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Scheduling Colonoscopy Patients in an Outpatient Endoscopy Clinic

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HSPIC, Orlando
March 3,2017

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HEALTHCARE ENGINEERING & PATIENT SAFETY
UNIVERSITY OF MICHIGAN

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

Presentation Outline

- **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[1]

[1. Peery, Anne F., et al, 2012]

Colonoscopy Procedure

- Screening test for Colorectal Cancer (CRC)
  - 2nd leading cause of cancer-related death in the US[2]
  - 4.5 million age-eligible subjects in the US (≥50 years)[3]

- Enables a gastroenterologist to evaluate the inside of the large intestine (rectum and colon)
  - Spot existing cancer, prompting treatment
  - Prevent future cancer (***polyps***)

[2. American Cancer Society]

[3. Jain et al (2015)]

Colonoscopy Scheduling

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

Duration	Prep Quality	Health Conditions	No. of Polyps	Type of Sedation
Short	Adequate	Good	Low	Conscious
Long	Poor	Poor	High	Anesthesia

* 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)

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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

Duration	Prep Quality	Health Conditions	No. of Polyps	Type of Sedation
Short	Adequate	Good	Low	Conscious
Long	Poor	Poor	High	Anesthesia

- Type likelihood $\gamma = 0.75$
- Simplest model
  - Short: 30 minutes with 0.75 probability
  - Long: 90 minutes with 0.25 probability
- Complex model
  - Short: $Normal(30, \sigma_s^2)$ with 0.75 probability
  - Long: $Normal(90, \sigma_l^2)$ 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

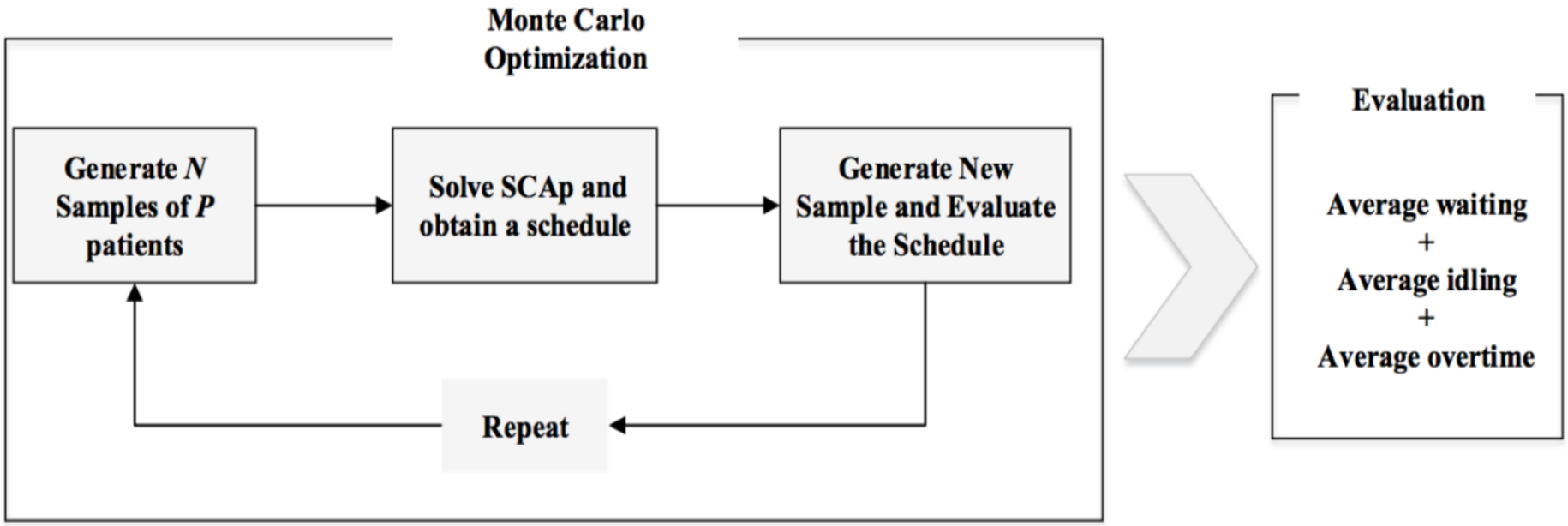

Figure 1: Steps of Monte Carlo Optimization

Impact of Duration Uncertainty

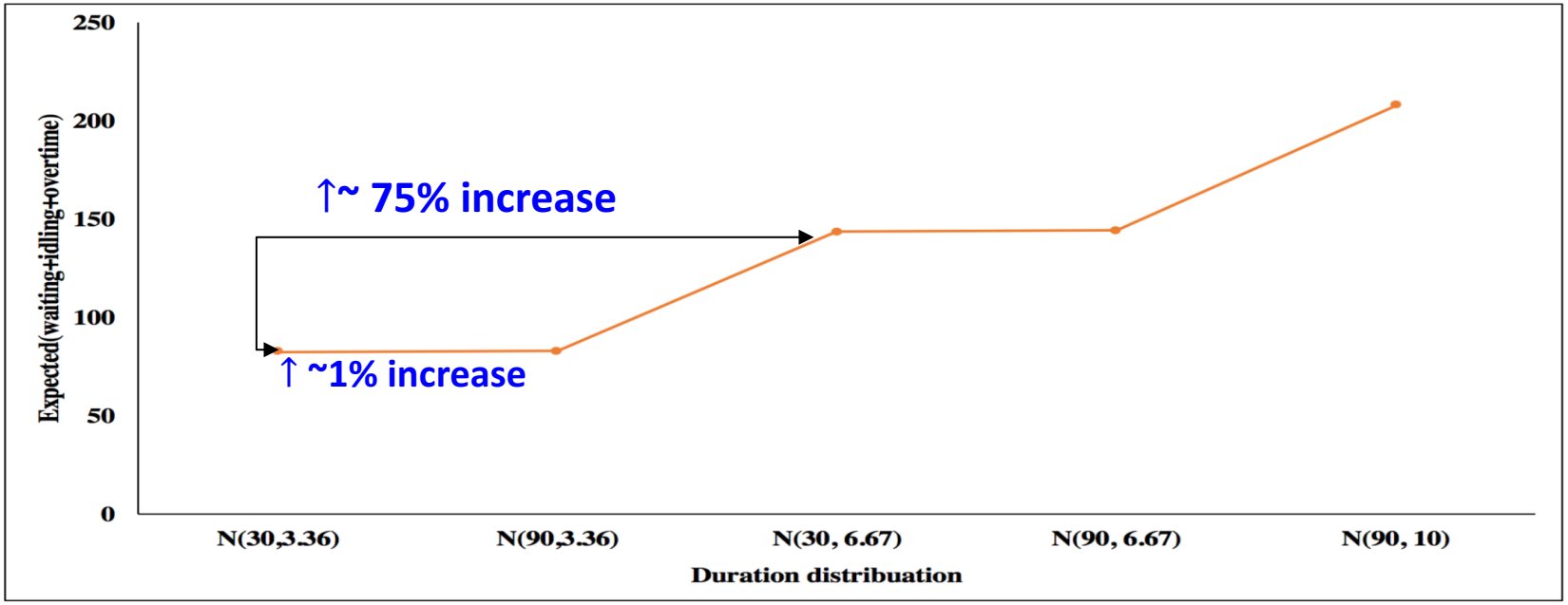

Figure 2: Effect of duration uncertainty on schedule performance

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

Impact of procedure type

- Balanced (5 short: 5 long):

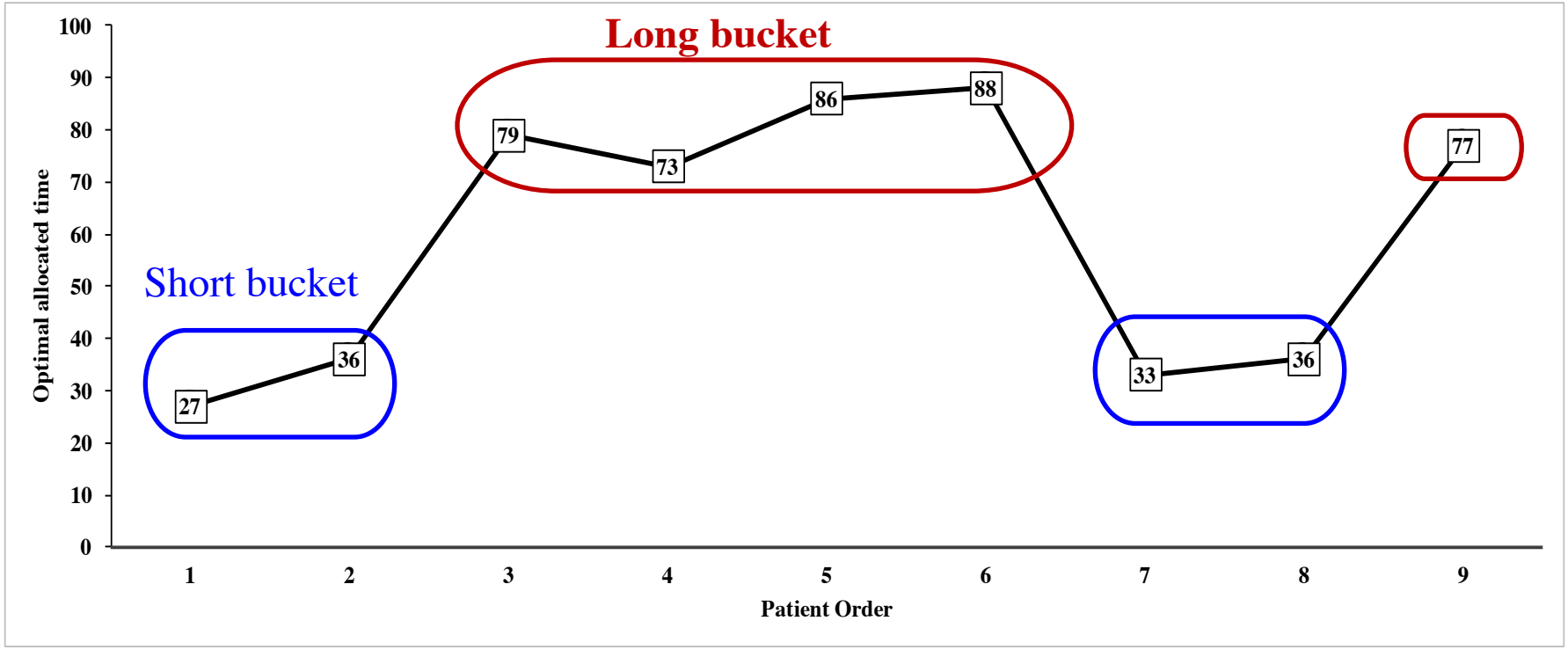

Figure 3: Effect of procedure type on optimal scheduling policy

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)

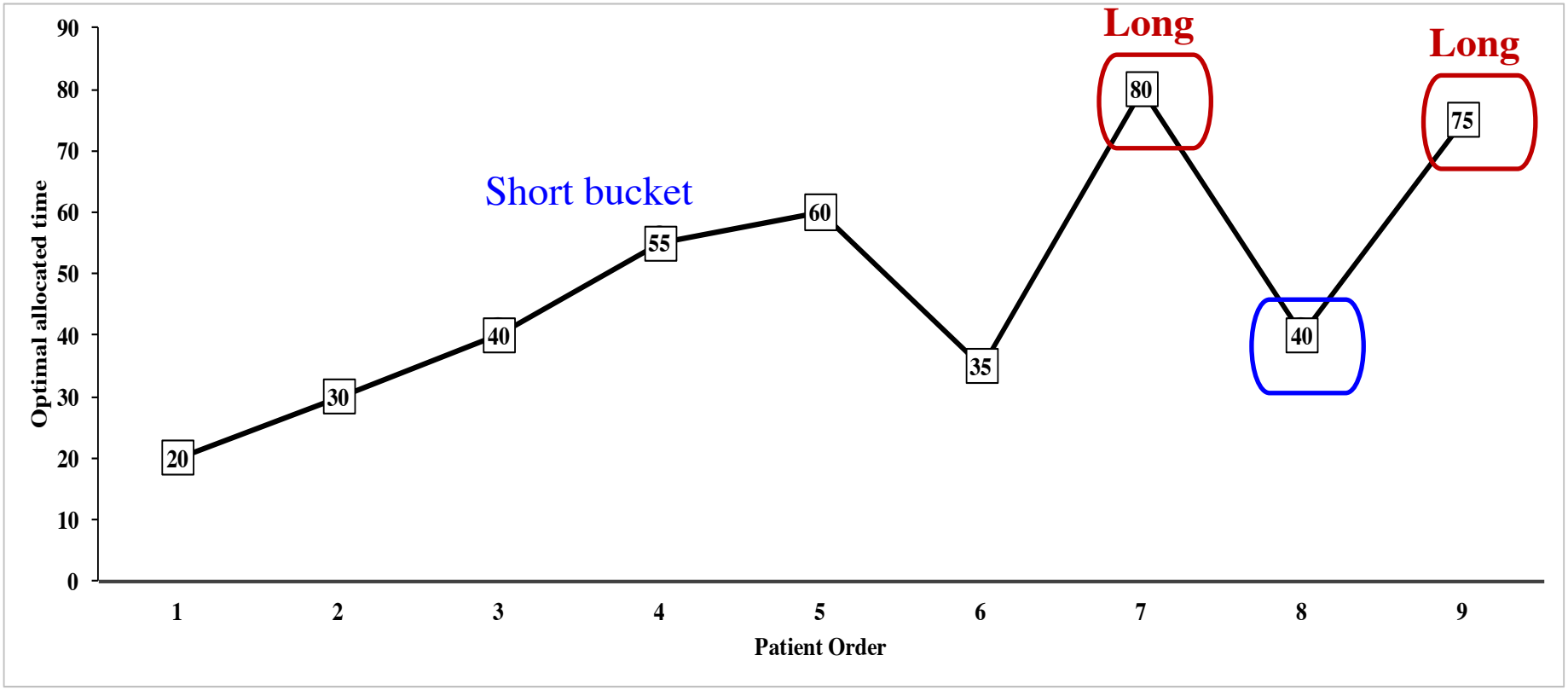

Figure 4: Effect of procedure type on optimal scheduling policy

Short : e.g. good prep, conscious sedation colonoscopy, etc.
Long: e.g. poor prep, monitored anesthesia colonoscopy, etc.

Impact of Arrivals Uncertainty

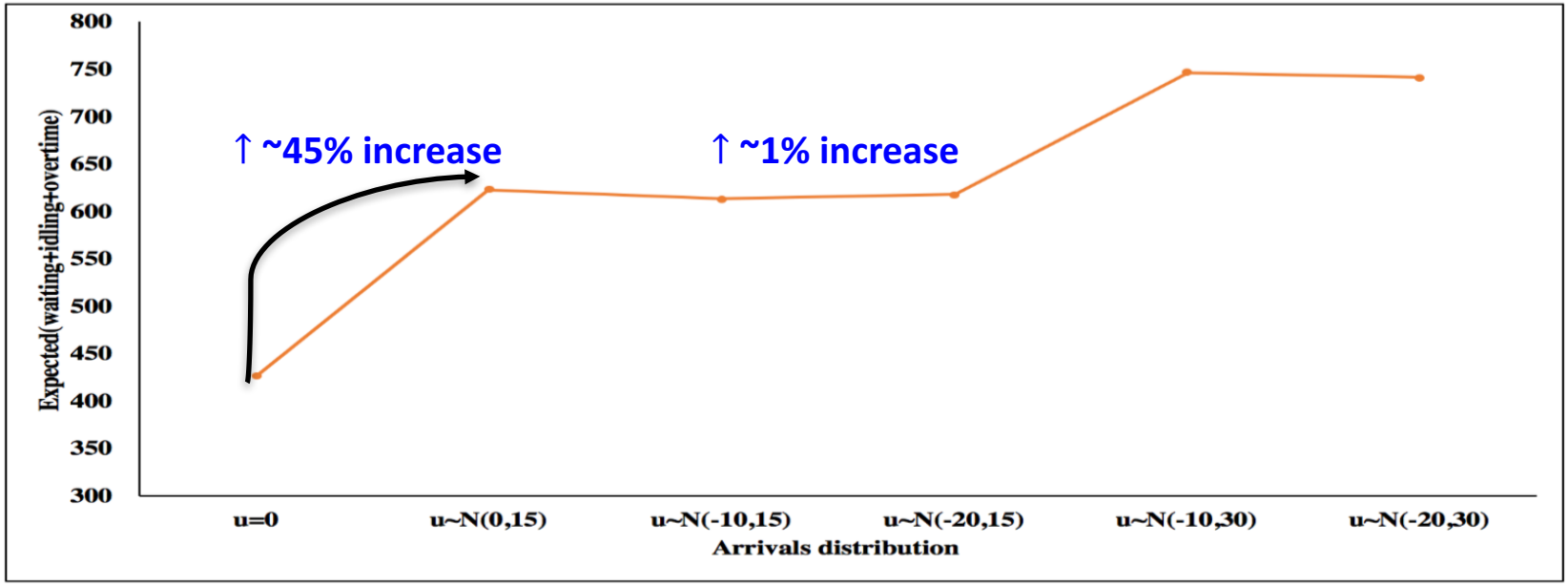

Figure 3: Effect of arrivals uncertainty on schedule performance

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

Impact of No-Show

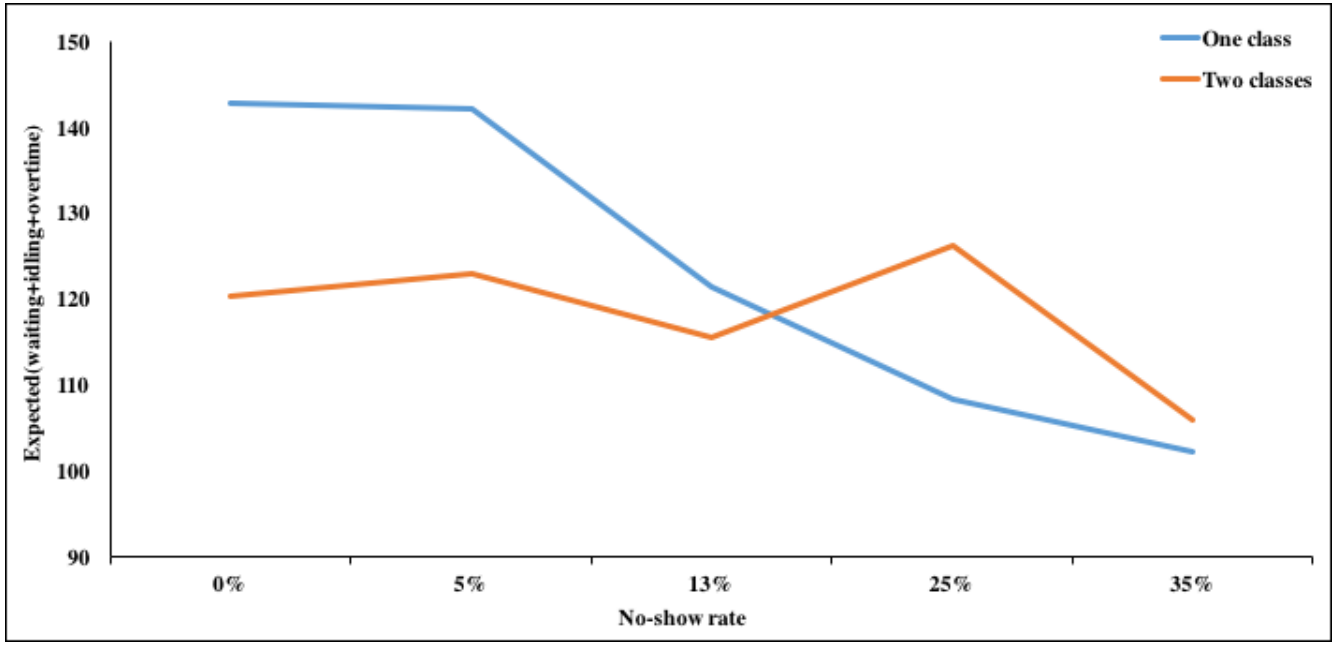

Figure 6: changes in optimal schedule performance for one classes of no-show (blue) as the rate changes from 0% to 35% and for two patient classes (red) where the rate is 18% for one class and ranges from 0% to 35% for the other class

Observations:

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

Impact of No-Show

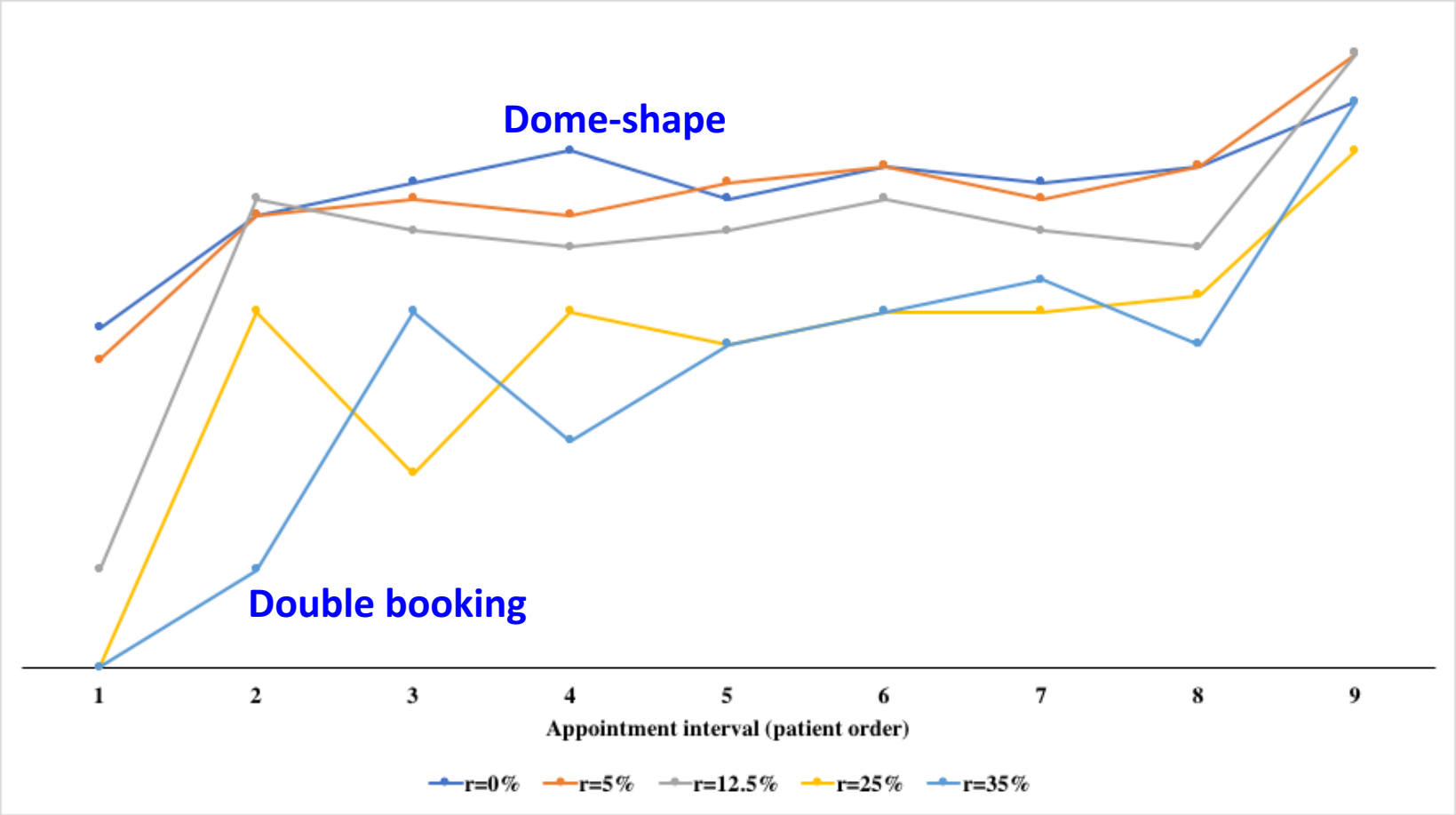

Figure 7: Effect of patient no-shows on optimal inter-appointment time for the case of one class of no-shows

Impact of No-Show

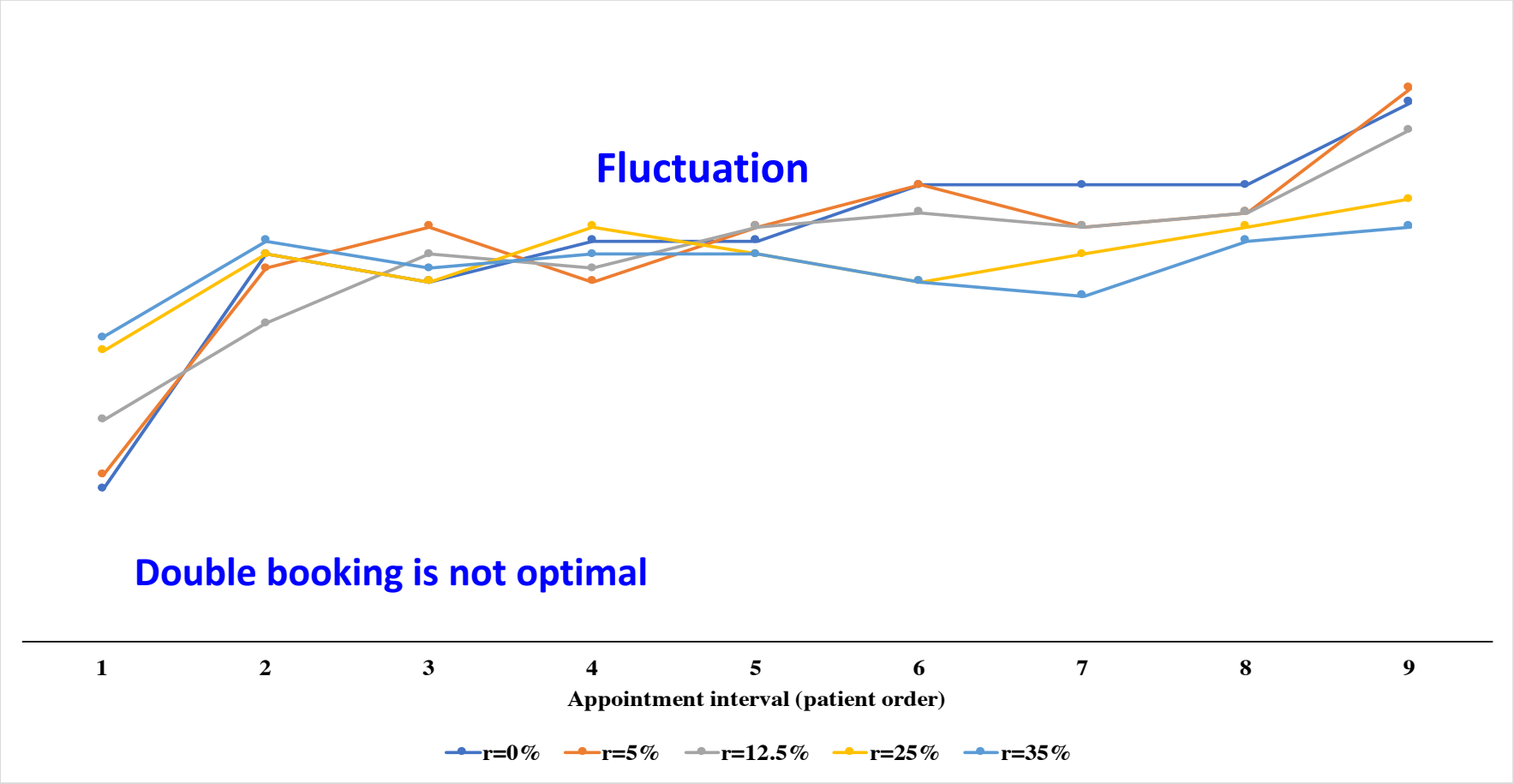

Figure 8: Effect of patient no-shows on optimal inter-appointment time for the case of two classes of no-shows

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Benchmarks

- **SCAp1**: optimal SCAp sequence with schedule time approximated down to the nearest 5
  - e.g $\lfloor 7.27 \rfloor$ =7.25
- **SCAp2**: optimal SCAp sequence with schedule time approximated down up to the nearest 5
  - e.g $\lceil 7.27 \rceil = 30$
- **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): a**ppointment lengths are smaller at the beginning and end of day and longer in the middle of the day

Performance Comparison: Examples

Table 2: Change in average performance from optimal
(0% no-show, punctual)

Policy	waiting+idle +overtime	waiting	idling	overtime
IBFI	15.15 %	43.23 %	-34.58 %	-3.16 %
2BEG	>100 %	>100 %	-96.93 %	-25.73 %
DC1F	27.5 %	-39.54 %	85.84 %	>100 %
SCAp1	4.90 %	16.99 %	-12.9 %	-7.37 %
SCAp2	0 %	-9.92 %	10.68 %	14.87 %

Performance Comparison: Examples

Table 3: Change in average performance from optimal (18% no-show, early on average)

Policy	waiting+idle +overtime	waiting	idling	overtime
IBFI	32.11 %	77.38 %	-47.01 %	-47.01 %
2BEG	76.56 %	>100 %	-65.84 %	-65.84 %
DC1F	>100 %	>100 %	>100 %	>100 %
SCAp1	0.70 %	2.88 %	-6.36 %	-6.36 %
SCAp2	0.08 %	-2.91 %	10.74 %	10.74 %

Performance Comparison: Examples

Table 4: Change in average performance from optimal (18% no-show, 50% early and 50% late on average)

Policy	waiting+idle +overtime	waiting	idling	overtime
IBFI	30.12%	56.31%	-24.06%	7.24 %
2BEG	75.13%	>100%	-58.02%	-60.70%
DC1F	>100%	>100%	-73.22%	-59.20%
SCAp1	2.50 %	4.39 %	-4.15 %	-3.49%
SCAp2	1.48 %	-3.73 %	6.53%	36.61%

Example for Practical and Optimal Template

Example

Table 5: Duration Variability Only

Slot	Type	Time	Length
1	C1	7.30	30
2	C1	8.00	30
3	C2	8.30	95
4	C2	10.05	90
5	C1	11.35	35
6	C1	12.05	35
7	C2	12.40	45

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

Slot	Type	Time	Length
1	C1	7.00	20
2	C2	7.20	85
3	C1	8.45	25
4	C2	9.10	85
5	C1	10.30	40
6	C1	11.10	35
7	C2	11.45	70

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

Presentation Outline

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- 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

Thank You!

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

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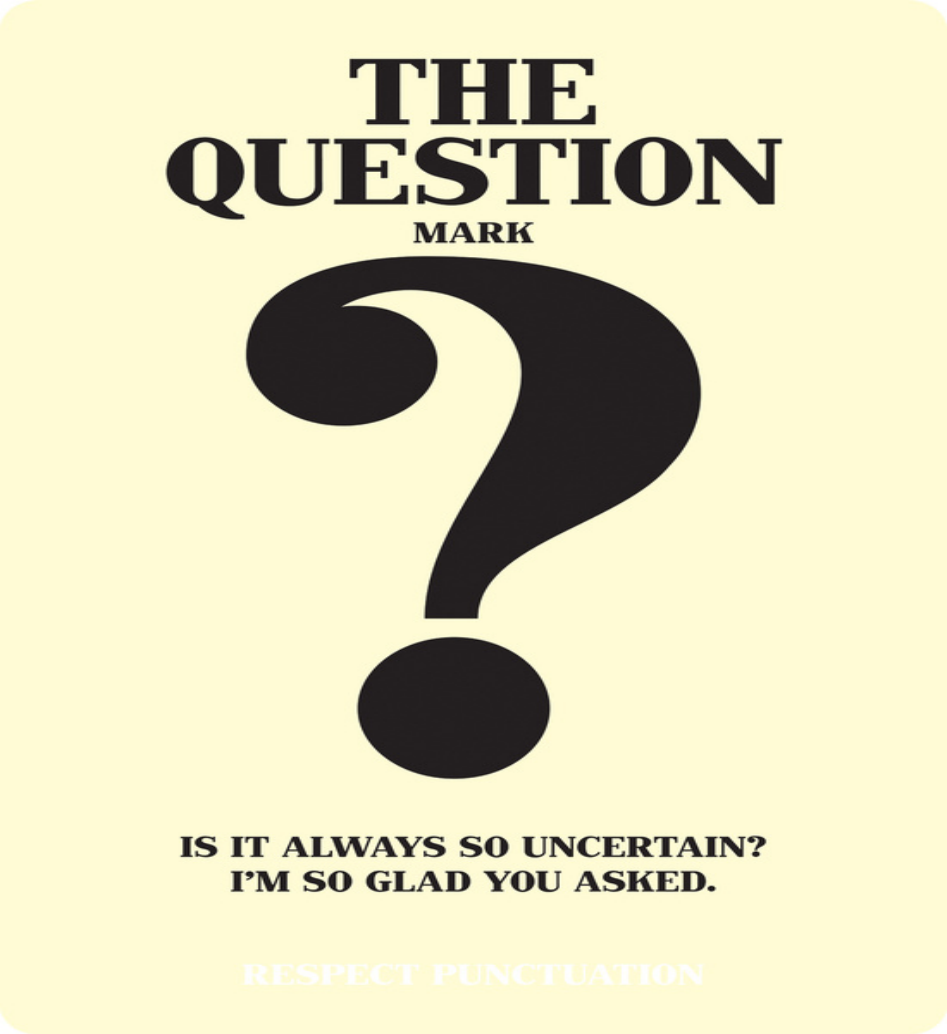
Questions


THE
QUESTION
MARK
IS IT ALWAYS SO UNCERTAIN?
I'M SO GLAD YOU ASKED.
RESPECT PUNCTUATION

Notations

Table 1: *S-CAP* sets, indices and variables

Indices and sets	
$p \in P$	Set of patients
$i \in P$	Set of appointment order
$\omega \in \Omega$	Set of scenarios
Fixed model parameters	
$\mathcal{L}$	Planned length of the shift.
λ_1	Weight assigned to total patient *waiting* time.
λ_2	Weight assigned to total provider *idle* time.
λ_3	Weight assigned to *overtime*
Scenario dependent model parameters	
τ_p^w	Procedure duration for patient p in scenario ω
u_p^w	Un-punctuality of patient p in scenario ω
η_p^w	Probability of no-show for patient p in scenario ω
ϕ^ω	Probability of scenario ω
Decision variables	
x_{ip}	1 if patient p is the *ith* patient; 0 otherwise
t_i	Scheduled appointment time of the *ith* patients
a_p^ω	Arrival time of patient p under scenario ω
s_p^ω	Start time of patient p under scenario ω
I_i^ω	Idle time before the*ith* patient under scenario ω
o^ω	overtime under scenario ω

SCAp Formulation

$$S-CAP \quad \min \psi = \sum_{w\in\Omega} \phi(\omega)\Big[\sum_{i\in P} \lambda_1(s_i^\omega - a_i^\omega) + \lambda_2 I_i + \lambda_3 o^\omega\Big]$$

Min total expected waiting, idling & overtime

$$\text{s.t.} \quad \sum_{i\in P} x_{ip} = 1 \qquad \forall p \in P$$

$$\sum_{p\in P} x_{ip} = 1 \qquad \forall i \in P$$

Every appointment 1 patient and every patient gets 1 appointment

$$t_1 \geq 0$$

$$t_i \geq t_{i-1} \qquad \forall i > 1$$

$$t_i \leq \mathcal{L} \qquad \forall i \in P$$

Scheduled time obey the order and within the planned length

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

Arrival time= scheduled$\pm$un-punctuality

$$s_1^w \geq t_1 \qquad \forall \omega \in \Omega$$

$$s_i^\omega \geq a_i^\omega \qquad \forall i \in P$$

$$s_i^\omega \geq s_{i-1}^\omega + \sum_{p\in P} \tau_p^\omega x_{i-1p} \qquad \forall \omega \in \Omega, i > 1 \in P$$

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

$$I_1^\omega \geq a_1^\omega - t_1 \qquad \forall \omega \in \Omega$$

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

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

$$o^\omega \geq s_P^\omega + \sum_{j\in P} \tau_j^\omega x_{Pj} - \mathcal{L} \qquad \forall \omega \in \Omega$$

Overtime

$$I^\omega, o^\omega \geq 0 \qquad \forall \omega \in \Omega$$

$$x_{ip} \in \{0,1\} \qquad \forall i, p \in P$$

Impact of Arrivals Uncertainty