Using Simulation To Determine The Need For ICU Beds For Surgical Patients At The Sir Mortimer B. Davis Jewish General Hospital

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Motivation For Study

• At the time, there were frequent cancellations of operative procedures requiring immediate ICU stays

• In particular, late in 2007 there was an extended period during which a very large number of cardiac surgeries needed to be postponed due to a lack of ICU beds

• As a result, Dr. Rosenberg wished to determine the number of beds that would be needed if there were a surgery only ICU
Literature Review On Surgery ICU Beds

• There are a number of papers discussing the issue of reserving ICU beds for surgical patients

• Some suggest limiting the daily number of surgeries requiring immediate ICU stays

• Others argue that any reservation of ICU beds for surgical patients will negatively impact care for medical patients

• This is a non-issue for very large hospital systems (such as the MAYO Clinic) that have sufficient demand to justify dedicated surgical and medical ICUs
Actual Parameters Investigated

• Rather than just looking at the number of needed beds, instead looked at:
  – The total number of ICU beds (TOTAL)
  – The minimum level of occupied beds at which operative procedures that require an ICU stay, immediately after the procedure, are canceled (FUNCTIONAL)

• Wished to determine how the parameters individually and jointly would affect the shortage of ICU beds for surgical patients
Study Research Goals

• Build a tool that could be used to answer questions about the need for ICU beds for surgical patients

• Use tool to determine relationship between lack of availability of ICU beds for surgical patients, and TOTAL and FUNCTIONAL

• Use tool to identify potential avenues for further resolving bed shortage
Our Approach

• Monte Carlo Simulation Study
  – Statistical experiment using samples generated from pseudo-random numbers
  – Using a discrete event model of ICU bed utilization
  – Try to measure mean:
    • Wait time for operative procedures requiring an immediate ICU stay (wish to decrease)
    • Number of parked patients (wish to decrease)
    • Number of operative procedure cancellations due to lack of available ICU beds (wish to decrease)
    • Utilization of ICU beds (wish to increase)
Steps Of The Study

• Collect and characterize data
• Build simulation model
• Input data
• Test model
• Validate model
• Collect results
• Characterize results
Required Data

• Average inter-arrival time between operative procedure requests
• Probability of each operative procedure type
• Probability of each operative procedure type being an emergency
• Probability distribution of the time needed for each operative procedure type
• Probability of required ICU stay for each operative procedure type
• Probability distribution of the time between the end of the operative procedure, to when the ICU stay started, for each operative procedure type
• Probability distribution of ICU visit stay times, for each operative procedure type
Collected Data

- A list of all operative procedures performed by each service from April 2007 through March 2008 (from the hospital's surgical information system)

- For each type of procedure, a probability as to the fraction of the procedures of this type that required an ICU stay immediately after the procedure (provided by the chief anesthetist and an intensivist)

- A list of all ICU visits by surgical patients, the time at which their ICU stay started, and the length of their stay

- The operative procedure schedule for each service
Approach Used To Estimate Probability Distributions

• Did not try to fit the data to particular probability distributions
  – There were too many distributions to fit
  – No reason to believe that the data fit particular distributions

• Instead, created empirical distributions
  – Possible issue for operative procedures with low frequencies
  – Since they had low frequencies, this seemed unlikely to significantly affect results
Model Validation

• Compared, against expected values:
  – The number of queued up operative procedure requests at the end of the first three month warm-up period
  – The number of operative procedures performed per year
  – The number of queued up operative procedure requests at the end of the simulation run

• Presented the model to a committee of subject matter experts, a sitting hospital task force deliberating over how to address ICU bed shortages, to ensure that it met their criterion of reasonableness
The Monte Carlo Simulation Study

• For each level of FUNCTIONAL:
  – Performed 64 runs each using a different set of pseudo-random numbers
  – Computed average, standard deviation, and standard error of the mean for metrics

• When computing confidence intervals of metric means (in paper)
  – Since there was a total of 36 confidence intervals
  – Adjusted alpha of each confidence interval to 0.01 / 36
  – To compensate for Bonferonni Inequality/Multiple Comparisons Problem
  – To obtain .99 probability that all confidence intervals contain their true mean
**Results – Mean Wait (Days)**

- For cardiac operative procedures requiring an immediate ICU stay (proxy)

<table>
<thead>
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<th>Mean Wait</th>
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<tr>
<td>17</td>
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</table>

- Notes:
  - Cardiac operative procedures needing an immediate ICU stay were used as a proxy
  - For reasons discussed in paper, mean waiting times are actually larger than displayed for low levels of FUNCTIONAL
  - Mean wait is strictly a function of FUNCTIONAL
Results – Mean Number Of Parked Patients

- Mean # of patients that should be in ICU that are parked elsewhere

<table>
<thead>
<tr>
<th>FUNCTIONAL</th>
<th>TOTAL</th>
<th>Mean</th>
<th>TOTAL</th>
<th>Mean</th>
<th>TOTAL</th>
<th>Mean</th>
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<td>19</td>
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</table>

- Notes:
  - A mean of 1 implies that sum of hours all patients are parked is 24 * 365
  - This is a function of FUNCTIONAL and TOTAL, particularly for low levels of FUNCTIONAL
Results – Canceled Blocks

• Number of blocks of OR time in which at least 1 operative procedure was canceled due to a lack of available ICU beds

  – FUNCTIONAL  |  Canceled Blocks
  6             |  473
  7             |  404
  8             |  336
  9             |  262
  10            |  195
  11            |  136
  12            |   88
  13            |   50
  14            |   24
  15            |   12
  16            |    5
  17            |    2

• Notes:
  – This metric was used as a proxy for cancellations of operative procedures
  – It is strictly a function of FUNCTIONAL
# Results – ICU Bed Utilization

- **Mean utilization of all ICU beds**

<table>
<thead>
<tr>
<th>FUNCTIONAL</th>
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<th>Utilization</th>
<th>TOTAL</th>
<th>Utilization</th>
<th>TOTAL</th>
<th>Utilization</th>
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<td>7</td>
<td>61.4%</td>
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<td>66.0%</td>
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<td>68.8%</td>
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</tr>
<tr>
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<td>67.2%</td>
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<td>48.4%</td>
<td>18</td>
<td>45.8%</td>
<td>19</td>
<td>43.4%</td>
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</table>

- **Mean utilization is a function of both TOTAL and FUNCTIONAL**
**Contributions**

• In addition to a tool for analyzing ICU surgical bed needs, also developed:
  – Set of metrics to be measured
  – Understanding of many of the processes affecting surgery and ICU performance
  – Knowledge of data needed for simulating those processes
  – Ability to characterize that data so it can be used for such a simulation
Contributions

• The minimum level of occupied beds at which surgeries requiring immediate ICU stays are canceled (FUNCTIONAL) affects:
  – Average wait time for (cardiac) surgeries requiring an immediate ICU stay
  – Average number of parked patients
  – Average number of cancellations due to lack of available ICU beds
  – Average utilization of ICU beds

• The total number of ICU beds (TOTAL) affects:
  – Average number of parked patients
  – Average utilization of ICU beds
Study Observations

• For our hospital, beds in a surgical only ICU would not be consistently well utilized:
  – This in turn would exacerbate ICU nurse staffing challenges
  – This does not mean that there is no need to increase the total number of ICU beds
ICU Visit Observations

• While frequently very busy, there are periods of time in which there are available ICU beds

• Some of the patients in the ICU need respiratory care more than they need intensive care
Other observations

• The ICU is intimately linked to many other parts of the hospital

• Any analysis/optimization of the ICU needs to include:
  – Surgical scheduling
  – PACU
  – Ward

• There is currently a disconnect between surgery scheduling and (ICU and Ward) bed availability
Two Approaches To Bridging The Disconnect

• Static surgery schedule optimization

• Dynamic schedule optimization
Static surgery schedule optimization

- Pick a fixed schedule
- So that it minimizes bed issues
- When simulated a large number of times
- Two recent papers:
  - Martin Puterman at UBC
Dynamic schedule optimization

– Delay surgery scheduling as long as possible
– Before finalizing the schedule simulate it a large number of times for several days
– Change the schedule if it results in (a significant number of) bed issues
– Two efforts:
  • Ours here at the JGH
  • University Of Michigan doctoral student
Dynamic Surgery Scheduling – JGH Effort

• Java based simulation:
  – To obtain speed needed for optimization
  – To provide appropriate animation
  – To make it possible to embed it in other software
JGH Effort – Cont'd.

• The simulation will include the following:
  – Surgical processes (from initial surgeon visit through procedure)
  – Recovery in PACU, ODS and/or ICU
  – Recover in wards
  – Complications

• It will also include other ICU supply and demand issues including:
  – Availability of nurses
  – Demand for ICU beds from the E.D. and medical wards
  – Nurse/patient staffing ratios

• I am hoping that in the future it will include:
  – The E.D.
  – Other relevant areas of the hospital
JGH Efforts – ICU Data Requirements

• These efforts will require data from the ICU including:
  – Patient arrival information
  – Patient departure information
  – Other patient event information (as it affects nurse staffing)
  – Patient/nurse staffing information over time
  – Nurse vacation and sick leave data
  – Epidemic information
  – Patient diagnosis information
  – Some measure of patient status
JGH Efforts – Ultimate Goals

• Very significantly reduce operative procedure cancellations

• Smooth out demand for surgical ward, PACU, and ICU beds

• Reduce delays for surgical and intensive care

• Reduce hospital staff stress