Evaluating Overutilization Variability in Operating Rooms

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1. Introduction

Problem: Overutilization of operating rooms (ORs)

- Increase costs for staffing and other resources (Donald C. Tyler, 2003)
- Affect patient outcomes (Andreas Fügener, 2015)
- Affect care provider satisfaction (Andreas Fügener, 2015)

Goal: To find management strategies to decrease OR overutilization variability using quantitative methods like Structural Equation Model, Monte Carlo Simulation, and Discrete Event Simulation

Definition

- **Prime Time**: The scheduled hours for elective cases.

- **Overutilized time**: The time duration between the last surgery completion time and the end of the prime time.

- **Turnover time:** The time duration between two successive cases in the same OR on the same day.

- **Elective case:** Cases scheduled before noon of the preceding day.

- **Add-on case:** Emergency cases and cases scheduled based on an elective case.

2. Data

July 1, 2017-Feb 28, 2018	11264	15	28
Data	**Cases**	**Features**	**Operating Rooms**

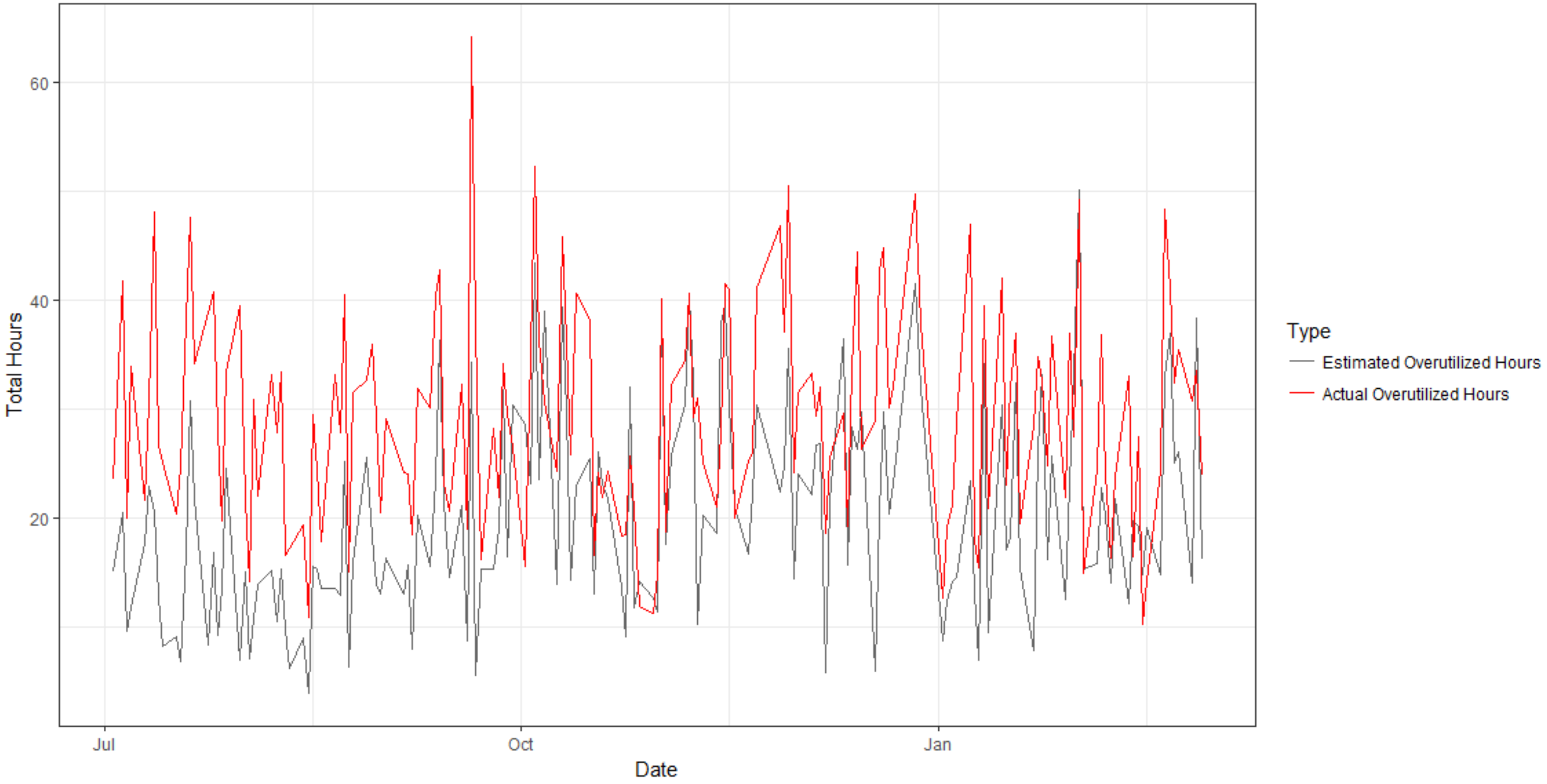
Case Number : 9830 elective cases and 1434 add-on cases.

Main Features:

- Surgery date of each case
- Time patient entered an OR
- Time patient left the OR
- Scheduled start and end time of each operation
- Classification of operation (elective or add-on case)
- OR in which the operation was performed
- Primary Service (the type each operation belongs to)

28 Operating Rooms: OR2001 to OR2012, OR2014 to OR2027, OR2029 and PROC

Total Over-utilized Hours



Total number of hours for elective and adds-on cases

After removing weekend cases and 3 special cases performed in wait room.

Outliers removed from our analysis

- Extreme data points on
  2017-07-04 Independence Day
  2017-09-04 Labor Day
  2017-11-23 to 11-24 Thanks Giving Day
  2017-12-25 to 12-26 Christmas Day
  2017-12-29 and 2018-01-01 New Year’s Day

- After removing special cases, including weekends and holidays, we have 10405 cases and 165 days in total.

Notations

- $X_{a,i}$ = total prime time for the i^{th} day
- $y_{ee,i}$ = total estimated time of elective cases for the i^{th} day
- $y_{e,i}$ = total actual time of elective cases for the i^{th} day
- $y_{a,i}$ = total actual time of add-on cases for the i^{th} day
- $y_{ae,i}$ = total estimated time of add-on cases for the i^{th} day
- $y_{t,i}$ = total turnover time for the i^{th} day
- $y_{o,i}$ = total overutilized time for the i^{th} day

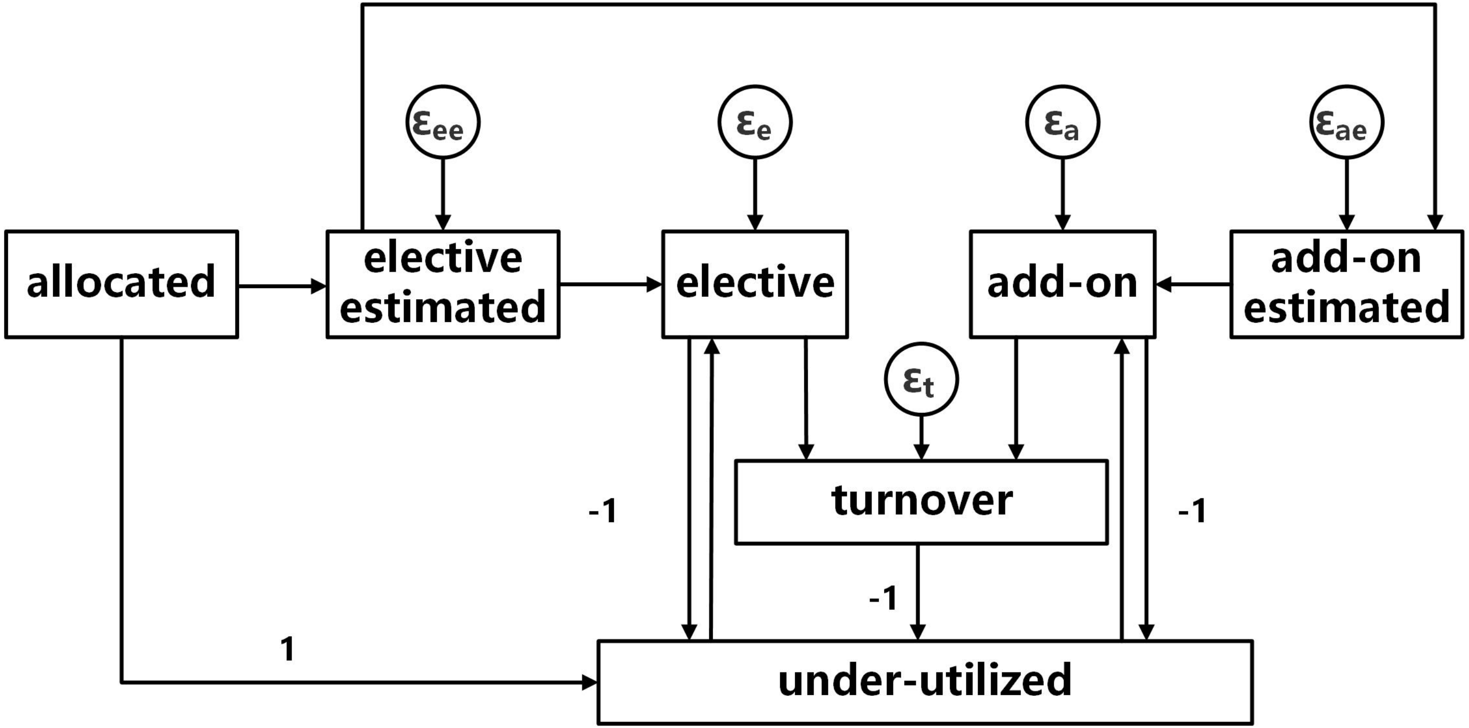
- X: exogenous
- Y: endogenous

Observed Covariance Matrix (units of hours^2)

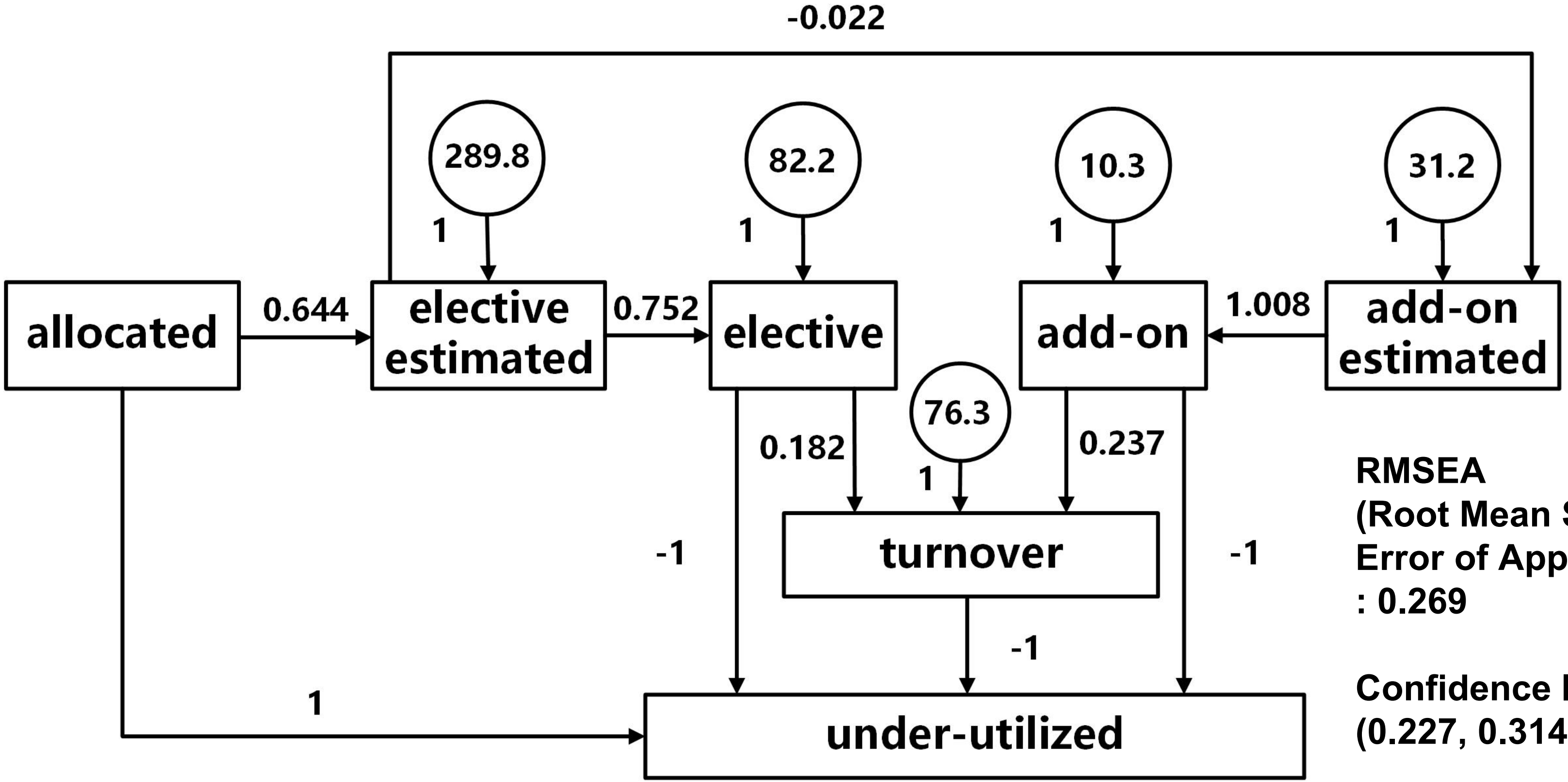
	$\mathbf{x_a}$	$\mathbf{y_{ee}}$	$\mathbf{y_e}$	$\mathbf{y_a}$	$\mathbf{y_{ae}}$	$\mathbf{y_t}$	$\mathbf{y_o}$
$\mathbf{x_a}$	680.155						
$\mathbf{y_{ee}}$	390.711	653.129					
$\mathbf{y_e}$	390.984	484.595	519.362				
$\mathbf{y_a}$	-2.356	-41.137	-35.271	93.865			
$\mathbf{y_{ae}}$	1.370	-4.473	-14.720	71.113	71.085		
$\mathbf{y_t}$	108.141	107.056	82.020	27.517	30.515	91.566	
$\mathbf{y_o}$	-54.248	49.998	67.179	40.315	35.423	30.544	97.084

3. Structural Equation Model – Underutilization
Dexter et al. (1999)

Structural Equation Model



Result

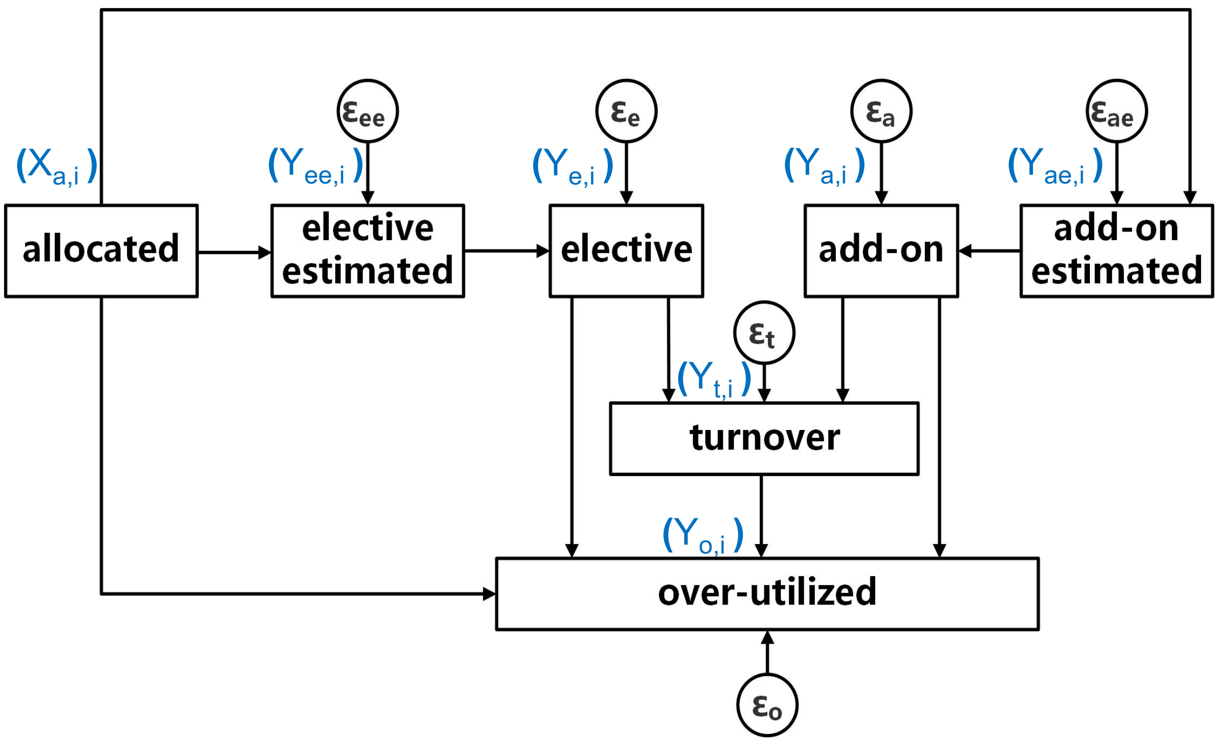


RMSEA (Root Mean Square Error of Approximation) : 0.269

Confidence Interval (0.227, 0.314)

4. Structural Equation Model - Overutilization

Structural Equation Model



$$y_{ee,i} = c_{x\to ee}x_{a,i} + \varepsilon_{ee,i}.$$

$$y_{ae,i} = c_{x\to ae}x_{a,i} + \varepsilon_{ae,i}.$$

$$y_{e,i} = c_{ee\to e}y_{ee,i} + \varepsilon_{e,i}.$$

$$y_{a,i} = c_{ae\to a}y_{ae,i} + \varepsilon_{a,i}.$$

$$y_{t,i} = c_{e\to t}y_{e,i} + c_{a\to t}y_{a,i} + \varepsilon_{t,i}.$$

$$y_{o,i} = c_{e\to o}y_{e,i} + c_{a\to o}y_{a,i} + c_{t\to o}y_{t,i} - c_{x\to o}x_{a,i} + \varepsilon_{o,i}$$

Hadi’s Multivariate Outlier Detection

Find three outliers:

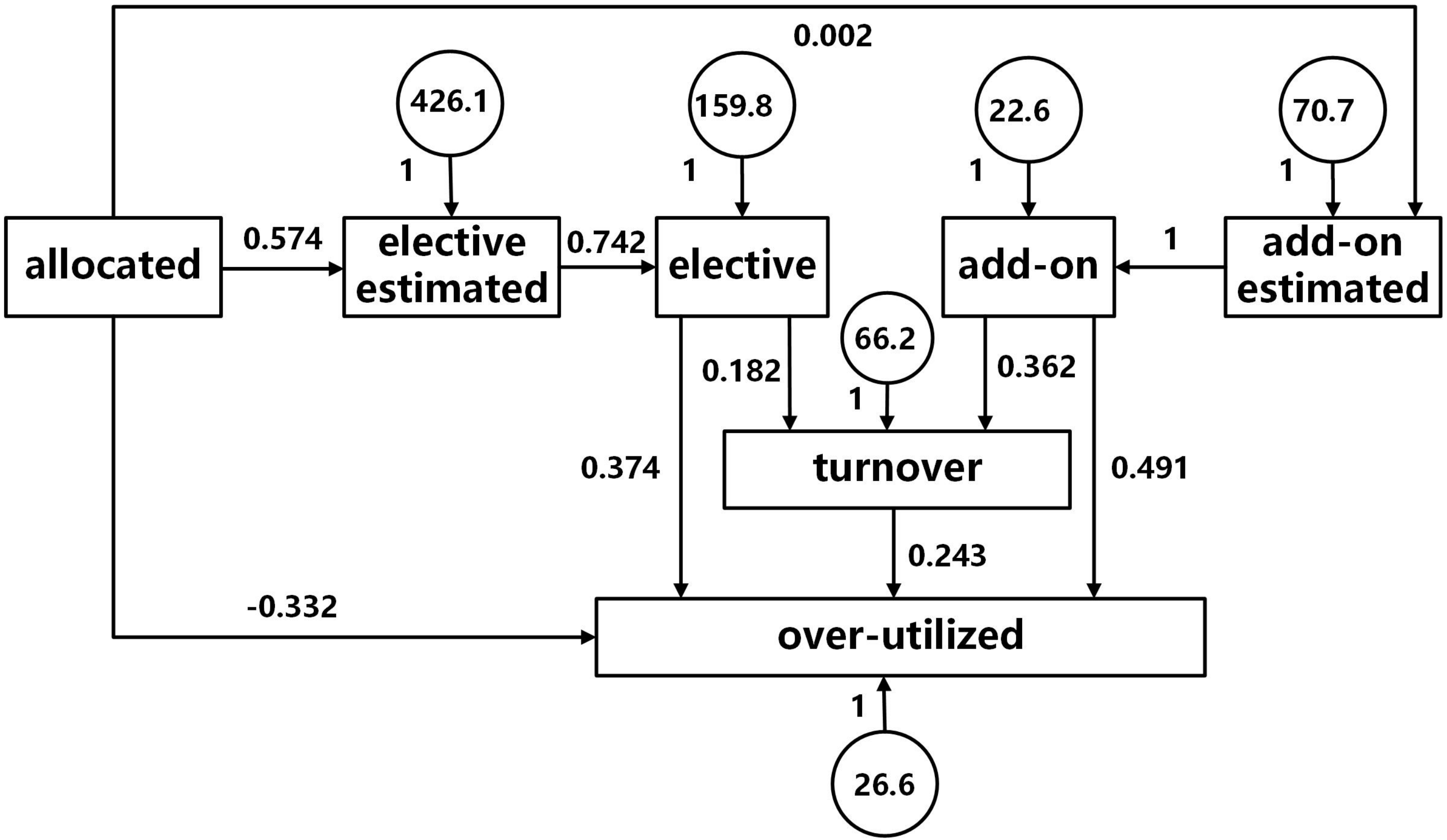
- 2017-7-20 : The gap between estimated and actual elective cases is 27 hours
- 2017-7-28 : The gap between estimated and actual add-on cases is 19 hours
- 2018-1-17 : 21 hours gap between estimated and actual add-on cases with lowest actual elective hours equaled 136 hours.

- After removing the three outliers, we get a new observed Covariance Matrix.

Observed Covariance Matrix after Removing Outliers (units of $hours^2$)

	$\mathbf{x_a}$	$\mathbf{y_{ee}}$	$\mathbf{y_e}$	$\mathbf{y_a}$	$\mathbf{y_{ae}}$	$\mathbf{y_t}$	$\mathbf{y_o}$
$\mathbf{x_a}$	677.828						
$\mathbf{y_{ee}}$	381.303	619.943					
$\mathbf{y_e}$	379.762	458.392	495.867				
$\mathbf{y_a}$	4.186	-18.300	-18.428	82.735			
$\mathbf{y_{ae}}$	2.565	9.362	-8.433	64.622	65.021		
$\mathbf{y_t}$	103.421	105.008	78.057	28.701	30.694	89.432	
$\mathbf{y_o}$	-55.193	57.330	70.636	37.466	32.081	30.861	96.636

SEM Result



RMSEA : 0.151

Confidence Interval (0.118,0.184)

Correlation Residual Matrix

	$\mathbf{x_a}$	$\mathbf{y_{ee}}$	$\mathbf{y_e}$	$\mathbf{y_a}$	$\mathbf{y_{ae}}$	$\mathbf{y_t}$	$\mathbf{y_o}$
$\mathbf{x_a}$	0						
$\mathbf{y_{ee}}$	0	0					
$\mathbf{y_e}$	0.169	0	0				
$\mathbf{y_a}$	0.007	-0.087	-0.096	0			
$\mathbf{y_{ae}}$	0	0.04	-0.053	0	0		
$\mathbf{y_t}$	0.222	0.114	-0.03	-0.033	0.078	0	
$\mathbf{y_o}$	0.129	0.011	-0.111	-0.011	0.027	-0.143	0

5. Monte Carlo Simulation

Steps

1. Generate seven random numbers including six random errors and one prime time duration (X_a) according to their distribution.
2. Recalculate the y_o on each day according to equations 1-6, and get the standard deviation of y_o.
3. Simulate each management intervention situation with the same method above, and the corresponding mathematical methods are shown in table below.

Mathematical Method	Management Intervention
Set x_a to a fixed value	Allocate the same number of hours of OR prime time each day
Eliminate ε_{ee} (equal to 0)	Keep the number of estimated hours of elective cases same each day
Eliminate ε_{ae} (equal to 0)	Keep the number of estimated hours of add-on cases same each day
Eliminate ε_e (equal to 0)	Finish each elective case before the end of scheduled time
Eliminate ε_a (equal to 0)	Finish each add-on case before the end of scheduled time
Eliminate ε_t (equal to 0)	Keep the turnover time stable and eliminate unexpected delays between cases

4. Resample the same number of days from the original data for nine times, and use the nine new sets of data to repeat steps 1-3.

5. Calculate the mean and percentage decrease in y_o standard variation caused by each management intervention. The management intervention with the largest percentage decrease is the preferable one.

Management Intervention Effect on Standard Deviation of Daily Overutilized Time

	Standard Deviation of Daily Overutilized Time				
	$\varepsilon_a = 0$	$\varepsilon_{ae} = 0$	$\varepsilon_{ee}, \varepsilon_e = 0$	$\varepsilon_{ee}, \varepsilon_{ae} = 0$	$\varepsilon_{ee}, \varepsilon_t = 0$
Original Data	11.79	11.01	10.01	10.68	11.75
Resampling 1	11.67	11.36	9.86	10.15	11.35
Resampling 2	12.32	11.08	10.67	10.96	11.76
Resampling 3	12.17	11.63	10.18	10.4	11.94
Resampling 4	11.02	10.63	9.34	10.22	10.87
Resampling 5	11.85	11.33	9.89	10.47	11.76
Resampling 6	11.96	10.97	10.57	10.65	11.73
Resampling 7	12.48	11.73	10.3	11.36	12.15
Resampling 8	11.78	11.1	10.12	10.53	11.51
Resampling 9	12.14	11.04	10.5	10.75	11.75
Mean	11.92	11.19	10.14	10.62	11.66
Mean-"No Change" Mean	0	0.73	1.77	1.3	0.26
% decrease vs. "No Change"	0	6.12	14.88	10.91	2.18
	$\varepsilon_a = 0$	$\varepsilon_{ae} = 0$	$\varepsilon_{ee}, \varepsilon_e = 0$	$\varepsilon_{ee}, \varepsilon_{ae} = 0$	$\varepsilon_{ee}, \varepsilon_t = 0$
Original Data	11.37	11.28	8.28	8.93	9.66
Resampling 1	11.22	10.47	8.24	8.65	9.63
Resampling 2	11.87	11.31	9.3	9.83	10.33
Resampling 3	11.98	11.36	8.22	9.24	9.93
Resampling 4	10.73	10.16	8	8.08	9.15
Resampling 5	11.75	11.01	8.39	8.84	9.8
Resampling 6	11.71	11.28	9.07	9.66	10.22
Resampling 7	12	11.12	9.14	8.97	10.2
Resampling 8	11.29	10.64	8.77	8.99	9.95
Resampling 9	11.54	10.93	9.01	9.43	10.14
Mean	11.55	10.96	8.64	9.06	9.9
Mean-"No Change" Mean	0.37	0.96	3.28	2.86	2.02
% decrease vs. "No Change"	3.11	8.07	27.48	23.96	16.92

6. Discussion

Among all the management intervention methods we tried, there are two single management interventions that can achieve at least 10% decrease in overutilization variability including

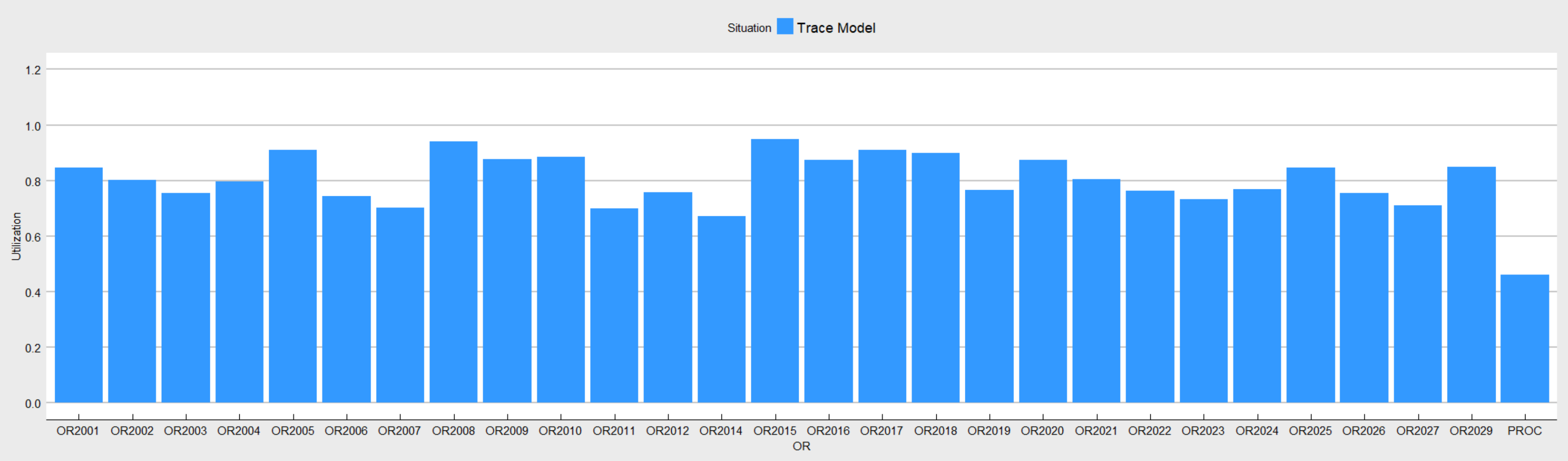
(1) Finish elective cases before the end of the estimated time .

(2) Assign the same number of hours of elective on each day.

The combination of the two management interventions performs best compared to other combinations.

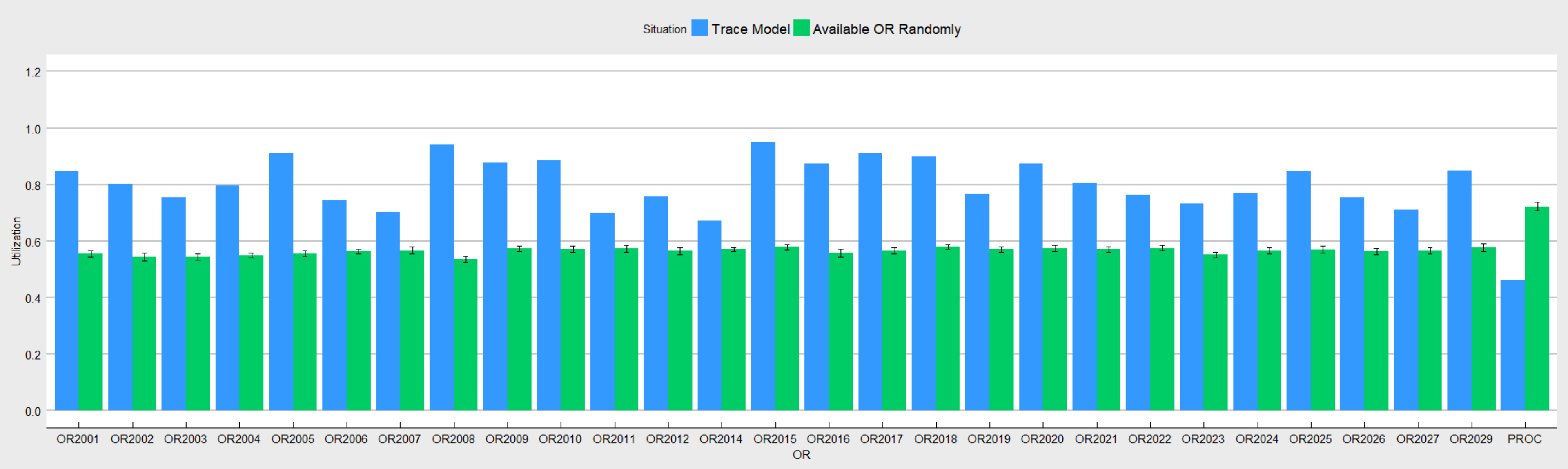
7.Discrete Event Simulation

DES 1: Trace model



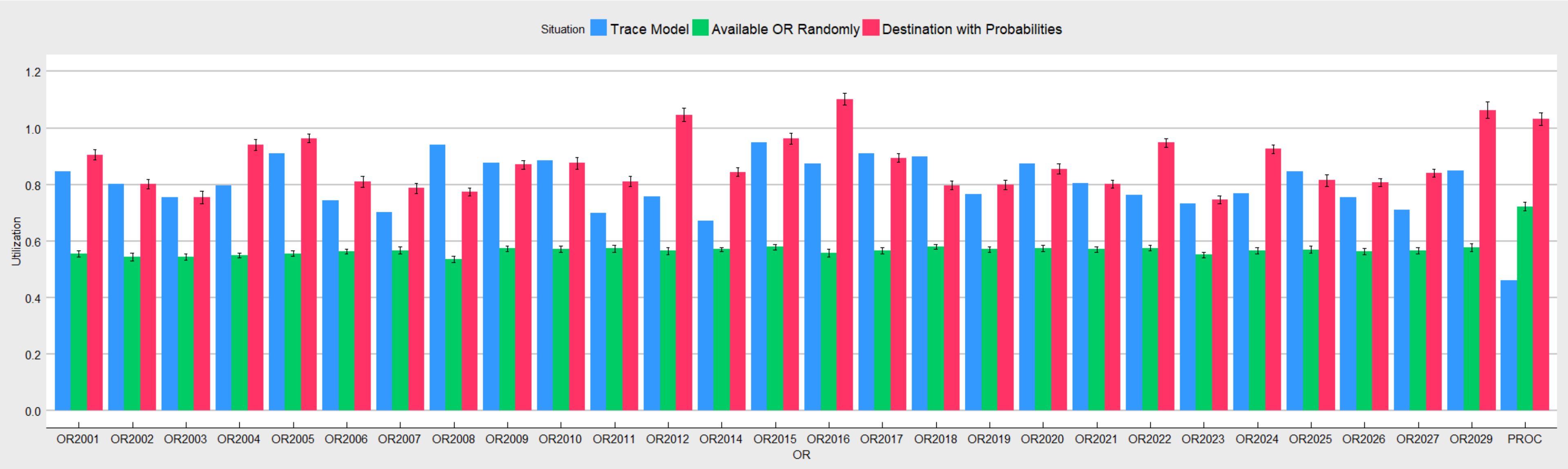
- Trace model : average utilization 0.798

DES 2: Assign cases to an available OR *randomly*



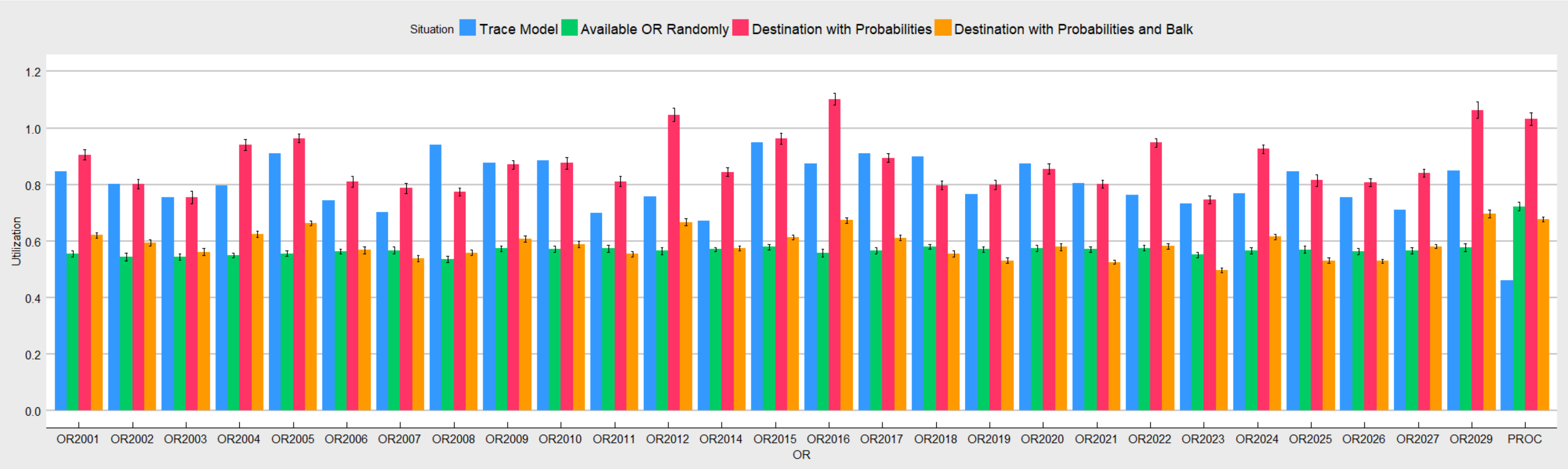
- Trace model : average utilization 0.798
- Random OR assignment model: average utilization 0.570, 95% CI (0.560, 0.581)

DES 3: Assign cases to an available OR *with Probabilities*



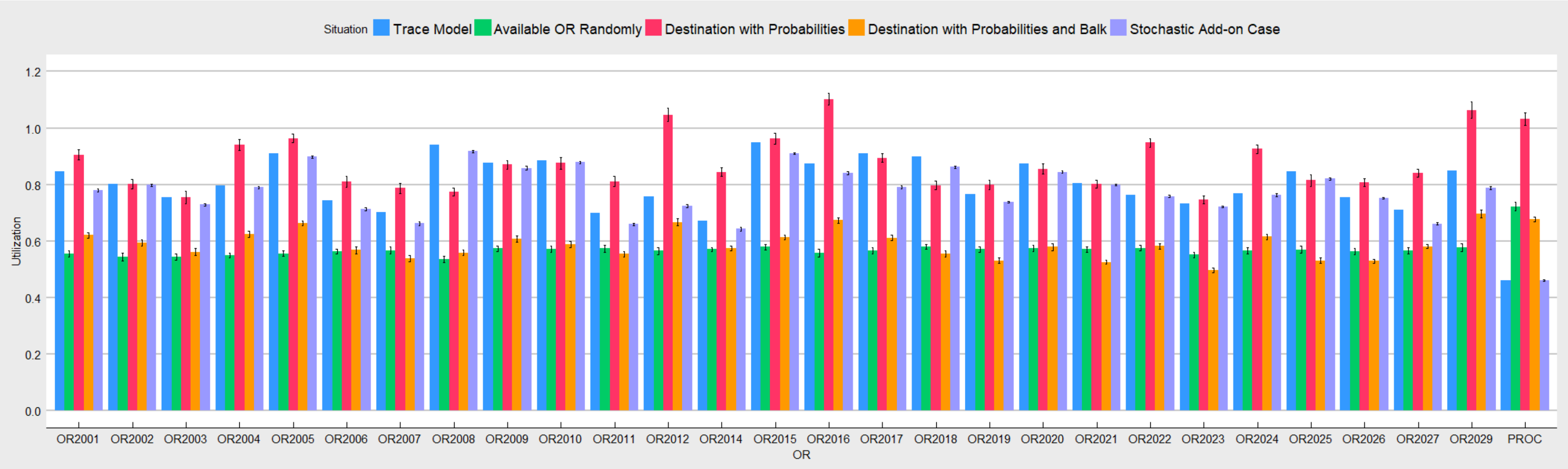
- Trace model : average utilization 0.798
- Random assignment model: average utilization 0.570, 95% CI (0.560, 0.581)
- Assign OR with probabilities model: average utilization 0.878, 95% CI (0.860, 0.896)

DES 4: Assign cases to an available OR *with Probabilities and balking (balking: if an assigned room is occupied, search next available room given a probability distribution)*



- Trace model : average utilization 0.798
- Random assignment model: average utilization 0.570, 95% CI (0.560, 0.581)
- Assign OR with probabilities model: average utilization 0.878, 95% CI (0.860, 0.896)
- Assign OR with probabilities and balking model: average utilization 0.590, 95% CI (0.580, 0.600)

DES 5: Assign Add-on Cases by arrival rates



- Trace model : average utilization 0.798
- Random assignment model: average utilization 0.570, 95% CI (0.560, 0.581)
- Assign OR with probabilities model: average utilization 0.878, 95% CI (0.860, 0.896)
- Assign OR with probabilities and balking model: average utilization 0.590, 95% CI (0.580, 0.600)
- Add-on case model: average utilization 0.770, 95% CI (0.766, 0.774)

8.Conclusion

1. SEM and Monte Carlo Simulation

Finish elective cases before the end of the estimated time, assign the same number of hours of elective cases on each day, or the combination of the two management strategies can decrease the variability of overutilized time significantly. While a SEM approach provides an insight into causes and potential interventions to reduce OR variability, those interventions we can consider are limited to estimated/actual surgery start/end time and turnover time.

2. Discrete Event Simulation

DES model 4 (Assigning cases to an available OR with probabilities and balking queuing behavior) shows more balanced and decreased OR utilizations. A combination of optimization scheduling model (when to assign which cases to which room given the surgeon, block time, # of cases constraints) and a discrete simulation model can inform strategies to improve OR utilization and variability.