Using Operations Research Models and Algorithms to Resume Surgical Activity Post COVID-19 Ramp Down

Emmett Springer; Amy Cohn, PhD

INFORMS Annual Meeting

NOVEMBER 7-13, 2020

CHEPS

CHEPS

Rx

A prescription to address system complexity in healthcare

INNOVATING HEALTHCARE DELIVERY

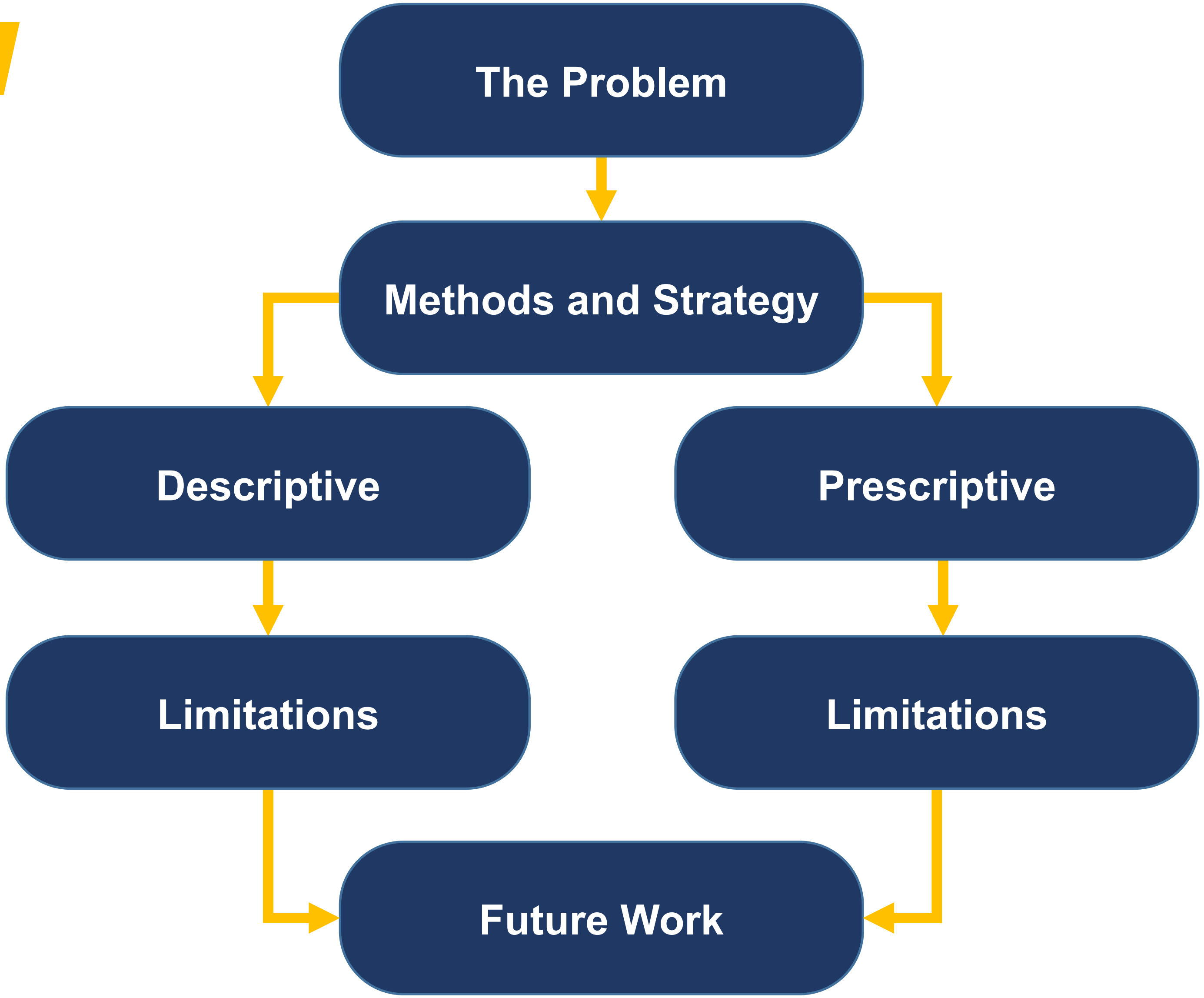
FOSTERING LEARNING

BUILDING COMMUNITY

POSITIVE IMPACT THROUGH...

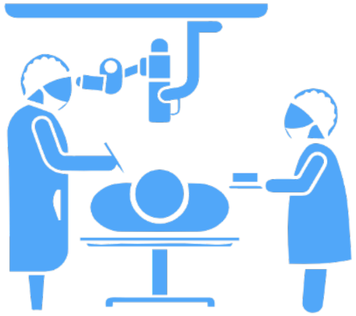
Research
Education
Implementation
Outreach
Dissemination

OVERVIEW


The Problem
Methods and Strategy
Descriptive
Prescriptive
Limitations
Limitations
Future Work

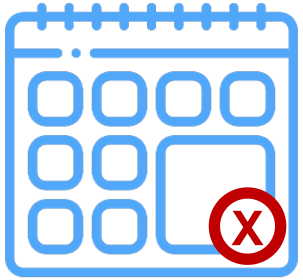
COVID AND ELECTIVE SURGERY

Elective Surgery



- Non-emergency, medically important surgical procedures
- Examples: mastectomy for breast cancer, angioplasty, hip replacements

COVID's Impact



- Many elective surgeries were postponed to conserve resources and to prevent the spread of the virus.
- Delayed surgery can result in the condition worsening and more drastic necessary intervention.

THE PROBLEM

- Many elective surgeries have been delayed for several months, causing a backlog of surgical cases to pile up.
- As concerns over slowing the spread of virus and conserving resources (such as PPE and ICU beds) wane, hospitals are performing elective surgeries again.
- **With limited OR capacity and resources such as PPE and ICU beds, how can hospitals catch up on their backlog of cases as quickly as possible while also accommodating new patients?**

METHODS AND STRATEGY

Descriptive Approach:

Applied various assumptions to predict the time and resources necessary to complete all backlogged surgeries

- Created three tools to guide surgical scheduling decision making
- Allows users to account for surgical urgency
- Accounts for limited resources

Prescriptive Approach:

Built algorithms to determine the most efficient method of scheduling backlogged surgeries and maximizing cases completed

- Applies bin-packing logic
- Constrained by available resources

DESCRIPTIVE APPROACH

Case Prioritization and Aggregation

What is the distribution of surgical urgency among the backlogged cases?

How long will it take to complete all cases in each priority group?

Time to Completion

What is the minimum time needed to complete all backlogged cases?

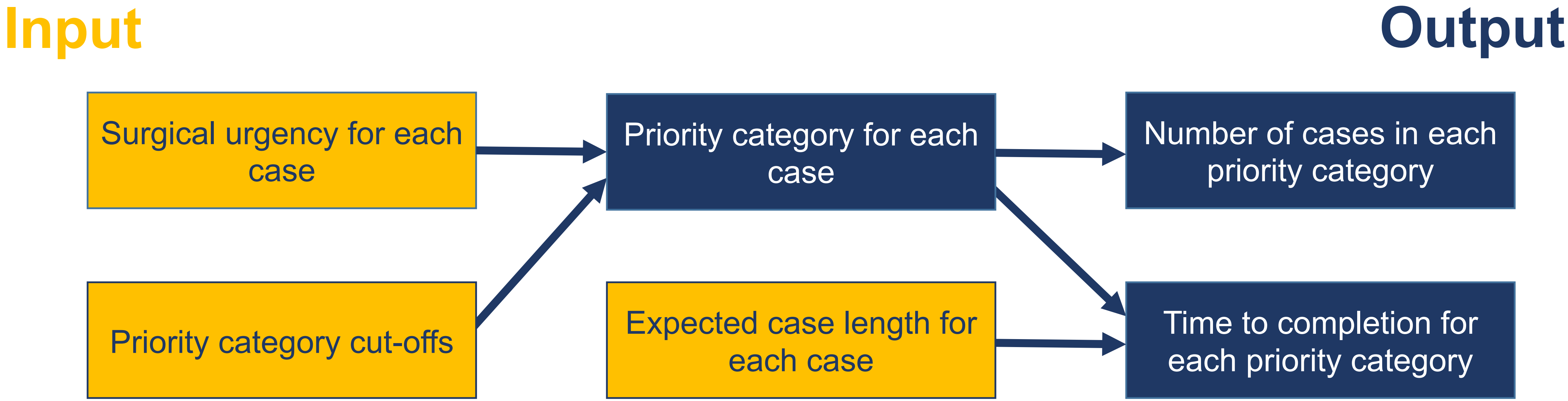
How does applying various constraints affect the time needed to complete all backlogged cases?

OR Allocation

How can operating rooms be allocated to complete the most urgent surgeries in the timeliest manner given resource constraints?

CASE PRIORITIZATION AND AGGREGATION

- What is the distribution of surgical urgency among the backlogged cases?
- How long will it take to complete all cases in each priority group?



CASE PRIORITIZATION AND AGGREGATION

Priority Category Cut-offs

Priority 1		Priority 2		Priority 3		Priority 4		Priority 5	
UB	LB	UB	LB	UB	LB	UB	LB	UB	LB
12	9.8	9.8	7.2	7.2	4.8	4.8	2.4	2.4	0

Number of Cases per Priority

TOTAL OR CASES TO FINISH:	3	Priority 1		Priority 2		Priority 3		Priority 4		Priority 5	
		UB	LB	UB	LB	UB	LB	UB	LB	UB	LB
Services:	OR Cas	12	9.8	9.8	7	7	4.5	4.5	2.4	2.4	0
Acute Care Surgery	1	1		0		0		0		0	
Orthopaedics	1	0		0		1		0		0	
Neurosurgery	1	0		0		0		0		1	

Length and Urgency per Case

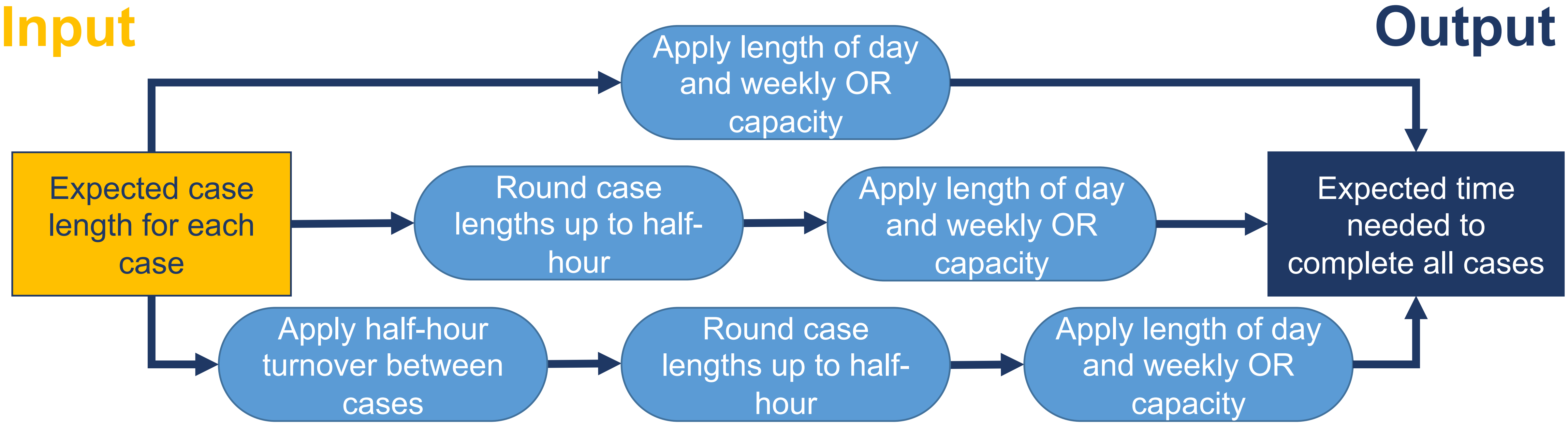
Case Number	Service	Length of Case (in minutes)	Urgency Score	Priority
1	Acute Care Surgery	456	11	1
2	Orthopaedics	333	6	3
3	Neurosurgery	890	1	5

Time to Complete per Category

Input Length of OR Day:	12.00	Priority 1		Priority 2		Priority 3		Priority 4		Priority 5	
TOTAL OR DAYS TO FINISH:	2.33	UB	LB	UB	LB	UB	LB	UB	LB	UB	LB
Service:	OR Day	12.00	9.60	9.60	7.00	7.00	4.50	4.50	2.40	2.40	0.00
Acute Care Surgery	0.63	0.63		0.00		0.00		0.00		0.00	
Orthopaedics	0.46	0.00		0.00		0.46		0.00		0.00	
Neurosurgery	1.24	0.00		0.00		0.00		0.00		1.24	

TIME TO COMPLETION

- What is the minimum time needed to complete all backlogged cases?
- How does applying various constraints affect the time needed to complete all backlogged cases?



TIME TO COMPLETION

Individual Case Data

Case Number	Surgeon	Case Length (minutes)	Service	Case Length Hours (rounded up to the half hour)
1	Surgeon A	120	Service 1	2
2	Surgeon A	90	Service 1	1.5
3	Surgeon A	120	Service 1	2
4	Surgeon B	135	Service 1	2.5
5	Surgeon B	115	Service 1	2
6	Surgeon C	280	Service 4	5
7	Surgeon C	265	Service 4	4.5

Time to Complete for 3 Scenarios

		Lower Bound	Case lengths rounded up to half-hour	With half-hour OR turnover & Case lengths rounded up to half-hour
OR day length (hours):	10			
OR days per week:	100			
Total OR days	non-service specific:	6	6	7
	service-specific:	8	8	10
Total OR weeks	non-service specific:	1	1	1
	service-specific:	1	1	1
Service 1		1	1	2
Service 2		1	1	2
Service 3		1	1	1
Service 4		3	3	3
Service 5		2	2	2

non-service specific means the total OR days summing up all the cases lengths without co

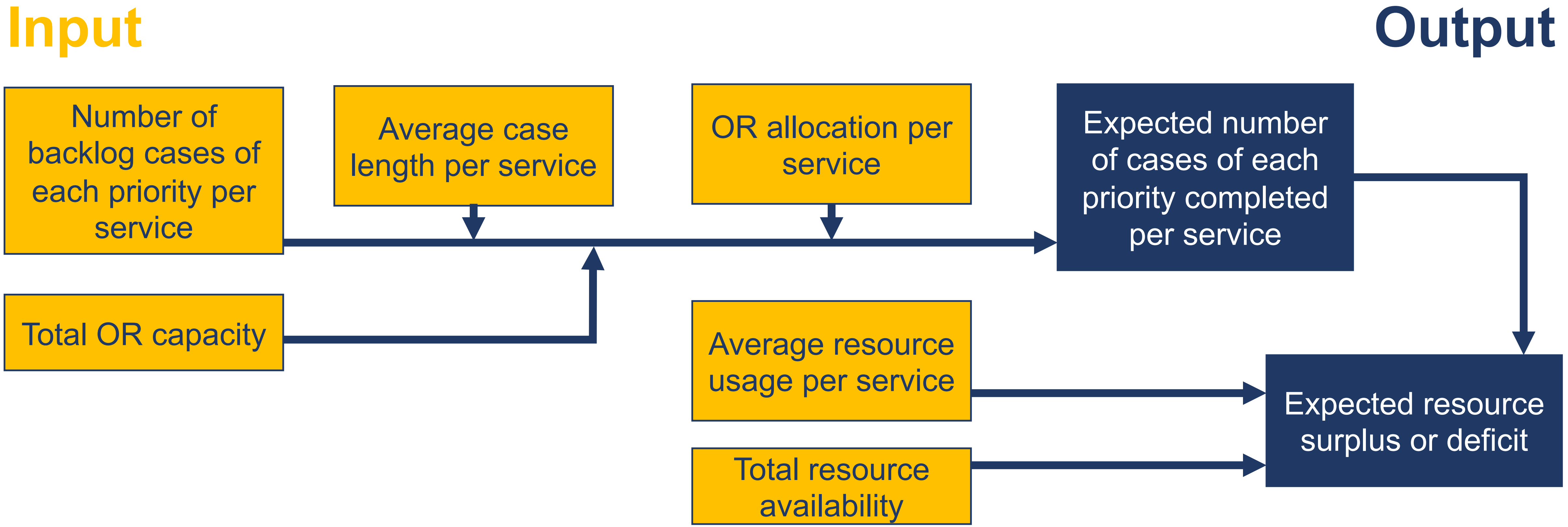
service-specific means the total OR days/wee values in services first, and then summing th

Update Model

Total Services:	5
Total Surgeons:	10
Total Cases:	20

OR ALLOCATION

- How can operating rooms be allocated to complete the most urgent surgeries in the timeliest manner given resource constraints?



OR ALLOCATION: INPUTS

Average Case Length per Service

Services	Avg. Case Length (Mins)
Cardiac Surgery	370
Neurosurgery	210
Urology Surgery	80
Service 4	

Backlog Per Service

Services: \ Priority Level:	Priority 1	Priority 2	Priority 3	Priority 4	Priority 5
Cardiac Surgery	120	58	45	21	6
Neurosurgery	90	118	88	3	0
Urology Surgery	24	43	130	152	17
Service 4	0	0	0	0	0

Resource Availability and Demand

Services: \ Case Resources:	ICU Bed Day	Case Resou	Cas
Total Weekly Supply:	**100**	**0**	**0**
Cardiac Surgery	3.5	0	0
Neurosurgery	0.5	0	0
Urology Surgery	0	0	0

Services: \ OR Resources:	Adhesive Mask	OR Resourc	OR
Total Weekly Supply:	**100**	**0**	**0**
Cardiac Surgery	5	0	0
Neurosurgery	5	0	0
Urology Surgery	5	0	0

OR ALLOCATION: OUTPUTS

OR Allocation and Cases Completed

Number of Weeks to Repeat For: 2

Surgical Sites:	Cardiac Center	Site 2	Site 3	Site 4	Site 5	Site 6	Site 7	Site 8	Site 9	Site 10
Hours per OR Day:	12	0	0	0	0	0	0	0	0	0
Capacity (ORs per Week):	25	0	0	0	0	0	0	0	0	0
Surplus/Deficit:	0	0	0	0	0	0	0	0	0	0

Services:	Weekly Allocated ORs:										Total OR Days Allocated:	Total OR Hours:	Total Cases:
Cardiac Surgery	50	0	0	0	0	0	0	0	0	0	100	1200	194
Neurosurgery	0	0	0	0	0	0	0	0	0	0	0	0	0
Urology Surgery	0	0	0	0	0	0	0	0	0	0	0	0	0

Cases Completed per Priority

Priorities: / Services:	Priority 1 Scheduled	Priority 1 Remaining	Priority 2 Scheduled	Priority 2 Remaining	Priority 3 Scheduled	Priority 3 Remaining	Priority 4 Scheduled	Priority 4 Remaining	Priority 5 Scheduled	Priority 5 Remaining
Cardiac Surgery	120	0	58	0	16	29	0	21	0	6
Neurosurgery	0	90	0	118	0	88	0	3	0	0
Urology Surgery	0	24	0	43	0	130	0	152	0	17

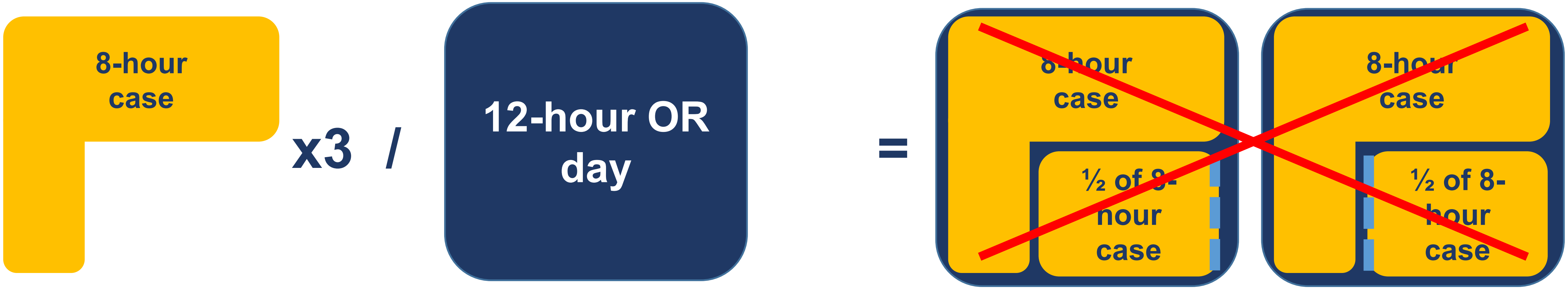
Resources Used

OR Resources: / Services:	Adhesive Mask	OR Resourc	OR
Total Utilized:	500	0	0
Surplus/Deficit:	-300	0	0
Cardiac Surgery	500	0	0
Neurosurgery	0	0	0
Urology Surgery	0	0	0

Case Resources: / Services:	ICU Bed Day	Case Resour	Cas
Total Utilized:	679	0	0
Surplus/Deficit:	-479	0	0
Cardiac Surgery	679	0	0
Neurosurgery	0	0	0
Urology Surgery	0	0	0
Service 4	0	0	0

LIMITATIONS OF DESCRIPTIVE APPROACH

- These descriptive decision tools apply many assumptions
  - Most notably, we assume cases can be split across different days



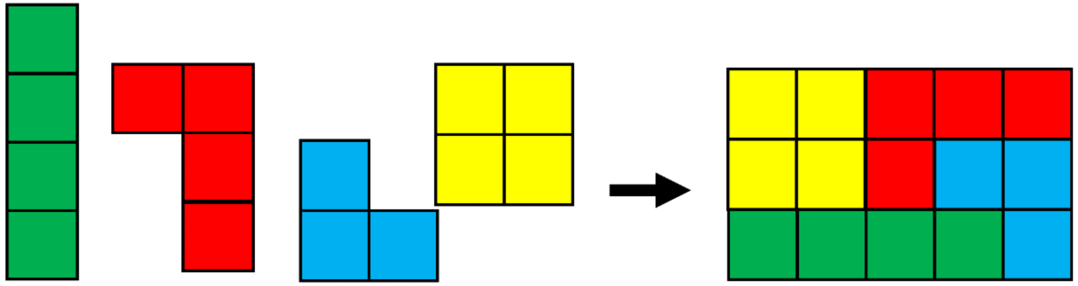
- These tools are not ideal for efficiently and accurately determining the optimal approach to scheduling procedures

PRESCRIPTIVE APPROACH

- The prescriptive approach addresses these two major limitations of the descriptive approach:
  - We apply bin-packing principles to create “surgical templates”, which give a framework for the combination of procedures that can be done in a single OR day
  - We use an integer program to prescribe the ideal number of templates to use for each surgeon based on:
    - The value of completing a case (based on surgical urgency)
    - The number of cases backlogged for each surgeon
    - The amount of resources needed per backlogged case
    - OR capacity and available resources

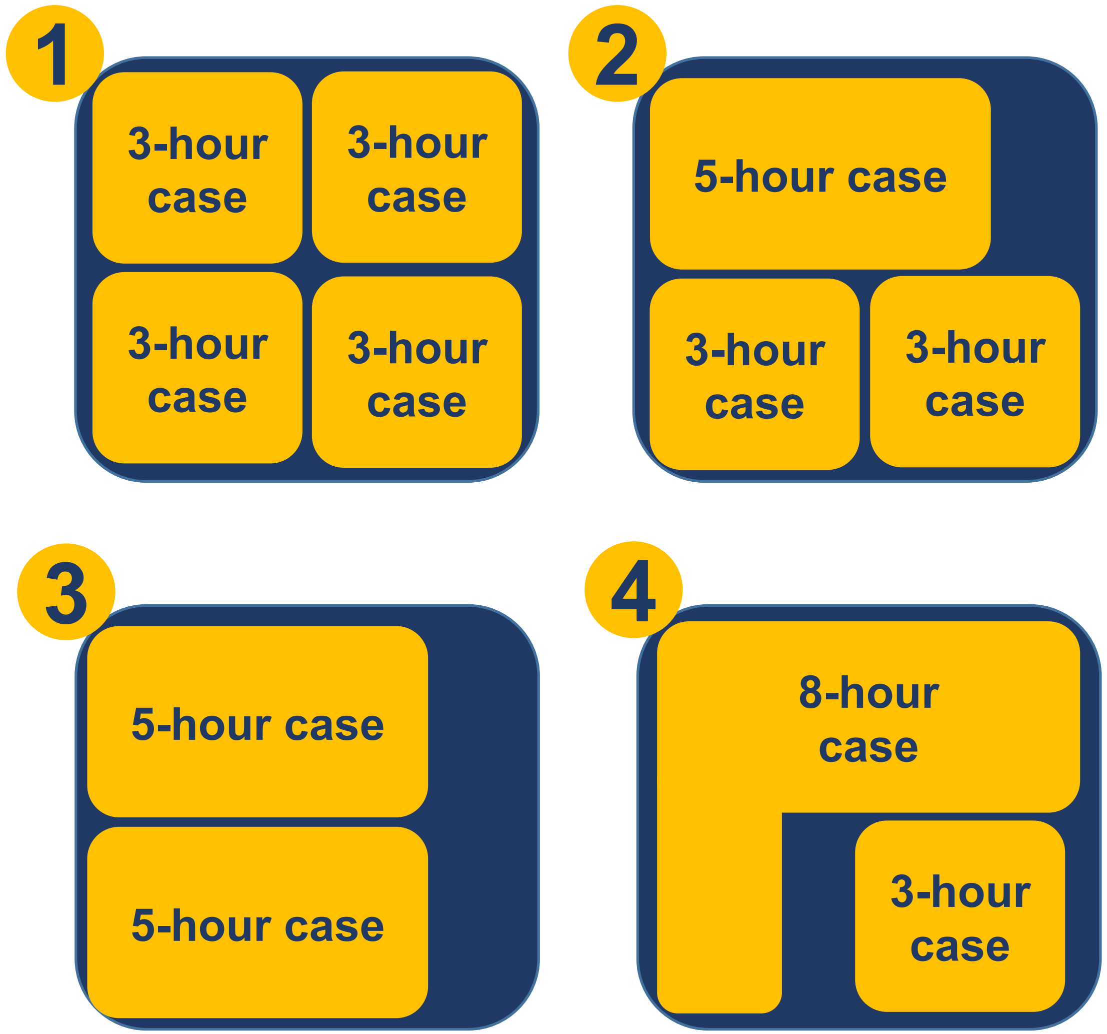
SURGICAL BIN-PACKING

- "Bin-packing" is a process during which items of different volumes must be packed into "bins" of a finite volume.
  - Bin-packing can be a bit like Tetris. You can't change the size or shape of the blocks, but you can arrange them so that they are packed tightly together and reduce the empty space
- Applying surgical bin-packing:
  - Ensures that cases are not split across days
  - Maximizes the number of cases that can be done within a certain time frame



SURGICAL TEMPLATES

- Different surgical templates are formed by cases of different lengths



FORMULATION

- **Objective Function:** Maximize the total value of cases completed
- **Decision Variables:**
  - Surgical templates per surgeon
  - Surgeon-OR assignment
- **Constraints:**
  - Each OR gets at most one surgeon
  - Allocate case only if the surgeon is assigned to an OR
  - Don’t perform more cases than are in backlog
  - OR use cannot be longer than length of OR day and includes turnover time
  - More resources cannot be used than are available

PRESCRIPTIVE MODEL - INPUT

Backlog by Surgeon

A	B	C	D	E	F	G	H	I	J	K	L	M	N	O
	Case Length (Hours)		**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
	Surgeon 1	**Value**	**1**	**1**	**1**	**1**	**10**	**1**	**1**	**5**	**30**	**1**	**1**	**1**
		Backlog	100	100	100	100	100	100	100	100	100	100	100	100
	Surgeon 2	**Value**	**1**	**1**	**1**	**1**	**10**	**1**	**1**	**1**	**1**	**1**	**1**	**1**
		Backlog	100	100	100	100	100	100	100	100	100	100	100	100

Available ORs and Other Resources

OR Length	12	
TurnoverTime	0.5	
Max OR avilable	30	
Input OR #	30	

OR available [Max 30]
OR1
OR2
OR3
OR4
OR5
OR6
OR7
OR8
OR9

	Resources Required													
	Case Length	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**Total Available**
Resources	Resource_1	2	2	2	2	2	2	2	2	2	2	2	2	200
	Resource_2	1	1	1	1	1	1	1	1	1	1	1	1	200
	Resource_3	1	1	1	1	1	1	1	1	1	1	1	1	200
	Resource_4	1	1	1	1	1	1	1	1	1	1	1	1	200
	Resource_5	1	1	1	1	1	1	1	1	1	1	1	1	200
	Resource_6	1	1	1	1	1	1	1	1	1	1	1	1	200
	Resource_7	1	1	1	1	1	1	1	1	1	1	1	1	200
	Resource_8	1	1	1	1	1	1	1	1	1	1	1	1	200

PRESCRIPTIVE MODEL - OUTPUT

Assigned ORs and Surgical Templates

OR	Surgeon	c1	c2	c3	c4	c5	c6	c7	c8	c9	c10	c11	c12
OR1	Surgeon 5												1
OR2	Surgeon 4												1
OR3	Surgeon 4	8											
OR4	Surgeon 6												1
OR5	Surgeon 4	8											
OR6	Surgeon 4	8											
OR7	Surgeon 4												1
OR8	Surgeon 4	8											
OR9	Surgeon 4	8											

Remaining Cases and Resources

		Remaining Backlog											
		1	2	3	4	5	6	7	8	9	10	11	12
	Value	20	3	4	5	6	7	8	9	10	10	10	30
Surgeon 1	Backlog	100	100	100	100	100	100	100	100	100	100	100	100
	Value	20	3	4	5	6	7	8	9	10	10	10	30
Surgeon 2	Backlog	100	100	100	100	100	100	100	100	100	100	100	100
	Value	20	3	4	5	6	7	8	9	10	10	10	30
Surgeon 3	Backlog	100	100	100	100	100	100	100	100	100	100	100	100
	Value	35	3	4	5	6	7	8	9	10	10	10	50
Surgeon 4	Backlog	20	100	100	100	100	100	100	100	100	100	100	93
	Value	20	3	4	5	6	7	8	9	10	10	10	50
Surgeon 5	Backlog	100	100	100	100	100	100	100	100	100	100	100	98

	Total available resourcesz	Resources consumed	Remaining Resources
Resource_1	200	200	0
Resource_2	200	100	100
Resource_3	200	100	100
Resource_4	200	100	100
Resource_5	200	100	100
Resource_6	200	100	100
Resource_7	200	100	100
Resource_8	200	100	100
Resource_9	200	100	100
Resource_10	200	100	100

ADDITIONAL LIMITATIONS AND FUTURE WORK

Prescriptive Approach Limitations:

- No variability in procedure length
- No individual case input
- The model considers a fixed time period with fixed resources

Future work:

- Incorporate uncertainty and variability into the model

ACKNOWLEDGMENTS

The Seth Bonder Foundation

CHEPS

CENTER FOR HEALTHCARE ENGINEERING & PATIENT SAFETY

Thank you to Eric Chen, Hannah Heberle-Rose, Jiaqi Lei, Emily Linblad, Luke Liu, Shradda Ramesh, Emmett Springer, Allison VanderStoep, Max Wagner, Nicholas Zacharek, and all prior CHEPS students who contributed to this work.