What can Health Economics learn from Operations Research?

Introduction

Praveen Thokala
University of Sheffield
Purpose of Workshop

• There are a variety of available approaches available to researchers for approaching different types of health economic evaluation problems.

• However, most training sessions at ISPOR focus on very specific techniques and certain types of problems.

• This workshop will present the approaches from operations research (OR) and focuses on the higher order issue of choosing the correct approach in the first place.

What is Operations Research?

• Operations Research (OR) is a discipline that applies mathematical techniques to help institutions (private, public, non-profit) and individuals make better decisions.

• OR has recently been called “the science of better” http://www.scienceofbetter.org

• OR focuses on finding ways to allocate scarce resources to activities.

• Number of different techniques under OR umbrella
Methods to be covered in this session

• Simulation modelling
• Optimization modelling
• Multi criteria decision analysis

Simulation modelling

• Most health economic modelling approaches assume
  • every patient is the same (cohort models)
  • no interactions between patients
  • that there are no resource capacity issues

• Simulation modelling techniques such as discrete event simulation, system dynamics and agent based modelling can help with capturing these issues
Optimisation

select items to pack in the knapsack to maximise comfort

item $x_1$, comfort = $p_1$, size = $w_1$

item $x_m$, comfort = $p_m$, size = $w_n$

Knapsack, size = $c$

Optimiser

Multi criteria decision analysis

* Priority setting of health interventions: the need for multi-criteria decision analysis, Rob Baltussen, Louis Niessen, Cost effectiveness and resource allocation (2006)
These approaches differ in terms of their

- Aim and Purpose
- Types of applications
- Key concepts
- Outputs
- Resources/skills needed

Plan for the session

- Simulation modelling – Deborah Marshall
- Optimization modelling – Alec Morton
- Multi criteria decision analysis - Janine van Til
- Audience polling - all
Simulation Modelling

Deborah A Marshall
University of Calgary, Canada
Simulation Modelling: Definition

“Simulation modelling methods are used to design and develop mathematical representations of the operation of processes and systems to experiment with and test interventions and scenarios and their consequences over time to advance the understanding of the system or process, communicate findings, and inform management and policy design.”


Key Concepts: Why **Systems** Perspective and Simulation Modelling in Health Care?

- Health Care is a Complex System with relationally dependent events with unpredictable outcomes - multiple stakeholders and interactions, feedback loops, non-linearities, uncertainty, etc.

- Simulation models support the design of systems by enabling a better understanding of the complexity and behaviour of the system that is modelled. This can translate into quality and healthcare improvement.

- Simulation models are means to synthesize data when direct experimentation is not possible or feasible.

- Mechanism to logically and systematically examine a policy problem. Evaluate intended and unintended consequences of an intervention using alternative “what if...?” scenarios BEFORE implementing.

- Identify need for additional data – what are the gaps?
## Aim/Purpose of Simulation Models

### Why do we build simulation models?
- Identify critical functional and relational aspects of a system
- Understand the system as a function of its organization and relationships
- Suggest how to intervene to achieve desired goals and outcomes

### What is Dynamic Simulation Modeling Used for?
- Model building process and simulation are learning processes themselves
- Identify critical functional and relational aspects in complex systems
- Understand why a system behaves the way it does as a function of its organization (structure).
- Shift paradigms and mental models

### Design and Evaluation of Health Care Delivery System Interventions
- Evaluate intended and unintended consequences of an intervention using “what if...?” scenarios
- Tool for designers (e.g. policy design, system design and re-design) that is more prescriptive in nature by informing decision making.

## Applications: Examples of Problems Addressed with Simulation Modelling Methods

<table>
<thead>
<tr>
<th>System Level</th>
<th>Types of Problems</th>
<th>Potential Approaches</th>
<th>Intervention Example</th>
</tr>
</thead>
<tbody>
<tr>
<td>Strategic Level</td>
<td>Policy</td>
<td>System Dynamics</td>
<td>Informing regional policy regarding implementation of a centralized intake system for referral to an appropriate provider for assessment and specialist consultation for patients with musculoskeletal pain.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Agent Based Modeling</td>
<td></td>
</tr>
<tr>
<td>Tactical Level</td>
<td>Management</td>
<td>Agent Based Modeling</td>
<td>Wait time management for referral for a specific service e.g., consultation with orthopaedic surgeon or rheumatologist</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Discrete Event</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Simulation</td>
<td></td>
</tr>
<tr>
<td>Operational Level</td>
<td>Logistics</td>
<td>Agent Based Modeling</td>
<td>Scheduling surgical dates for joint replacement in the operating room</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Discrete Event</td>
<td>Evaluating the change in hospital services due to a delay of total joint replacement in cases of severe osteoarthritis.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Simulation</td>
<td></td>
</tr>
</tbody>
</table>
Three Main Approaches to Simulation Modelling

- System dynamics – e.g. facilities for cancer treatment

- Discrete event simulation – e.g. surgical planning and scheduling

- Agent (Individual) based modelling - infectious disease control

System Dynamics Simulation

- Core elements: Stocks and Flows
  - Feedback: Feedback processes infer that effect is not proportional to the cause i.e. nonlinearity
  - Accumulations (stocks): Accumulation or aggregation of something (e.g., people, beds)
  - Rates (flows): Flows feed in and out of stocks and have the same units of stocks per time unit (e.g., people per hour, beds per year, and oxygen per minute)
  - Time Delays: People accumulate in stocks if the rate of flow out is less than in to the stock
Discrete Event Simulation

- E.g. surgical planning

- Core elements: Queues
  - Process: representing the system that is being studied
  - Entities: flowing through the process and have work done on them
  - Resources: used in the workflow to process entities
  - Events: cause changes in the state of the entity and/or system

Agent Based Simulation

- E.g. infectious disease modelling

- Core elements: Interactions
  - Entities: transition between states based on events and interactions
  - Interactions: dynamic behavior of the entities and their environment
  - Network: set of (dynamic) rules to determine the interactions
  - Space: entities’ behavior is influenced by their spatial location
Example: System Dynamics Model of Osteoarthritis

Modelling the complete continuum of care using system dynamics: the case of osteoarthritis in Alberta

SA Vanderby1, MW Carter2, T Noseworthy3 and DA Marshall3
1University of Saskatchewan, Saskatoon, Canada; 2University of Toronto, Toronto, Canada; and 3University of Calgary, Calgary, Canada

Estimating how many patients will require care, the nature of the care they require, and when and where they will require it, is critical when planning resources for a sustainable healthcare system. Resource planning must consider how quickly patients move among stages of care, the various different pathways they may take, and the resources required at each stage. This research presents a preliminary long-term, population driven system dynamics simulation developed to support resource planning and policy development relating to osteoarthritis care. The simulation models osteoarthritis patients as they transition through the continuum of care from disease onset through end-stage care, and provides insight into the size and characteristics of the patient population, their resource requirements, and associated health-care costs. Although the model presented is specific to the osteoarthritis care system in the Province of Alberta, Canada, similar methods could be applied to develop simulations relating to other chronic conditions. Journal of Simulation advance online publication, 20 February 2015. doi:10.1087/jos.2014.43

'What if' scenarios:
• Provide insight into relative effects of changes in care processes and/or resource use
• Demonstrate intended and unintended consequences

Case Example: What if we implemented a maximum 14 week wait time target for joint replacement surgery?

Example: System Dynamics Osteoarthritis (OA) Model Process Diagram
Cost Output: 14 Week Target for Joint Replacement

More surgeries = higher costs
Extra costs decrease over time
Save costs in wait for surgery

Simulation Modelling: Resources and Skills Needed

- **Software**
  - Mostly need specialised software for the specific modelling approach (of course everything can be done in Excel, but not efficiently)

- **Skills**
  - Need quantitative and modelling skills
  - Recommend working with someone who has experience in specific modelling approach

- **Data and Analysis**
  - Consider carefully the research question and problem
  - Consider the level of detail required for the data inputs and what will be data inputs vs outputs.
  - Need clinical and decision maker input on model structure and interpretation of results – validate with stakeholders
  - Some modelling approaches need a lot of data e.g. DES need individual level data; ABM needs behavioural data
What is Optimization?

- **Optimization** is a key tool in the *analytics armamentarium*.

- “**Optimization**: Narrowing your choices to the very best when there are virtually innumerable feasible options” INFORMS, The Science of Better
  

- “In a mathematical programming or *optimization* problem, one seeks to minimize or maximize a real function of real or integer variables, subject to constraints on the variables.” The Mathematical Programming Society
  
  [http://www.mathprog.org/mps_whatis.htm](http://www.mathprog.org/mps_whatis.htm)

- **Take home**: Optimization is an *applied, practical* subject, but also a *highly technical* one that uses cutting edge math and computation.
Optimisation: Aim/purpose

“To identify the ‘best’ solution”

- Example: your health center serves Regular or Severe Patients
- Some info:
  - Regular patients can achieve 2 units of health benefits, Severe patients can achieve 3 units of health benefits
  - Each patient takes fifteen minutes to be seen
  - Regular patients require $25 of medications, severe patients require $50 of medications
  - Total consultation time available is one hour (can only see one patient at a time) and total medication money available is $150
- Question: What’s the max. unit of health benefits that can be achieved?

Typical Health Care Decisions in Which Constrained Optimization is Used

<table>
<thead>
<tr>
<th>Type of health care problem</th>
<th>Typical decision makers</th>
<th>Typical decisions</th>
<th>Typical objectives</th>
<th>Typical constraints</th>
</tr>
</thead>
<tbody>
<tr>
<td>Resource allocation within or across disease programs</td>
<td>Health authorities, insurance funds</td>
<td>List of interventions to be funded</td>
<td>Increase population health</td>
<td>Overall health budget</td>
</tr>
<tr>
<td>Resource allocation for infectious disease management</td>
<td>Public health agencies, health protection agencies</td>
<td>Optimal vaccination coverage level</td>
<td>Ensure disease outbreaks can be rapidly and cost effectively contained,</td>
<td>Availability of medicines, disease dynamics of the epidemic</td>
</tr>
<tr>
<td>Allocation of donated organs</td>
<td>Organ banks, transplant service centers</td>
<td>Matching of organs and recipients</td>
<td>Matching organ donors with potential recipients</td>
<td>Every organ can be received by at most one person</td>
</tr>
<tr>
<td>Radiation treatment planning</td>
<td>Radiation therapy providers</td>
<td>Positioning and intensity of radiation beams</td>
<td>Minimizing the radiation on healthy anatomy</td>
<td>Tumor coverage and total average dosage</td>
</tr>
<tr>
<td>Disease management Models</td>
<td>Leads for a given disease management plan</td>
<td>Best interventions, timing for the initiation of a medication, best screening policies</td>
<td>Identify the best plan using a whole disease model, maximizing QALYs</td>
<td>Budget for a given disease or capacity constraints for providers</td>
</tr>
<tr>
<td>Workforce planning/ Staffing / Shift template optimization</td>
<td>Hospital managers, all medical departments (e.g., ED, nursing)</td>
<td>Number of staff at different hours of the day, shift times</td>
<td>Increase efficiency and maximize utilization of healthcare staff</td>
<td>Availability of staff, human factors, state laws (e.g., nurse-to-patient ratios), budget</td>
</tr>
<tr>
<td>Inpatient scheduling</td>
<td>Operation room/ ICU planners</td>
<td>Detailed schedules</td>
<td>Minimize waiting time</td>
<td>Availability of beds, staff</td>
</tr>
</tbody>
</table>
Optimization terminology

- **Decision variables** - mathematical symbols representing the inputs that can be changed to achieve optimal solution

- **Objective function** - a mathematical relationship describing an objective, in terms of decision variables - this function is to be maximized or minimized

- **Constraints** – requirements or restrictions placed on and stated in functions of the decision variables

- **Parameters** - numerical coefficients and constants used in the objective function and constraints

Optimisation: Outputs

Optimal solution; and list of final decision variables

- Example: your health center serves Regular or Severe Patients

- Some info:
  - Regular patients can achieve 2 units of health benefits, Severe patients can achieve 3 units of health benefits
  - Each patient takes fifteen minutes to be seen
  - Regular patients require $25 of medications, severe patients require $50 of medications
  - Total consultation time available is one hour (can only see one patient at a time) and total medication money available is $150

- Output: We can achieve 10 units health benefits by treating 2 regular patients and 2 severe patients
More on outputs

Explore how decisions change as constraints are varied


Balance competing objectives through generating tradeoff curves


Visualise the effects of uncertainty on decisions

Ö. Karsu and A. Morton (in preparation) Trading off health and financial protection benefits with multiobjective optimisation

Resources and skills needed

- **Software**
  - For small models and linear programming, you can use MSExcel
  - Beyond that consider investing in specialised software

- **Skills**
  - You DON’T need to be a mathematician
  - You DON’T need to be a computer scientist
  - BUT it’s probably a good idea to take a class or read a book

- **Time and eyeballs**
  - VALIDATE, VALIDATE, VALIDATE
  - Optimisation should complement stakeholders’ informal knowledge, it doesn’t substitute
Multi-criteria decision analysis (MCDA)

- “an extension of decision theory that covers any decision with multiple objectives. A methodology for appraising alternatives on individual, often conflicting criteria, and combining them into one overall appraisal…” (Keeney & Raiffa, 1976)

- “an umbrella term to describe a collection of formal approaches, which seek to take explicit account of multiple criteria in helping individuals or groups explore decisions that matter.” (Belton & Stewart, 2002)
Aim and Purpose

- **Aim:** an assessment of the relative desirability or acceptability of specified alternatives or choices among outcomes or other attributes that differ among alternative health interventions

- **Purpose:** to support a decision by:
  - Identifying which outcomes, endpoints, or attributes matter to stakeholders and why.
  - Determine how much different attributes matter to and the trade-offs that stakeholders are willing to make among them.

Key Concepts

- A preference is the choice of one thing over another with the anticipation that the choice will result in greater value, satisfaction, capability or improved performance of the individual, the organization or the society (stakeholders).

- Preference methods can reveal stakeholder values over both more relevant (higher priority) and less relevant (lower priority) endpoints or outcomes.
Key Concepts

- Criteria weight = a measure of the relative preference for changes in performance between criteria
- Can be seen as scaling factors
- Performance value = a measure of the relative preference (value) for performance outcomes within criteria
- Can be linear or non-linear

<table>
<thead>
<tr>
<th>Currency Rates</th>
<th>USD</th>
<th>EUR</th>
<th>GBP</th>
<th>CHF</th>
<th>CAD</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 USD =</td>
<td>1</td>
<td>0.7141</td>
<td>0.6164</td>
<td>1.0826</td>
<td>1.1006</td>
</tr>
<tr>
<td>1 EUR =</td>
<td>1.4004</td>
<td>1</td>
<td>0.8632</td>
<td>1.5160</td>
<td>1.5412</td>
</tr>
<tr>
<td>1 GBP =</td>
<td>1.6223</td>
<td>1.1585</td>
<td>1</td>
<td>1.7563</td>
<td>1.7855</td>
</tr>
<tr>
<td>1 CHF =</td>
<td>0.9237</td>
<td>0.6596</td>
<td>0.5594</td>
<td>1</td>
<td>1.0166</td>
</tr>
<tr>
<td>1 CAD =</td>
<td>0.9086</td>
<td>0.6488</td>
<td>0.5501</td>
<td>0.9836</td>
<td>1</td>
</tr>
</tbody>
</table>

\[ \nu(x) = \sum_{k=1}^{n} w_k \cdot \nu_k(x_k) \]
Applications: MCDA in Priority Setting

Table 4. Priority for Targeting Certain Risk Group Given by Different Stakeholder Groups, Based on 5-Point Likert Scale Scores

<table>
<thead>
<tr>
<th>Rank</th>
<th>Risk group</th>
<th>Mean score (SD)</th>
<th>Rank</th>
<th>Mean score</th>
<th>Rank</th>
<th>Mean score</th>
<th>Rank</th>
<th>Mean score</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>People who inject drugs</td>
<td>4.28 (0.74)</td>
<td>1</td>
<td>4.27</td>
<td>1</td>
<td>4.39</td>
<td>1</td>
<td>4.51</td>
</tr>
<tr>
<td>2</td>
<td>Female sex workers</td>
<td>4.20 (0.89)</td>
<td>2</td>
<td>4.09</td>
<td>2</td>
<td>4.20</td>
<td>2</td>
<td>4.19</td>
</tr>
<tr>
<td>3</td>
<td>Partners of HIV+ people</td>
<td>4.03 (0.90)</td>
<td>3</td>
<td>4.14</td>
<td>3</td>
<td>3.82</td>
<td>3</td>
<td>3.86</td>
</tr>
<tr>
<td>4</td>
<td>Clients of FSW</td>
<td>3.80 (1.09)</td>
<td>4</td>
<td>4.27</td>
<td>4</td>
<td>3.65</td>
<td>4</td>
<td>4.02</td>
</tr>
<tr>
<td>5</td>
<td>Prisoners</td>
<td>3.58 (1.19)</td>
<td>5</td>
<td>3.77</td>
<td>5</td>
<td>3.55</td>
<td>5</td>
<td>3.12</td>
</tr>
<tr>
<td>6</td>
<td>Men having sex with men</td>
<td>3.47 (1.19)</td>
<td>6</td>
<td>3.41</td>
<td>6</td>
<td>3.63</td>
<td>6</td>
<td>3.09</td>
</tr>
<tr>
<td>7</td>
<td>Transgender</td>
<td>3.40 (1.00)</td>
<td>7</td>
<td>3.18</td>
<td>7</td>
<td>3.45</td>
<td>7</td>
<td>3.05</td>
</tr>
<tr>
<td>8</td>
<td>People low at risk</td>
<td>2.74 (1.29)</td>
<td>8</td>
<td>3.32</td>
<td>8</td>
<td>2.94</td>
<td>8</td>
<td>2.42</td>
</tr>
</tbody>
</table>

Application: MCDA in Benefit Risk Analysis

1. Design
2. Elicit
3. Analyze
4. Apply

Clinical data

<table>
<thead>
<tr>
<th>Attribute</th>
<th>A</th>
<th>B</th>
</tr>
</thead>
<tbody>
<tr>
<td>DFS</td>
<td>60%</td>
<td>55%</td>
</tr>
<tr>
<td>Chronic DFS</td>
<td>61%</td>
<td>89%</td>
</tr>
</tbody>
</table>

Acceptability of treatments

Benefits and Risks of Cancer Care

Health Outcomes and Economics of Cancer Care

Key Words: Patient preferences • Regulatory science • Benefit-risk assessment • Multicriteria decision analysis
Application: MCDA in Shared Decision Making

The Use of Multi-Criteria Decision Analysis Weight Elicitation Techniques in Patients with Mild Cognitive Impairment: A Pilot Study

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1 Roessingh Research & Development, Enschede, the Netherlands
2 University of Twente, Enschede, the Netherlands
3 Unity Health System, Rochester, New York, USA
4 University of Rochester, Rochester, New York, USA
5 Leids Universitair Medisch Centrum, Leiden, the Netherlands

Outputs

- **Preference weights**: a measure of the relative importance of the different criteria that influence the decision

- **Performance values**: a judgement of the perceived value of (preference for) outcomes on each criterion

- **A rank order of options**: based on a broad evaluation of all relevant criteria that influence the decision
Skills/Resources

- Decision Analyst
- Decision Makers
- Time & Money

Discussion

Praveen Thokala
University of Sheffield
## Comparison of the methods

<table>
<thead>
<tr>
<th></th>
<th>Simulation modelling</th>
<th>Optimisation</th>
<th>MCDA</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Definition</strong></td>
<td>Mathematical representations of the operation of processes and systems</td>
<td>Using analytic methods to seek the best possible solution for a given problem</td>
<td>Support structured decision making involving trade-offs among conflicting criteria</td>
</tr>
<tr>
<td><strong>Aim/purpose</strong></td>
<td>Identify critical functional and relational aspects of a system and suggest how to intervene to achieve desired outcomes</td>
<td>To identify the ‘best’ solution</td>
<td>To compare alternatives on multiple criteria</td>
</tr>
<tr>
<td><strong>Types of applications</strong></td>
<td>Strategic, tactical and operational level planning</td>
<td>Resource allocation, scheduling, treatment planning</td>
<td>Priority setting, benefit risk analysis, shared decision making</td>
</tr>
<tr>
<td><strong>Key concepts</strong></td>
<td>SD: stocks/flows</td>
<td>Objective function, Decision variables, Constraints and Constant parameters</td>
<td>Options, Criteria, Weights and partial scores, Overall scores</td>
</tr>
<tr>
<td></td>
<td>DES: entities/activities/labels/resources</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>ABM: agents, rules, interactions</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Outputs</strong></td>
<td>Process measures (e.g. wait times), health/cost outcomes</td>
<td>Optimal solution; and list of final decision variables</td>
<td>Rank order of alternatives based on overall scores</td>
</tr>
<tr>
<td><strong>Skills needed</strong></td>
<td>Software programming; conceptual modelling with mental models</td>
<td>Problem structuring; Programming; using optimisation software</td>
<td>Facilitation skills; survey design; statistical skills</td>
</tr>
<tr>
<td><strong>Resources</strong></td>
<td>Data, clinical experts, decision makers</td>
<td>Data; clinical experts</td>
<td>Access to decision makers</td>
</tr>
</tbody>
</table>

**Audience polling**
- **For attendees using the mobile app:**
  Open the app >> Select “More” >> Select “Live Polling/Q&A” >> Select your session from the list

- **For attendees using the myISPORBarcelona.zerista.com web platform:**
  Go to the [myISPORBarcelona.zerista.com](https://myispor.cnf.io/) home page >> Click on [https://myispor.cnf.io/](https://myispor.cnf.io/) >> Select your session

- **For those not using the mobile app nor the web platform:**
  Go to your web browser and type in: [https://myispor.cnf.io/](https://myispor.cnf.io/) >> Select your session
Poll: There is a given health care budget, of say £50m. There are a number of interventions, each with data on total costs, QALYs and other elements of value. Need to identify how to spend the budget, which technique will you use.

Poll: You are the manager of a cancer hospital looking to reconfigure the services for breast cancer patients. Need to look at the whole pathway (i.e. from screening/diagnosis to treatment) to identify which interventions should be included in the pathway.
Poll: At a HTA agency there are 100s of potential new technologies that need appraising, with only preliminary data on the technology, condition, disease burden, effectiveness, etc. The agency only has capacity to evaluate 25 of them, how will you select?

Conclusions

- Simulation modelling is useful when modelling complex systems and interactions to systematically examine a problem and evaluate intended and unintended consequences of changes to the system.

- Constrained optimization is useful when health system budgets and resources limit an ability to expand/deliver services.

- MCDA is useful to prioritise from a range of alternatives that are conflicting on multiple criteria.

- These methods can work in tandem (or alone) with existing economic evaluation methods to provide useful insight into the feasibility of health care delivery system value.