A Simulation Framework to Leverage Patient-Specific Data in Improving Cardiac Intensive Care Unit Utilization

Amanda D. Moreno-Hernandez, Master’s Student
Amy Cohn¹, PhD
Hitinder Gurm², MD
Industrial & Operations Engineering, University of Michigan¹ | Michigan Medicine²
CHEPS

INNOVATING HEALTHCARE DELIVERY

FOSTERING LEARNING

BUILDING COMMUNITY

POSITIVE IMPACT THROUGH...
Research
Education
Implementation
Outreach
Dissemination
RESEARCH MOTIVATION

What is the aortic dissection (AD) patient experience?

Ensure adequate capacity for all transfer requests to the Cardiovascular Center (CVC) at Michigan Medicine (MM)
WHAT IS AN AORTIC DISSECTION?

Aortic dissection (AD) is an emergency cardiovascular condition affecting the aorta.

Mortality rate for AD increases 1% per hour [1]. Aortic dissections are rare, but when they occur, they are medical cardiovascular emergencies.

Cardiovascular disease is the leading cause of death in the US [3]. The most common surgeries in the United States (US) are cardiovascular [3].
INITIAL RESEARCH QUESTION
INITIAL RESEARCH QUESTION

X

It’s a lot more complicated than that…

= Aortic Dissection Patients
THE BIGGER PICTURE

= Aortic Dissection Patients
= All Other Cardiac Patient Types

Patient Needs
- OR
- Surgeon
- Staff
- ICU Bed
PATIENT FLOW IN CARDIOVASCULAR SURGERY

1. Arrival
2. OR
3. ICU
4. Step Down
5. Discharge
# How Do We Classify Patients?

<table>
<thead>
<tr>
<th>Level 1</th>
<th>Level 2</th>
<th>Level 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Arrival Type</td>
<td>Patient Type</td>
<td>Patient Information</td>
</tr>
<tr>
<td>Transfer from Another Facility</td>
<td>Elective</td>
<td>AGE</td>
</tr>
<tr>
<td>Transfer from UM ED</td>
<td>Urgent</td>
<td>COMORBIDITY</td>
</tr>
<tr>
<td>Scheduled Procedure</td>
<td>Emergent</td>
<td>SEX</td>
</tr>
</tbody>
</table>

- **Level 1**: Arrival Type
  - Transfer from Another Facility
  - Transfer from UM ED
  - Scheduled Procedure

- **Level 2**: Patient Type
  - Elective
  - Urgent
  - Emergent

- **Level 3**: Patient Information
  - Age
  - Comorbidity
  - Sex
  - BMI
  - Prior Dx
TRANSFER REQUESTS

Preliminary analysis conducted by the CVC staff showed that the most common reason for patient deferral when requesting transfer to Michigan Medicine is attributed to unavailable ICU beds.
PROBLEM STATEMENT

Test Policies to Increase Patients’ Access to High Quality Care

Current State

Future State

Educate Clinical Partners About Uncertainty
MiChart, a product of Epic, is Michigan Medicine’s patient-centric electronic health record.

Data Direct enables access to clinical data.

SQL Database contains all patients that visited the CVC ICU between Jan 2016 and May 2019.
SIMULATION FRAMEWORK

FIXED INPUTS
- Bed Count per Unit
- Time Horizon
- Replications

RANDOM INPUTS
- Patient Type
- Arrival Rate
- Service Time per Unit
SIMULATION FRAMEWORK

INPUTS TO LOGIC

- Arrival Rate
- Arrival Type & Patient Type
- Expected Length of Stay
- Run Model & Analyze Output
**SIMULATION FRAMEWORK**

**LOGIC**

- **Patient Arrives**
  - Open ICU Bed? (YES)
  - ICU
  - Ready for Transfer? (NO)
  - Open SDn Bed? (YES)
  - Step Down (YES)
  - Ready for Discharge? (NO)
  - Discharged (YES)

- **Patient Arrives**
  - Open ICU Bed? (YES)
  - ICU
  - Ready for Transfer? (NO)
  - Open SDn Bed? (NO)
  - Patient Denied

**Assumptions**
- OR, surgeon and staff are always available
- Any patient can be denied
# SIMULATION FRAMEWORK

## METRICS

<table>
<thead>
<tr>
<th>Overall</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Patients Requesting Care (Patient Arrival)</td>
<td></td>
</tr>
<tr>
<td>Accepted Patients</td>
<td></td>
</tr>
<tr>
<td>Declined Patients</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>ICU</th>
<th>Stepdown (SDn)</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Patient LOS</td>
<td>• Patient LOS</td>
</tr>
<tr>
<td>• Unnecessary days in an ICU bed (SDn status)</td>
<td>• Bed Utilization</td>
</tr>
<tr>
<td>• Bed Utilization</td>
<td></td>
</tr>
</tbody>
</table>
ANALYSES

1. SDn Variation
   - Change number of shared SDn beds

2. Arrival Rate
   - Change the hourly patient admission rate
BASE CASE PARAMETERS

- 2 Patient Types:
  - Internal Transfers (Includes Elective Surgery)
  - Outside Transfers

- Internal Arrival Rate = 0.25 patient/hr
- Outside Arrival Rate = 0.06 patient/hr

- Time Horizon = 1 Year
- Replications = 1,000
BASE CASE PARAMETERS

• Bernoulli trial for transfer and discharge from respective units

INTERNAL TRANSFER

- \[ P_{\text{ICU Transfer 1}} = 0.24 \]
- \[ P_{\text{SDn Discharge 1}} = 0.25 \]

OUTSIDE TRANSFER

- \[ P_{\text{ICU Transfer 2}} = 0.18 \]
- \[ P_{\text{SDn Discharge 2}} = 0.25 \]
### ANALYSIS 1: SDN VARIATION

<table>
<thead>
<tr>
<th>Percentage of Shared Beds Available</th>
<th>25%</th>
<th>50%</th>
<th>75%</th>
<th>100%</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Allocated Stepdown Beds</strong></td>
<td>25</td>
<td>34</td>
<td>43</td>
<td>52</td>
</tr>
<tr>
<td>Patient Arrival</td>
<td>2718</td>
<td>2715</td>
<td>2717</td>
<td>2716</td>
</tr>
<tr>
<td>Outside Transfer Declined</td>
<td>3%</td>
<td>2%</td>
<td>2%</td>
<td>2%</td>
</tr>
<tr>
<td>Internal Transfer Bottleneck</td>
<td>12%</td>
<td>9%</td>
<td>9%</td>
<td>9%</td>
</tr>
<tr>
<td>ICU Average LOS Outside Transfer</td>
<td>4.93 days</td>
<td>4.93 days</td>
<td>4.93 days</td>
<td>4.95 days</td>
</tr>
<tr>
<td>ICU Avg LOS Internal Transfer</td>
<td>3.63 days</td>
<td>3.62 days</td>
<td>3.62 days</td>
<td>3.62 days</td>
</tr>
<tr>
<td>ICU Average LOS SDn status</td>
<td>0.27 days</td>
<td>0.01 days</td>
<td>0 days</td>
<td>0 days</td>
</tr>
<tr>
<td>SDn Average LOS</td>
<td>3.56 days</td>
<td>3.81 days</td>
<td>3.83 days</td>
<td>3.83 days</td>
</tr>
</tbody>
</table>

- Time Horizon = 1 Year
- Replications = 1,000
- 32 ICU Beds
- 16 Dedicated SDn Beds
## ANALYSIS 2: ARRIVAL RATE

### Outside Transfer Arrival Rate Increments

<table>
<thead>
<tr>
<th>Outside Transfer Arrival Rate</th>
<th>0.0602</th>
<th>0.0783</th>
<th>0.1017</th>
<th>0.1323</th>
<th>0.1719</th>
</tr>
</thead>
<tbody>
<tr>
<td>Patient Arrival</td>
<td>2716</td>
<td>2875</td>
<td>3076</td>
<td>3345</td>
<td>3695</td>
</tr>
<tr>
<td>Outside Transfer Declined</td>
<td>2%</td>
<td>4%</td>
<td>6%</td>
<td>9%</td>
<td>14%</td>
</tr>
<tr>
<td>Internal Transfer Bottleneck</td>
<td>9%</td>
<td>12%</td>
<td>15%</td>
<td>17%</td>
<td>20%</td>
</tr>
<tr>
<td>ICU Average LOS Outside Transfer</td>
<td>4.95 days</td>
<td>4.95 days</td>
<td>4.98 days</td>
<td>4.98 days</td>
<td>5.02 days</td>
</tr>
<tr>
<td>ICU Avg LOS Internal Transfer</td>
<td>3.62 days</td>
<td>3.64 days</td>
<td>3.66 days</td>
<td>3.68 days</td>
<td>3.71 days</td>
</tr>
<tr>
<td>ICU Average LOS SDn status</td>
<td>0 days</td>
<td>0 days</td>
<td>0 days</td>
<td>0 days</td>
<td>0 days</td>
</tr>
<tr>
<td>SDn Average LOS</td>
<td>3.83 days</td>
<td>3.83 days</td>
<td>3.84 days</td>
<td>3.83 days</td>
<td>3.83 days</td>
</tr>
</tbody>
</table>

- Time Horizon = 1 Year
- Replications = 1,000
- 32 ICU Beds
- 52 SDn Beds
- Internal Transfer Arrival Rate = 0.25 patient/hr
ANALYSES TAKEAWAYS

Analysis 1: SDn Variation

• Outside transfer declined and internal transfer bottleneck remains constant regardless of the amount of dedicated SDn beds.

Analysis 2: Arrival Rate

• Increase in internal transfer bottleneck metric suggests evaluation of the internal patient flow prior to arrival at the ICU.
FUTURE RESEARCH

• Expanding the tool
  • Relaxing assumptions
  • Include Bounce Backs

• Conducting Analysis
  • More Data!!
  • Collaborator goals: Explore smoothing elective surgery
ACKNOWLEDGEMENTS

The Seth Bonder Foundation

FRANKEL CARDIOVASCULAR CENTER
MICHIGAN MEDICINE

PRECISION HEALTH
UNIVERSITY OF MICHIGAN

Acknowledgments

AD ICU TEAM

CHEPS STAFF
Julia Warner
Liz Fisher

IOE FACULTY & STAFF
Joi-Lynn Mondisa, PhD
Rod Capps

SPECIAL THANKS TO
Donald Richardson, PhD
Luke Liu
Questions?
# LITERATURE REVIEW

<table>
<thead>
<tr>
<th>First Author</th>
<th>Reference</th>
<th>Year</th>
<th>Objective/Purpose</th>
</tr>
</thead>
<tbody>
<tr>
<td>Levin, S.</td>
<td>[5]</td>
<td>2011</td>
<td>To test policies to reduce patient's length of stay (LOS) and increase patient throughput.</td>
</tr>
<tr>
<td>Marmor, Y.</td>
<td>[6]</td>
<td>2013</td>
<td>To predict minimum bed needs to achieve the high patient service level demanded for the cardiovascular ICU.</td>
</tr>
<tr>
<td>Levin, S.</td>
<td>[7]</td>
<td>2015</td>
<td>To estimate patients’ wait time while integrating the effect of the transition process (i.e. wait time for a bed to become available) with queuing using embedded regression models.</td>
</tr>
<tr>
<td>Kolker, A.</td>
<td>[8]</td>
<td>2009</td>
<td>To establish a quantitative link between the daily load leveling of elective surgeries (i.e. elective schedule smoothing) and ICU diversion of multiple ICU units including cardio ICU.</td>
</tr>
</tbody>
</table>
REFERENCES


