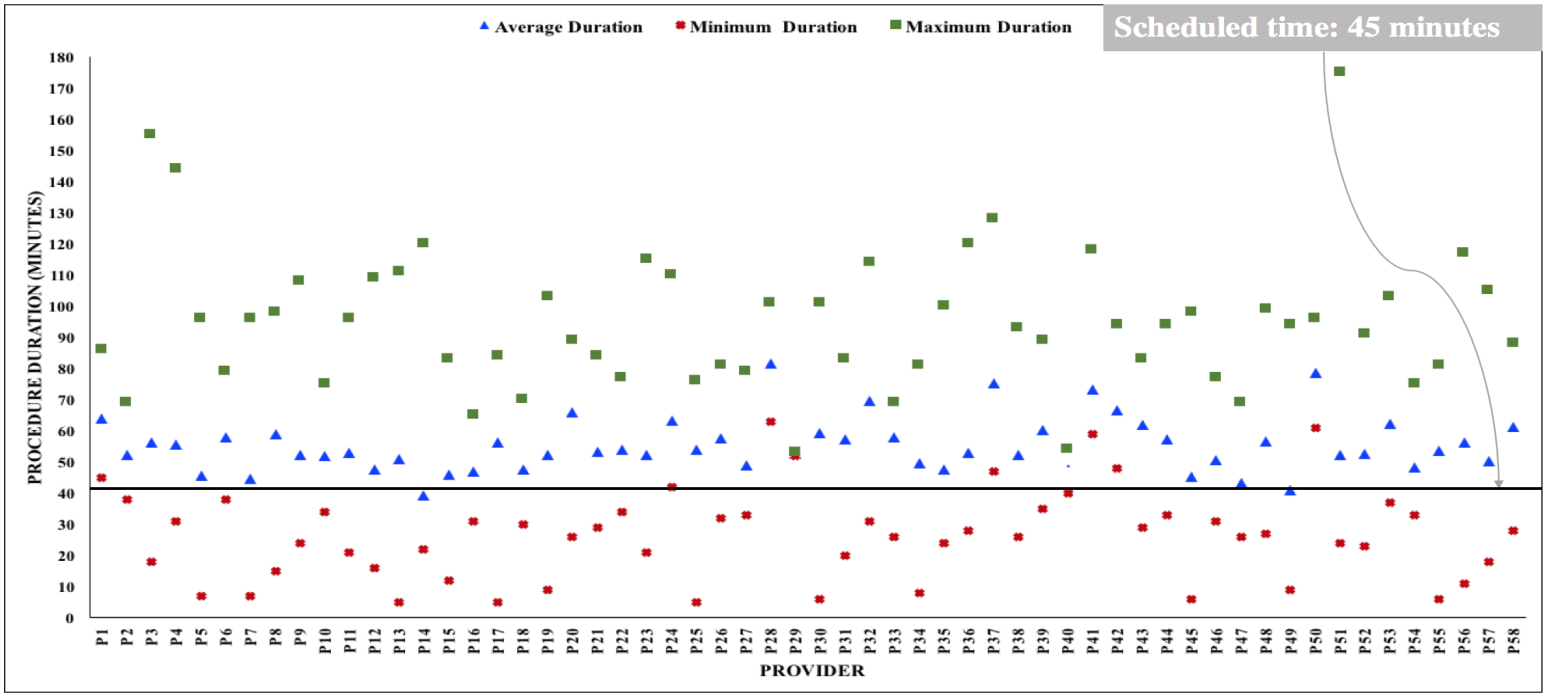

Figure 1: Minimum, Average, and Maximum Colonoscopy Duration Across the University of Michigan Medical Procedure unit Providers in the Period of 1/1/2016 to 1/27/2017.

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.*"

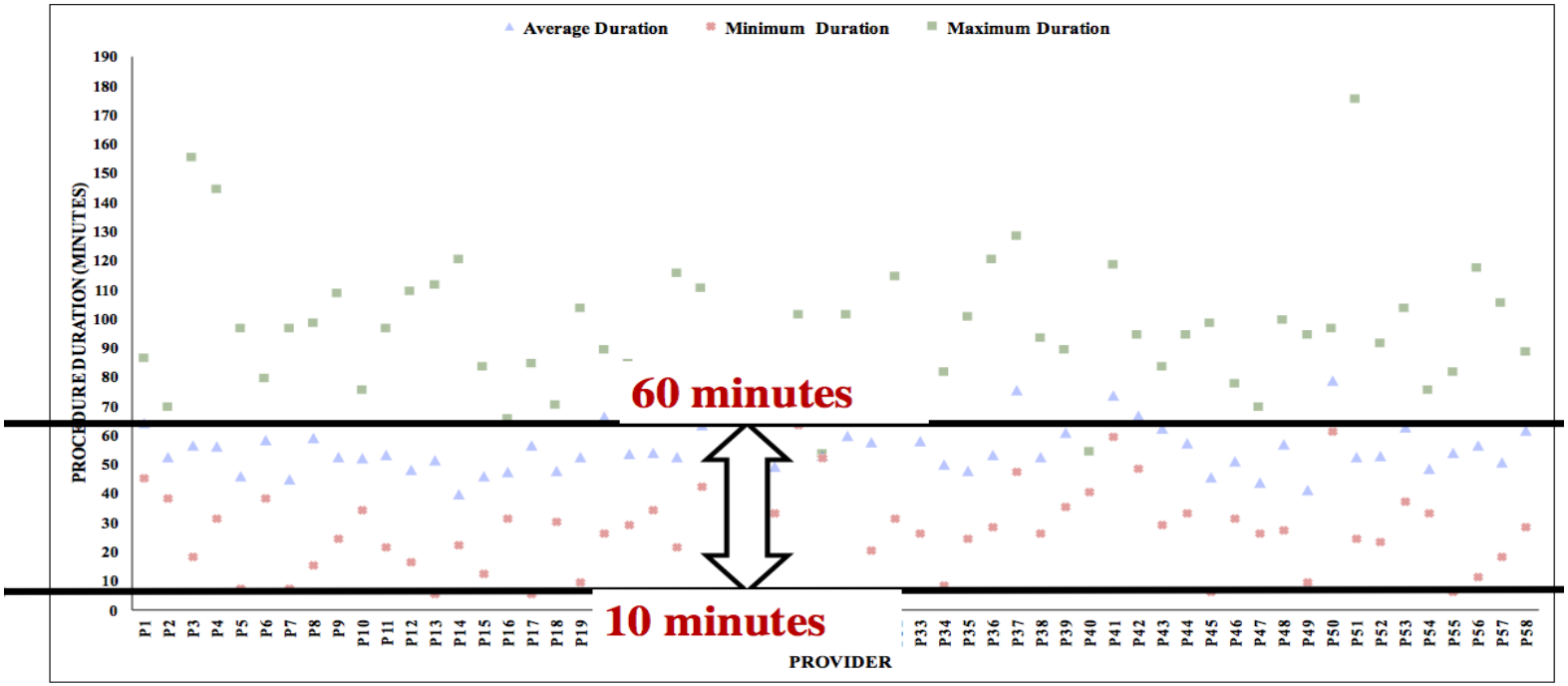

Figure 1: Observed colonoscopy duration range according to the University of Michigan Medical Procedure unit Staff

Do We Really Have a Problem? How Severe?

- 10-60 minutes Colonoscopies: 808 out of the 3,270 procedures

% of Colonoscopies≥45 minutes (scheduled time)	48% (390 out of 808)
Waiting time from arrival to prep	18 minutes on average
Waiting time from prep to procedure	54 on average

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?

First, Conceptual and Expert-Based Duration Model

- The Expert and the Data Suggests:

Short Procedure (s)		
	Lowest-Highest Observed Duration (LOD-HOD)	10-60 minutes
	Average Observed Duration	51 minutes
Long Procedure (l)		
	Observed with 0.1 probability	
	Lowest-Highest Observed Duration (LOD-HOD)	>60-75 minutes

First, Conceptual and Expert-Based Duration Model

- The Expert and the Data Suggests:

Short Procedure (s)		
	Lowest-Highest Observed Duration (LOD-HOD)	10-60 minutes
	Average Observed Duration	51 minutes
Long Procedure (l)		
	Observed with 0.1 probability	
	Lowest-Highest Observed Duration (LOD-HOD)	>60-75 minutes

- One possible mathematical translation:

$$\star\ |N(\mu_{l(s)}, \sigma^2_{l(s)})|$$

$$\star\ \sigma_{l(s)} = \frac{HOD - LOD}{6}$$

$$\star\ f^{\text{short}} = |N(51, 8.3^2)|, f^{\text{long}} = |N(68, 5)|$$

- 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

$v_N = \min f_N$

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

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

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

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

$$g_i^n = s_{i+1}^n - (s_i^n + \sum_{p=1}^{P} d_p^n \cdot x_{i,p}) \qquad \forall i < P, n \qquad \text{(idle time after the } ith \text{ procedure)}$$

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

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

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 ith procedure; 0 otherwise
t_i : scheduled time of the ith patient

Metric variables

s_i^n : start time of ith procedure under scenario n
g_i^n : idle time after the ith procedure under scenario n
o^n : idle time before the start of the ith patient under scenario n

Second, Template Optimization Model

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

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

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Third, Articulation for Managerial Preferences

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

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- Clinic Manager preference toward patient and provider time are tycially 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

$$
\begin{aligned}
v_N = \text{minimize } f_N \; &:= \lambda \cdot \left(\frac{1}{N} \sum_{n=1}^{n} \sum_{i=1}^{P} (s_i^n - t_i) \right) + (1-\lambda) \cdot \left(\frac{1}{N} \sum_{n=1}^{n} \sum_{i=1}^{P} g_i^n + o^n \right) \\
&= \lambda \cdot \texttt{Expected Total lWaiting} + (1-\lambda) \cdot \texttt{Expected Total idle and overtime} \\
&= \lambda \cdot \mathbb{E}[\mathbb{TW}] \qquad\qquad\qquad\qquad + (1-\lambda) \cdot (\mathbb{E}[\mathbb{TI}] + \mathbb{E}[\mathbb{O}])
\end{aligned}
$$

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\end{aligned}
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- 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

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\end{aligned}
$$

- Results:

Table 1: Example of Pareto Optimal Templates

λ	Optimal Template	$\mathbb{E}[\mathbb{TW}]_\lambda$	$\mathbb{E}[\mathbb{TI}]_\lambda$	$\mathbb{E}[\mathbb{O}]_\lambda$
0	$(\mathbf{X}, t)_0$	100 min	10 min	5 min
0.05	$(\mathbf{X}, t)_{0.05}$	93 min	15 min	6 min
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Presentation Overview

Example: A Typical Colonoscopy Scheduling Problem

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

Parameters	**Details**
Number of procedures (P)	10 Colonoscopies
Clinic working hours $(0 - \mathcal{L})$	0-expected duration for 10 Colonoscopies
Poor prep/long procedure-probability	$\alpha = 0.1$
Colonoscopy duration distribution	short$\sim \lvert Normal(51, 8.3^2)\rvert$
	long$\sim \lvert Normal(68, 5)\rvert$

Articulation for Managerial Preferences

$$\text{minimize} \quad \lambda \cdot \mathbb{E}[\mathbb{TW}] + (1-\lambda) \cdot (\mathbb{E}[\mathbb{TI}] + \mathbb{E}[\mathbb{OT}])$$

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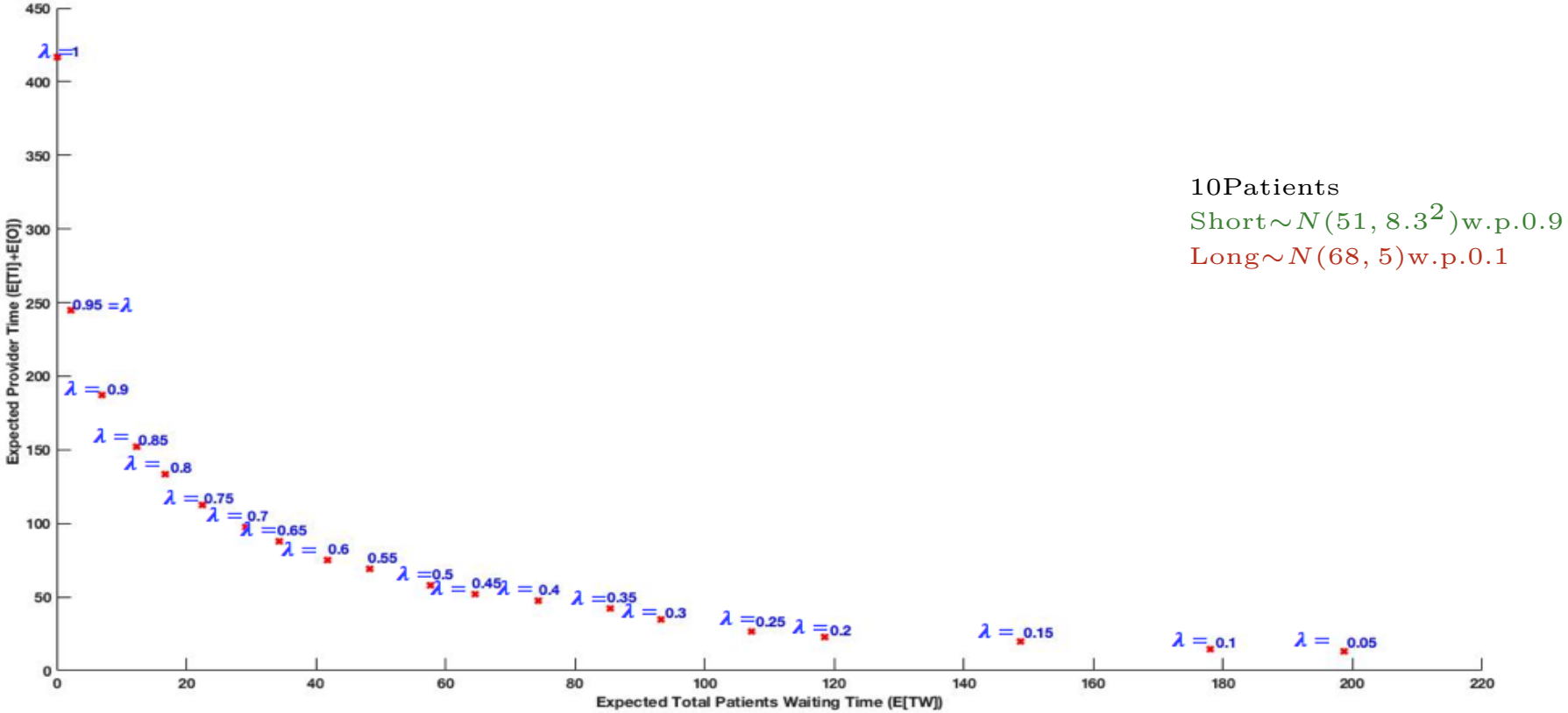

Figure 2: Expected performance of Pareto optimal schedules as function of the trade-off level λ.

Articulation for Managerial Preferences

$$\text{minimize} \quad 0.25 \cdot \mathbb{E}[\mathbb{TW}] + 0.75 \cdot (\mathbb{E}[\mathbb{TI}] + \mathbb{E}[\mathbb{OT}])$$

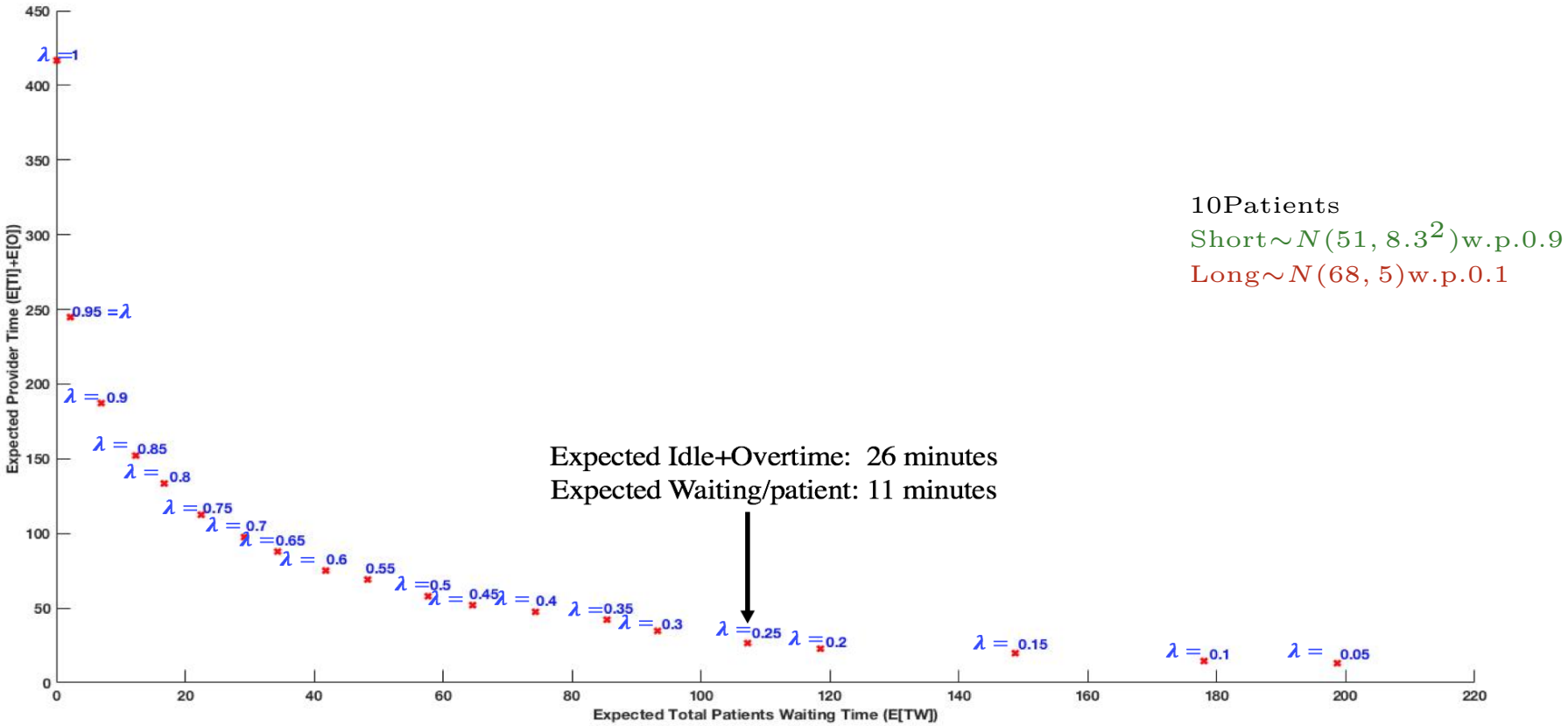

Figure 2: Expected performance of Pareto optimal schedules as function of the trade-off level λ.

Scheduling Templates Adjusted to No-Show

⋆ No-show rate (r)=0%

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

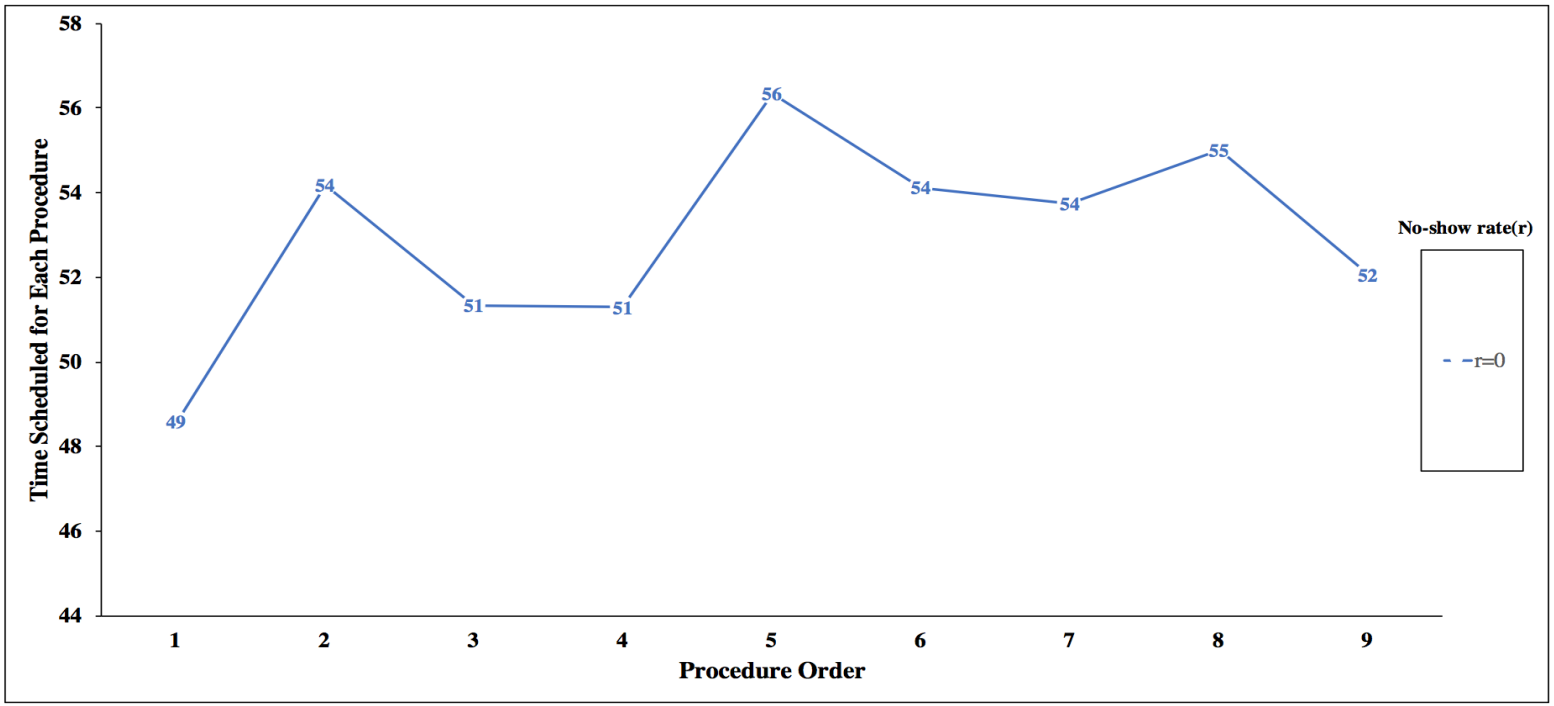

Figure 3: Optimal time to schedule for each colonoscopy as the the no-shows rate varies from 0 % to 50 %

Scheduling Templates Adjusted to No-Show

⋆ No-show rate (r)=10%

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

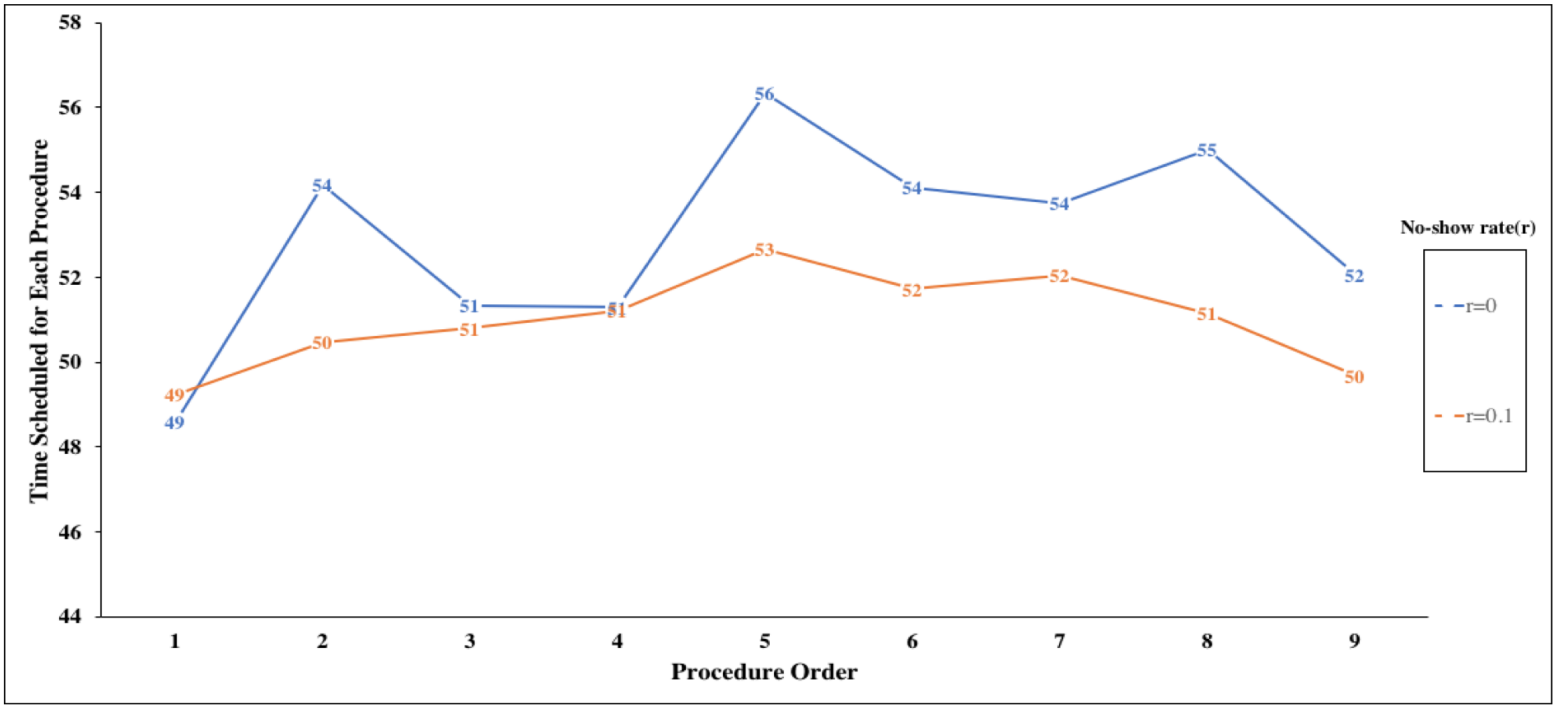

Figure 3: Optimal time to schedule for each colonoscopy as the the no-shows rate varies from 0 % to 50 %

Scheduling Templates Adjusted to No-Show

⋆ No-show rate (r)=15%

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

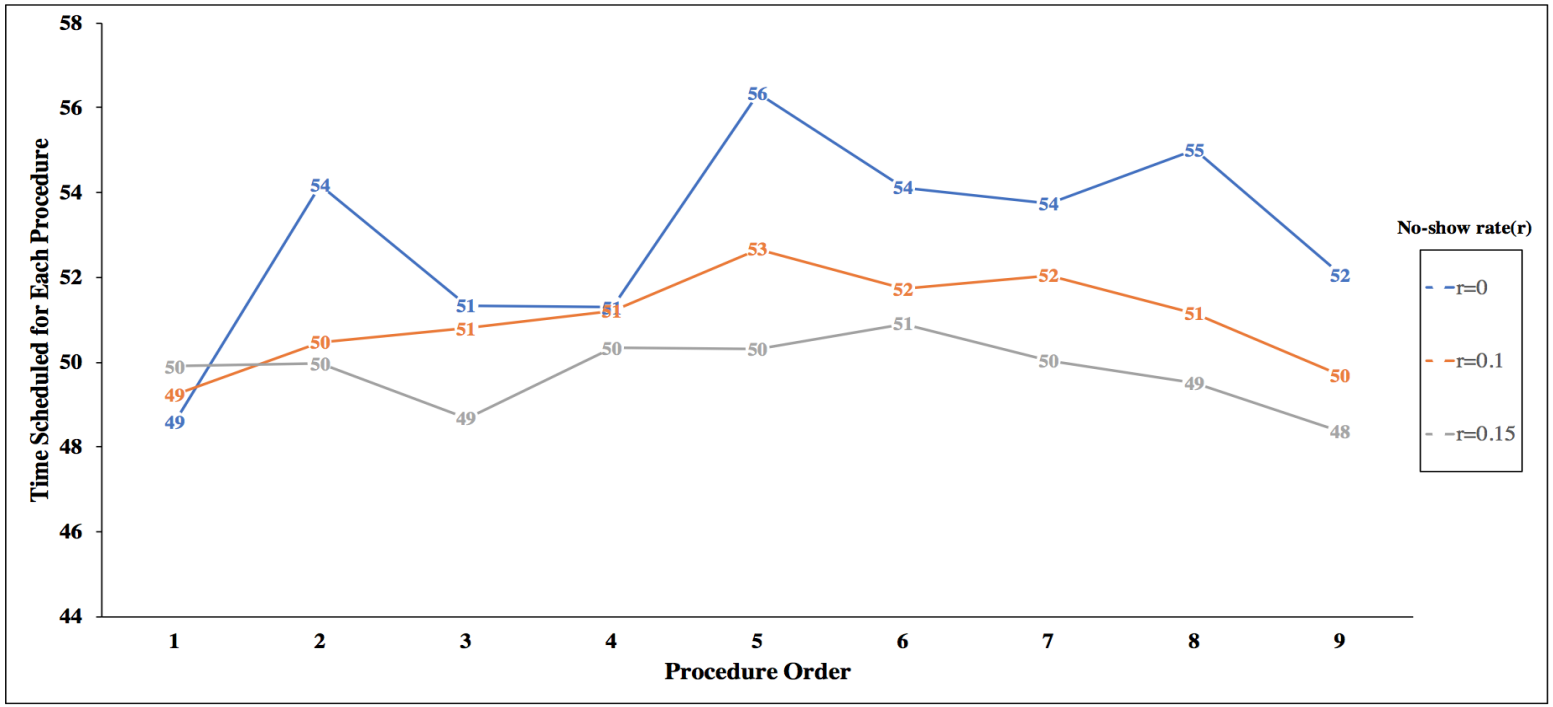

Figure 3: Optimal time to schedule for each colonoscopy as the the no-shows rate varies from 0 % to 50 %

Scheduling Templates Adjusted to No-Show

⋆ No-show rate (r)=20%

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

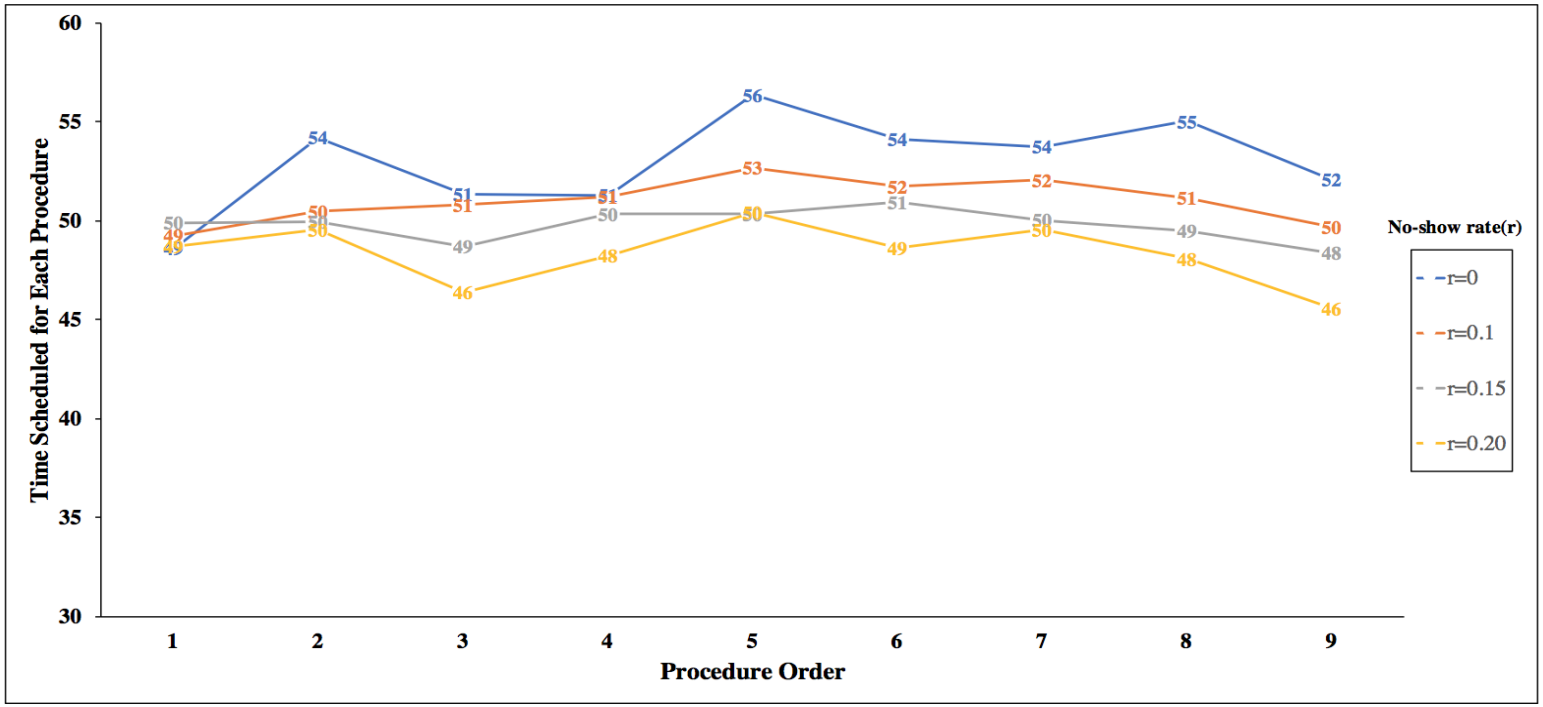

Figure 3: Optimal time to schedule for each colonoscopy as the the no-shows rate varies from 0 % to 50 %

Scheduling Templates Adjusted to No-Show

⋆ No-show rate (r)=30%

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

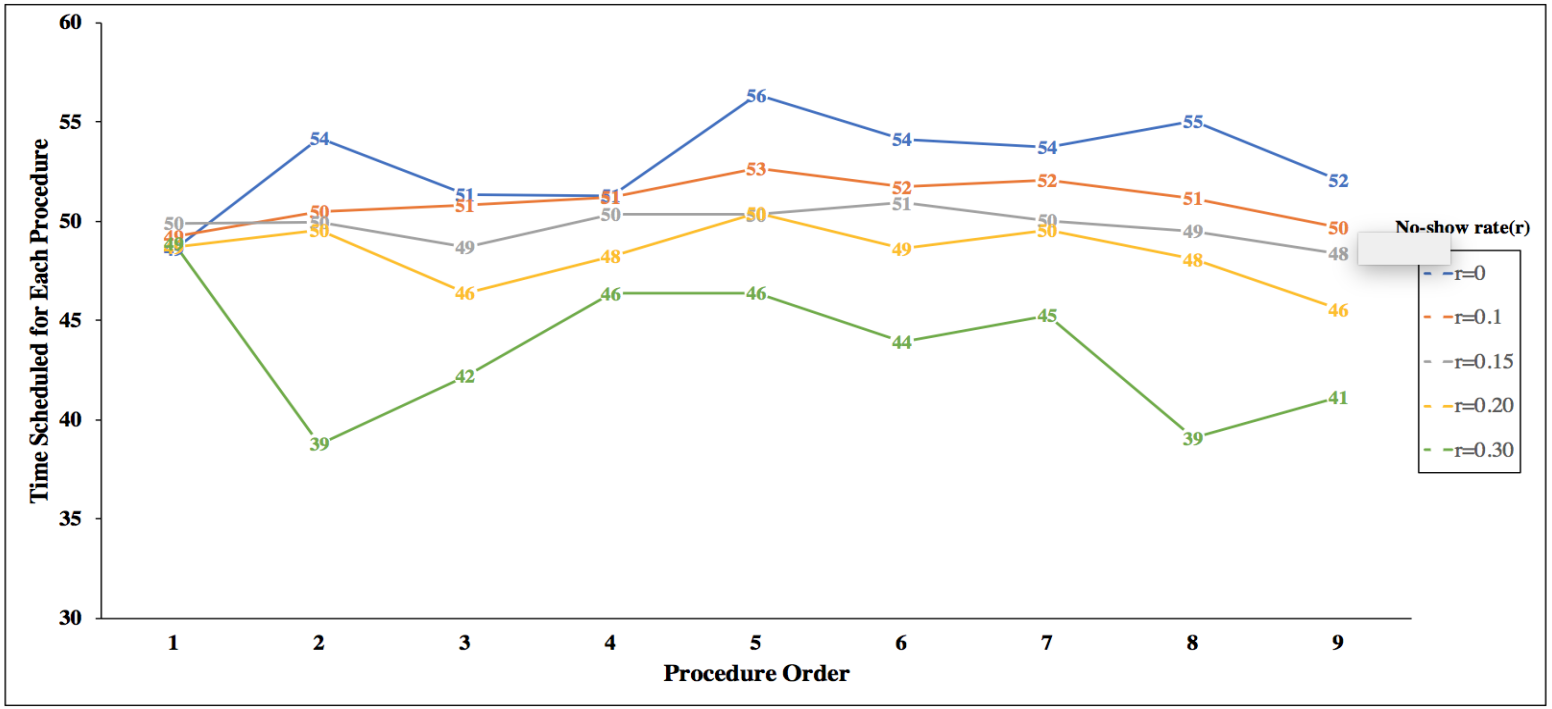

Figure 3: Optimal time to schedule for each colonoscopy as the the no-shows rate varies from 0 % to 50 %

Scheduling Templates Adjusted to No-Show

⋆ No-show rate (r)=50%

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

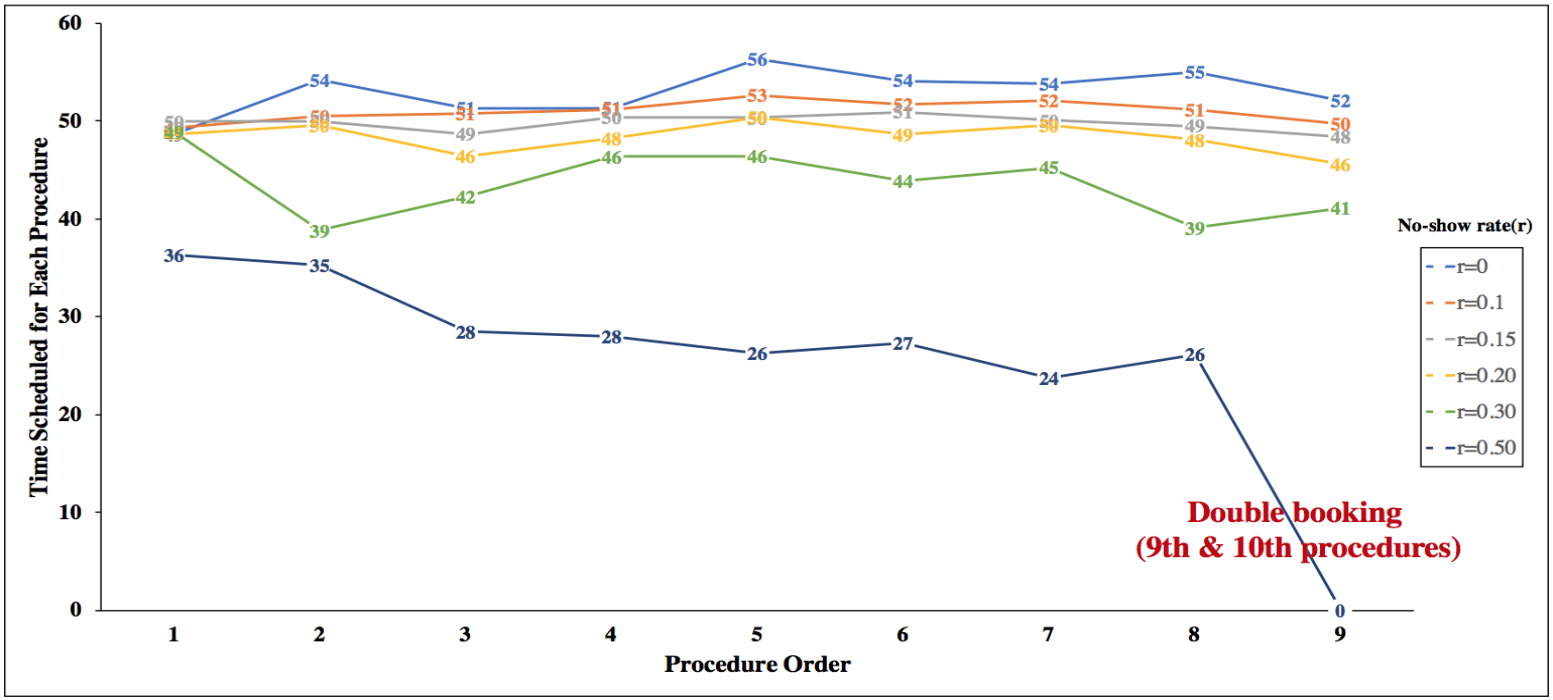

Figure 3: Optimal time to schedule for each colonoscopy as the the no-shows rate varies from 0 % to 50 %

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?

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

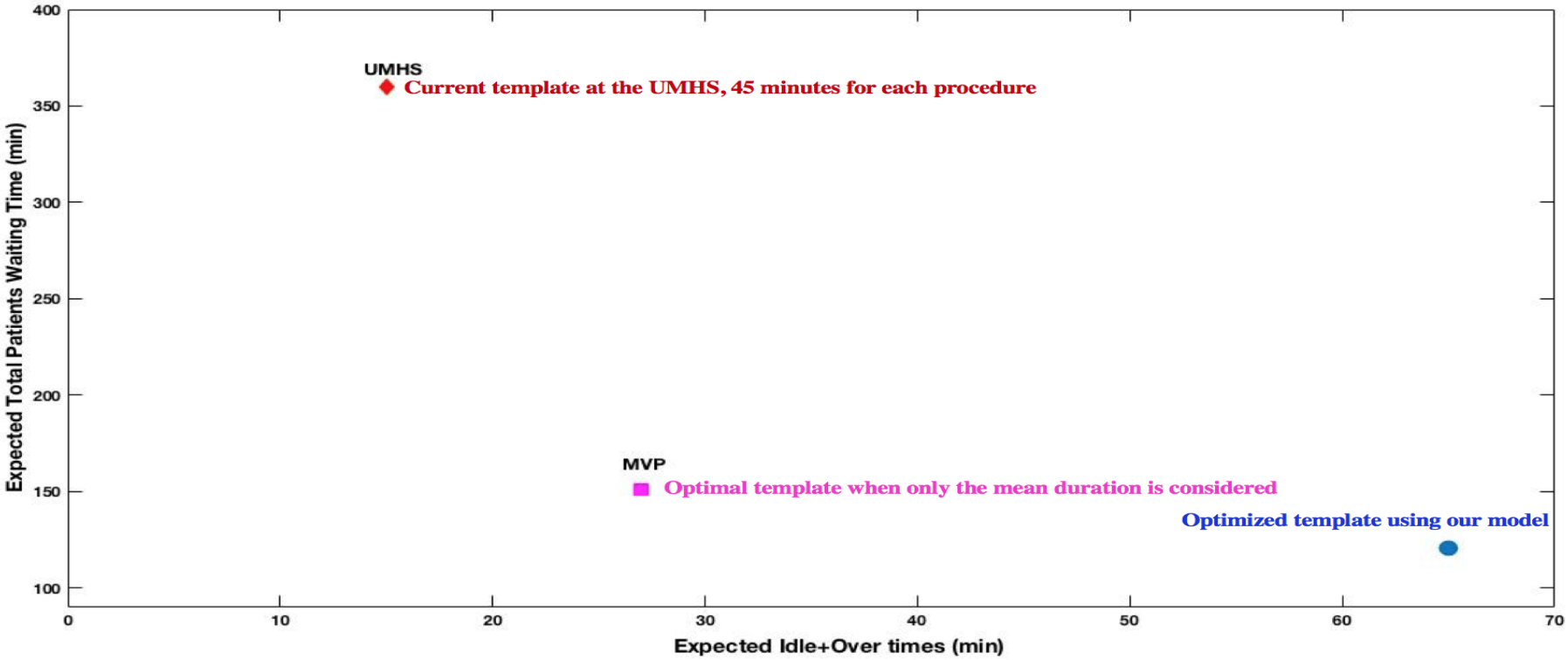

Figure 4: Expected performance from 1,000 simulation days of the optimized template using our model (blue), the current UMHS template (red), and the optimal template to the mean value problem (MVP) with once scenario equal to the mean duration (pink)

Presentation Overview

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

Thank You!

"***No one can whistle a symphony. It takes a whole orchestra to play it***"

Q&A

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