Operations Research in Health Care: Perspectives from an engineer, with examples from emergency medicine and cancer therapy

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Clinical and Population Research Rounds
St. Michael’s Hospital
October 20, 2011
Overview

• Introduction to Operations Research (OR)

• The landscape of OR and health care: three categories of problems
  – AED location example (policy)
  – Radiation therapy example (micro)
  – Clinic scheduling example (macro)
What is Operations Research?

• “The most important field you’ve never heard of”
• “A liberal education in a technological world”
  – Boston Globe article, 2004

• “OR is the study of improving operations and decisions through the use of quantitative techniques”
  – Optimization, probability, statistics, computer modeling, simulation, queuing, game theory, etc.
  – “Useful applied math”

• The lack of a universal definition is both a strength and a weakness of our field
Where is OR used?

• Historically, OR has been applied to areas such as:
  – **Military**: What is the optimal size of a convoy (during WWII)?
  – **Manufacturing**: How to minimize cost of production while meeting demand?
  – **Transportation**: How to configure a supply chain to minimize transportation costs?
  – **Finance**: What is the best basket of stocks to hold to maximize return while keeping risk at an acceptable level?

• More recently, OR has been used in the realms of:
  – **Entertainment**: Queue management at Disney World
  – **Pricing**: Dynamic pricing of airline tickets and hotel rooms
  – **Sports**: Scheduling a season of MLB games
  – **Health care**: …
OR applications in Health Care – Three categories

Policy
“For the system”
- Cost effectiveness
- Guidelines in public health

Micro
“For the patient”
- Medical decision making
- Treatment design

Macro
“For the provider”
- Resource allocation
- Utilization, throughput
A Policy Problem: Public AED location

• Collaboration with Steve Brooks, Laurie Morrison

• “Automated External Defibrillators (AED) in hotspots”
  – Determine new “hotspots” where AEDs should be added or redeployed from “colder” areas

• Automated external defibrillators (AEDs) can be used by bystanders to diagnose and treat a cardiac arrest victim prior to EMS arrival
  – AEDs useful if nearby
Public access defibrillation (PAD) programs

• Public access defibrillation: place AEDs in public locations so that they may be used to treat cardiac arrest victims by lay responders

• Organizations produce guidelines to help inform public AED deployment
  – Locations with high historical incidence

• Where public AEDs are actually placed can be highly variable from city to city
  – Specific donors/campaigns may want to see AEDs placed in certain locations
How to “optimize” PAD programs

1. Place AEDs in appropriate geographical locations throughout the city
2. Place AEDs in appropriate buildings and locations within buildings
3. Aid lay responders in finding a nearby AED
4. Make sure AEDs are accessible
5. Ensure responders are willing to operate an AED in an emergency situation
Goals

- To develop a methodology that can identify cardiac arrest “hotspots” in any city and prioritize geographies for AED deployment
- To identify hotspots that may be missed by other methods
- To test and validate methodology using data from Toronto
Optimization model

- Maximal covering location model
  - Maximize # of cardiac arrests “covered” (within certain radius) by deploying AEDs to $N$ locations

\[
\begin{align*}
\text{maximize} & \quad \sum_{j=1}^{n} x_j, \\
\text{subject to} & \quad \sum_{i \in I_n} y_i \leq N, \\
& \quad y_i = 1, \quad \forall i \in I_c, \\
& \quad \sum_{i=1}^{m} z_{ij} = x_j, \quad \forall j \in J, \\
& \quad z_{ij} \leq a_{ij} y_i, \quad \forall i \in I, \forall j \in J, \\
& \quad x_j, y_i, z_{ij} \in \{0, 1\}, \quad \forall i \in I, \forall j \in J.
\end{align*}
\]
Data

• Cardiac arrests (1310)
  – Resuscitation Outcomes Consortium Epistry database
  – Location and other info for cardiac arrest cases from December 2005 – July 2010
  – Inclusion criteria: Toronto, public locations, atraumatic, EMS-attended

• Currently deployed AEDs (1669)
  – Registry from Toronto Emergency Medical Services with location info
  – Registration not mandatory; likely more AEDs out there but no visibility by EMS

• Potential AED locations (25,851)
  – Building database from City of Toronto Employment Survey
Results
Results

Legend
- Public Cardiac Arrests
- Downtown Toronto
- Registered AEDs
Results
## Results

<table>
<thead>
<tr>
<th>Performance metric</th>
<th>Baseline</th>
<th>Optimization</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total cardiac arrests covered</td>
<td>304 (23%)</td>
<td>356</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(27%)</td>
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<tr>
<td>Average distance from cardiac arrest to closest AED</td>
<td>281 +/- 229 m</td>
<td>273 m</td>
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<tr>
<td></td>
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<td>266 m</td>
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<td>262 m</td>
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<table>
<thead>
<tr>
<th></th>
<th>(N=10)</th>
<th>(N=20)</th>
<th>(N=30)</th>
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</thead>
<tbody>
<tr>
<td>Total cardiac arrests covered</td>
<td>416</td>
<td>386</td>
<td>416</td>
</tr>
<tr>
<td>(23%)</td>
<td>(27%)</td>
<td>(29%)</td>
<td>(32%)</td>
</tr>
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<td>Average distance from cardiac arrest to closest AED</td>
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</tr>
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![Graph](image1.png) ![Graph](image2.png)
Observations

- Lots of cardiac arrests occur “outside”
  - Hard to classify the building type in which they occur, so most analyses miss these locations
- Some downtown hotspots have >5 historical cardiac arrests
  - In more troubled areas
  - Many candidate locations for AED deployment
- Hit diminishing returns relatively quickly
  - Need to balance impact of location optimization with other initiatives that may improve PAD programs
Collaborating with Engineers

• Provides a fresh viewpoint on a problem
• Alternative approaches, frameworks, methods may become apparent
  – Approaches to non-health care problems may lend well to health care problems through analogy
• Engineers have tools, methods and expertise not available to the health care researcher
Collaborating with Engineers

• Caveats
  – Engineers can be strange and threatening
  – We speak different languages
    • Need to invest in mutual education about the art of the other
  – Spend a lot of time learning about the methods being used and make sure that they make sense for the real world problem
    • Pay attention to model assumptions and parameters as they relate to the real world problem
A Policy Problem: Summary

- Developed mathematical model to optimize locations of AEDs to cover as many (historical) cardiac arrests as possible

- Cardiac arrest coverage can be improved significantly with a small number of AEDs deployed in priority locations
  - Diminishing returns reached quickly

- Optimization is only a small part of improving survival from OHCA through increased AED use
  - Any advance that increases the coverage radius can significantly improve performance of the system
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A Micro Problem: Radiation therapy

- Optimization algorithms used to design radiation therapy treatments (beam angles, intensity of each radiation beamlet, etc.)

- Uncertainty (e.g., setup error, breathing motion) can reduce treatment effectiveness

- Goal: Design treatment plans that are insensitive to uncertainty while achieving other objectives
Radiation Therapy Overview

- Linear accelerator used to deliver radiation
- Deliver from multiple angles
- Fractionated treatment
- “Therapeutic advantage”
Treatment Planning Process

- Take pre-treatment 4DCT scan

- Physician outlines target and critical structures – this becomes problem data

- Planner solves optimization problem to produce treatment plan

- Go back and forth between planner and physician

- Traditionally, deliver same treatment every day over treatment course (little data re-acquisition and re-planning)
External beam radiation therapy

3D conformal Rx

- This is OK if the tumor doesn’t move…
Motion and motion uncertainty

Breathing motion trace

Purple outline = “margin”
Treatments trade off between tumour vs. healthy tissue

Minimum tumor dose versus mean left lung dose (PMF sequence 1)

Aggressive treatment
(little motion uncertainty)

Balanced treatment
(moderate motion uncertainty)

Conservative treatment
(lots of motion uncertainty)
A Micro Problem: Summary

- Use optimization to design radiation therapy treatments that
  - Target tumor
  - Spare healthy organs
  - Compensate for uncertain breathing motion
A Macro Problem: Clinic Scheduling

• Hospitals schedule ambulatory clinics throughout the week
• Clinic schedule affects operations of many shared resources
  – Upstream blood lab
  – Downstream chemo day care
  – Nursing
  – Rooms
• Currently being studied at Princess Margaret Hospital and Women’s College Hospital
• Goal: Create clinic schedule that balances shared resource utilization
Conclusion

• Operations research has the capability to solve a wide range of practical problems, especially large-scale, complex, data-intensive ones

• Keys to success:
  – Access to reliable data and collaborators
  – Formulating a good model (art vs. science)
  – Recognizing limitations of model
  – Translating abstract solutions into implementable recommendations

• Operations researchers are always looking for challenges and collaborators in new fields
  – We’d like to believe we have a hammer for everybody’s nail
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