Hôpital général juif
Jewish General Hospital

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)

FUNCTIONAL	Mean Wait
6	535
7	411
8	304
9	207
10	131
11	79
12	43
13	24
14	13
15	9
16	7
17	7

- 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

FUNCTIONAL	TOTAL	Mean	TOTAL	Mean	TOTAL	Mean	
6	6	2.11	7	0.89		8	0.28
7	7	1.91	8	0.75		9	0.23
8	8	1.75	9	0.68		10	0.20
9	9	1.44	10	0.50		11	0.13
10	10	1.10	11	0.36		12	0.09
11	11	0.83	12	0.25		13	0.06
12	12	0.58	13	0.16		14	0.03
13	13	0.34	14	0.10		15	0.02
14	14	0.18	15	0.05		16	0.01
15	15	0.10	16	0.03		17	0.01
16	16	0.04	17	0.01		18	0.00
17	17	0.02	18	0.00		19	0.00

- 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

FUNCTIONAL	TOTAL	Utilization	TOTAL	Utilization	TOTAL	Utilization
6	6	57.9%	7	67.1%	8	66.3%
7	7	61.4%	8	68.1%	9	66.4%
8	8	63.7%	9	68.5%	10	66.4%
9	9	66.0%	10	68.8%	11	65.8%
10	10	67.2%	11	67.9%	12	64.5%
11	11	66.8%	12	66.0%	13	62.4%
12	12	65.3%	13	63.5%	14	59.9%
13	13	62.5%	14	59.8%	15	56.4%
14	14	58.7%	15	55.7%	16	52.5%
15	15	54.8%	16	51.8%	17	48.9%
16	16	51.5%	17	48.6%	18	46.0%
17	17	48.4%	18	45.8%	19	43.4%

- 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