Hôpital général juif
Jewish General Hospital

A Peri-Operative Process Simulation Model

Philip M. Troy, Ph.D.

Lawrence Rosenberg, M.D., Ph.D.

HÔPITAL D'ENSEIGNEMENT DE L'UNIVERSITÉ MCGILL | A MCGILL UNIVERSITY TEACHING HOSPITAL

Thesis

- To improve peri-operative services as a whole, ultimately, it's necessary to have a whole picture:
  - Of the complete set of peri-operative processes
  - Of how non-peri-operative processes interact with the peri-operative ones

- It's also necessary to be able to see the effect of changing individual processes on the overall performance of peri-operative services

- In Canadian healthcare, improving the performance of all aspects of hospitals is critical

- This implies . . .

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The Sir Mortimer B. Davis Jewish General Hospital

- Full service university affiliated medical center
  - Serves a large and diverse population in Montreal
  - Provides a broad range of inpatient and outpatient services
  - Has major tertiary & quaternary cardiovascular, neurosciences, oncology (including robotic surgery) and neo-natology programs

- Performs 13,000 - 15,000 operative procedures per year
  - This number is expected to grow 2% per year through 2015
  - Approximately 40% of these require overnight patient stays after the procedure

- It has 637 beds including 154 surgical beds, and 20-22 staffed ICU beds

Peri-Operative Process Issues

- Unavailability of ICU beds leads to cancellation of procedures
- Unavailability of surgical ward beds leads to:
  - Congestion in the PACU
  - Cancellation of procedures
- Waiting for PACU beds leads to:
  - Patients being parked in an OR
  - Which in turn leads to cancellation of procedures
- Admissions from ED often leads to downstream cancellation of procedures
- Scheduling of procedures is tricky:
  - Bed availability
  - Pre-surgical screening
  - Surgical blocks

Addressing The Issues Effectively

- To address these issues, ideally need analysis tool that can simultaneously:
  - Include relevant parts of all peri-operative processes
  - Include relevant parts of non peri-operative processes
  - Facilitate visualization of processes
  - Reflect randomness inherent to those processes
  - Make it possible to experimentally evaluate changes to those processes
  - Optimize the complete set of peri-operative processes
  - Perform this optimization in a state dependent manner
- Such a tool could be used in:
  - The very short term for predicting and precluding problems
  - The short term for scheduling operative procedures
  - The medium term for evaluating process changes
  - The longer term for strategic planning and capacity sizing

Randomness in Peri-Operative Processes

- Randomness can be found in the:
  - Rate of demand for each type of operative procedures for each surgeon
  - Wait for the procedures
  - Length of the procedures
  - Length of PACU, ICU and surgical ward stays
  - Outcomes of the procedures
- Randomness results in:
  - Varying demand and income, for both the hospital and individual surgeons
  - Complications and loss of functionality for patients while waiting for the procedures
  - Making it harder to schedule use of operating rooms effectively
  - Making it harder to effectively utilize beds
  - Variations in the need for additional medical and nursing care after operative procedures

Randomness in Peri-Operative Processes

- To see the effect of randomness consider a 3 bed ICU
  - To which 3 patients arrive every day at exactly 13:00
  - Three patients leave every day at exactly 12:00
  - There are three orderlies/housekeeping staff available at 12:00
  - It takes exactly one hour to clean a bed
  - There will never be a delay in getting a bed
- Now consider the same ICU
  - To which an average of 3 patients arrive every day at exactly 13:00
  - An average of 3 patients leave every day at exactly 12:00
  - The orderlies/housekeeping availability and bed cleaning times remain the same
  - Over time a queue with occur

Optimization Across All Peri-Operative Processes

- When you don't optimize across all processes, you run the risk of suboptimization:
  - "Suboptimization of a system: separate optimization of every system, which results in underutilization of the performance potential of the whole system and may result in a deterioration of overall performance."

    Focused operations management for health services organizations,
    Boaz Ronen, Joseph S. Pliskin, Shimeon Pass, 2006.

- Suboptimization of hospital processes seems to be the norm for most hospitals

Suboptimization Example

- Dynamic Simulation Modeling Of ICU Bed Availability

  Proceedings Of The 1999 Winter Simulation Conference
  Cahill, W., M. Render. 1999
  - They investigate use of simulation to determine the need for ICU beds for a Veterans Administration hospital, in context of a rapid growth of medical and neurological patients.
  - Of particular note is their finding that "increased ICU bed availability resulted in increased telemetry and medical floor bed utilization downstream and increased length of stay on the medical service as the proportion of post-ICU patients increased on the floors."
- This finding illustrates the interconnectedness of peri-operative processes
- It also illustrates need to simultaneously analyze/optimize all peri-operative processes

State Dependent Optimization

- If we define the state of a set of peri-operative processes to be:
  - Patients currently in operating rooms and their remaining time there
  - Patients already in the PACU, ICU or wards, and their remaining length of stay

- State Dependent Optimization
  - Takes into consideration the patients already in the system
  - Uses this information to improve system performance

- State Independent Optimization
  - Does not take into consideration the patients already in the system
  - Does not use this information to improve system performance

State Independent Optimization - Example

- Process modeling of ICU patient flow: effect of daily load leveling of elective surgeries on ICU diversion.

  Journal of Medical Systems 33:27-40, 2009
  Kolker, A.

  - They address the question as to the "maximum number of elective surgeries per day should be scheduled (along with the competing demand from emergency surgeries) in order to reduce diversion in an ICU with fixed bed capacity to an acceptable low level, or prevent it at all?"
  - The demonstrated via simulation the effectiveness of a number of scheduling policies
  - The question they didn't answer is whether they could do even better if they developed a policy that optimized scheduling based on the current number of patients in the ICU and their expected remaining length of stays.

State Independent Optimization - Example

- Reducing Surgical Ward Congestion At The Vancouver Island Health Authority Through Improved Surgical Scheduling

  Vincent Chow, Martin Puterman, Neda Salehirad, Wenhai Huang, Derek Atkins

  - Integer programming model to schedule blocks and slates of surgeries so as to minimize excess of bed usage over capacity
  - Spreadsheet (non-DES) simulation model to evaluate proposed schedules

- Their work made it possible to examine and optimize static schedules

- It does not make it possible to dynamically vary schedules based on current circumstances

Research Goal

- Develop an analysis capability that could simultaneously:
  - Reflect randomness inherent to peri-operative processes (and all health care)
  - Optimize performance of the complete set of peri-operative processes
  - Perform this optimization in a state dependent manner

- Possible tools include:
  - Queuing theory
  - Dynamic Programming/Policy Iteration
  - Mathematical Programming/Heuristics
  - Discrete Event Simulation
  - Decision Support Systems

Queuing Theory

- Developed around the turn of the previous century to determine the number of switches needed to handle demand for phone conversations
- Is mathematically based and thus facilitates analysis/optimization for small problems
- When used to analyze multiple processes simultaneously generally requires problem characteristics that do not happen in peri-operative processes
- Our sense is that it is not appropriate for analyzing/optimizing multiple interconnected peri-operative processes

Dynamic Programming/Policy Iteration

- A mathematical analysis/optimization capability that is extremely flexible
- Is often used for state dependent optimization of single queue processes
- Mathematically intractable when there are a large number of possible states
- Our sense is that it is not appropriate for this
- Insights from it suggest the potential benefits of state dependent optimization applied to peri-operative processes

Mathematical Programming

- Encompasses a variety of mathematical optimization techniques
- Generally used for problems without randomness
- Sometimes used for problems with randomness
- Requires that the problem be formulated mathematically
- Generally assumes certain mathematical characteristics which may or may not exist in the problems we are addressing
- When it can be used it tends to be extremely helpful

Heuristics

- Some mathematical optimization problems:
  - Do not have mathematical characteristics needed to guarantee success of mathematical programming techniques
  - Would take an extremely long time to solve
- A number of heuristics have been developed for these problems:
  - Are not guaranteed to successfully solve them
  - But often do, and in considerably less time
- Heuristics that often work well:
  - Simulated Annealing
  - Tabu Search

Discrete Event Simulation

- It can be thought of as being statistical experimentation

- It entails:
  - Building a model of the processes to be analyzed
  - Repeatedly running the model with different random inputs
  - Tabulating the results from the different runs to identify process statistics and the likelihood of particular outcomes

- It cannot be directly used for optimization

- It can be combined with optimization techniques or heuristics

Our Initial Approach

- Build a simulation model with a commercial simulation tool

- Use hospital data

Primary Issues With That Approach

- Simulation modeling methodology
  - Most commercial simulation packages use drawing to build simulations as some form of flow chart
  - As evidenced by the use of multiple diagrams in UML, it can be very hard to represent both the logic and the interactions in a complex set of processes with a single type of diagram
  - Many simulation packages require some form of programming to supplement diagrams

- For complex peri-operative processes, all of these together make it hard:
  - To design and build the model in a consistent and repeatable manner
  - To validate the model
  - For management and staff to understand the details of the model

Primary Issues – Cont'd.

- Performance
  - Consider the use of simulation for evaluating schedules if:
    - Evaluating 10,000 possible schedules
    - Each schedule is tested with 100 runs
  - When:
    - Each run takes 36 seconds and one processor is used, schedule evaluation takes 10,000 hours
    - Each run takes .36 seconds and one processor is used, schedule evaluation takes 100 hours
    - Each run takes .36 seconds and one hundred processors are used, schedule evaluation takes 1 hour
- This suggests the potential benefit of using:
  - A high speed simulation tool
  - Where individual runs can be performed in parallel on different computers (this can be very expensive when using commercial software that costs $1000+ per seat)

Primary Issues – Cont'd.

- Animation
  - Most commercial simulation software includes excellent animation on the user's pc
    - Some animate flowcharts
    - Some are more geographical (2D or 3D)
  - We wished to make it possible to simultaneously display over the web:
    - 2D geographical animations of multiple locations or floors
    - State transitions and probabilities for multiple types and/or individual entities
    - Performance scorecards

Primary Issues – Cont'd.

- Validation
  - Peri-operative processes are complex
  - We wished to have several types of tools to facilitate validation
    - Animation (discussed above)
    - Other reports that would facilitate validation
    - Analysis such as that done by Peter Kemper et al http://www.cs.wm.edu/~kemper/traviando/papers/2005_WSC.pdf

Our Revised Approach

- Build a high speed simulation platform in Java that utilizes multiple-processors and that can be distributed via applets
- Include a simple multi-level 2D geographical animation engine now and state probability & transitions for individual entities in the future
- Design/build models using a simple object oriented analysis methodology; the first model includes several peri-operative processes
- Use hospital data

Revised Approach – Modeling Methodology

- Similar to that used for object oriented analysis (& Agent Based Simulation)
- Steps:
  - Identify geographical points of interest
  - Identify links between these points
  - Identify routes using these links
  - Identify entities
  - Identify attributes for each entity
  - Identify the events to be modeled (including simulation start, end and reset)
  - Identify the activities to be performed for each event by each entity
  - Identify the types of inter-entity communications each entity must be able to handle
  - Specify the details of each activity for each entity
  - Specify the states each entity can take on
  - Specify the states each entity must be in for each activity

Revised Approach – Modeling Methodology – Cont'd.

- For small models this typically involves more work
- For more complex (i.e. peri-operative processes) models this methodology:
  - Is simple
  - Leads to models that are consistently developed
  - Is easier to validate
- Has lead/is leading to the design/development of a library of:
  - Peri-operative entity classes
  - Peri-operative messages
- Will hopefully lead to the development of capability to automatically document simulation model
- Will hopefully lead to code generators for creating most of the simulation

Peri-Operative Entity Classes

- Entity classes that have been or are being designed and developed include:
  - Physical Entities
    - Stationary Entities
      - Bed, Exam Room, Wait Spot, Desk
      - Unit, Medical office, Operating Room, Surgical Ward
    - Moving Entities
      - Patient
      - Unit Agent, Medical Office Receptionist
      - Doctor, Surgeon, Nurse, Orderly, House Cleaning Staff
  - Non-physical Entities
    - Bed Request, Surgery Request
    - Bed Manager

Data

- Operative procedure duration data by surgeon, procedure type and technique
- Recovery length of stay by procedure type and technique
- Both of the above types of data were converted to empirical distributions specifying 0^{th}, 1^{st}, 2^{nd}, . . .100^{th} percentiles
- Surgical block times by surgeon

Model Built With Platform

- Currently includes:
  - Preliminary patient visit to surgeon
  - Scheduling of operative procedures by surgeon
  - Operative procedures by surgeon on patients
  - Recovery in surgical wards

- Will include:
  - PACU, ODS and ICU stays
  - Nurses
  - Anesthetists
  - Respiratory therapists
  - Orderlies

Use Of The Model

- Not statistically validated

- To give director of surgical nursing a picture of needed number of beds

- Will:
  - Be statistically validated
  - Be segmented by bed type to facilitate analysis of beds for each surgical service (or for other ways of organizing surgical beds)
  - Will include ICU
  - Will hopefully include ED

Plans For Using The Platform
Predict PACU/ODS Utilization By Time Of Day

- To help the head of surgical nursing make ICU patient parking decisions
  - The PACU is often very crowded mid-afternoon
  - The head of surgical nursing is often asked to park (ICU) patients in the PACU
  - Before making the decision, the head of surgical nursing would like to know how busy she can expect it to be at different times of the day

- To facilitate this
  - Embed simulation module into PACU bed monitoring capability
  - Load real time data from bed monitoring capability and surgical information system
  - Use that data to initialize simulation
  - Use simulation results to plot expected number of busy beds in PACU every 15 minutes of the day

Plans For Using The Platform Improve Surgery Scheduling

- To help OR scheduler evaluate expected performance measures on proposed schedules in context of:
  - Current bed utilization data, including estimated length of stay, from bed tracking system
  - Proposed surgery schedule from surgical information system

- To automate peri-operative scheduling
  - Same concept as above
  - Add automatic optimization
  - Issues include:
    - Identification of objective function***
    - Optimization algorithm (simulated annealing, tabu search)***
    - Processing requirements***

Plans For Using The Platform To Evaluate Proposed Process Changes

- Have proposed possible approaches to changing surgery schedules e.g. cataract surgeries at the end of the day

- Evaluate effect of proposed pooling of ICU, PACU, CCU and Step Down Unit nurses

- Evaluate effect of changing how beds are organized
  - Currently organized by specialty with a separate ICU
  - What if they were sub-organized within each specialty by acuity?

Plans For Using The Model For Strategic And Capacity Planning

- Surgical bed requirements analysis (on a regular basis)
- ICU bed requirements analysis
- Staffing levels for proposed pre-surgical screening unit
- . . .