Taxonomy of Model Structures for Health Economics

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Healthcare Modeling

- Models inform decision makers
  - Simple: understandability and theoretical utility
  - Complex: added realism

- Occam: The simplest model to answer a question is preferred

- Complexity aside, does choice of given type of model systematically influence decisions?
  - Brennan, Chick, Davies (2006), other examples
Roadmap

- **Taxonomy of Model Structures**
  - System dynamiX; Markov chain; discrete event simulation at patient level
  - Examples of why the type of model matters
    - Independence and system dynamics
    - Stochastic versus deterministic
    - Patient-level, discrete-event simulations

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Decision Tree

<table>
<thead>
<tr>
<th>Mean values</th>
<th>Independent outcomes</th>
<th>Implicit timing</th>
<th>QALY</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>1</td>
</tr>
<tr>
<td>0.8</td>
<td>Cured</td>
<td></td>
<td>1</td>
</tr>
<tr>
<td>Treat</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0.2</td>
<td>Negative side effect</td>
<td></td>
<td>0.5</td>
</tr>
<tr>
<td>Not Treat</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0.3</td>
<td>Some healing</td>
<td></td>
<td>0.8</td>
</tr>
<tr>
<td>0.7</td>
<td>Mild degradation</td>
<td></td>
<td>0.7</td>
</tr>
</tbody>
</table>
Markov Model

Stochastic cohort
Distributions
Timing

Time 0  Time 1  Time 2
Healthy 0.95  Healthy 0.95  Healthy

Healthy

0.05 0.05

Healthy

0.75 0.75

Ill

0.25 0.25

Ill

Discrete Event Simulation
of Patients / Resources

Curse of dimensionality  Rich randomness
Interaction, constraints  Scheduling, operational…
Some Models

- Decision tree (rollback)
- Markov: sample # patients that transition
- Discrete event simulation
- System dynamics (ODE)
- Decision tree (rollback)
- Markov: sample # patients that transition
- Discrete event simulation
- Stochastic decision tree
### Some Models

- **System dynamics (ODE)**
- **Discrete event simulation**
- **Markov: sample # patients that transition**
- **Patients evolve on discrete-time grid**
- **Decision tree**
- **Stochastic decision tree**
- **Stochastic decision tree with covariates**

### Model Hierarchy

<table>
<thead>
<tr>
<th>Timing / constraints</th>
<th>Aggregate level</th>
<th>Patient level</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Continuous time</strong></td>
<td>Deterministic continuous state / mean value</td>
<td>Stochastic discrete counts</td>
</tr>
<tr>
<td><strong>System dynamics (ODE)</strong></td>
<td>Stochastic Markov model (queue,...)</td>
<td>Patient-level simulation (interact)</td>
</tr>
<tr>
<td><strong>Discrete time</strong></td>
<td>Finite difference model</td>
<td>Markov: sample # patients that transition</td>
</tr>
<tr>
<td><strong>Untimed</strong></td>
<td>Decision tree</td>
<td>Stochastic decision tree</td>
</tr>
</tbody>
</table>
Roadmap

- **Model Type**
  - System dynamics; Markov chain; discrete event simulation at patient level
- **Independence and system dynamics**
  - Water treatment policy for the E.P.A.
- **Stochastic versus deterministic**
  - Infectious disease control: NTHi
- **Patient-level, discrete-event simulations**
  - Time oriented, resource constraints, social dynamics

Waterborne Transmission of Infection and Risk of Infectious Disease

- **Public health**
  - Crypto, giardia, legionella, …
  - Candidates: adeno- & caliciviruses, …
  - Outbreak!
    - Milwaukee, Crypto, 1993, …
  - Endemic:
    - May be more significant!
Comparative Analysis: Milwaukee in Retrospect

- Immuno-compromised?
  - Contaminated water ⇒ exposure to HIV community
  - Susceptibility? Outcome severity?
- Chemical Risk: Filter (local) vs. Ozone (global)
  - $100 Million question
  - Decision-tree assessment: Filters 10x more effective than ozone
- Microbes:
  - Is ozone “better” than filters, given secondary transmission?

Simplified Transmission System: ODE Infection Transmission Model

- Infection dynamics
  \[
  \frac{dS}{dt} = -(\text{water} + \text{human loops}) + \text{recovery rate} - \left( r \phi W + c \beta \frac{I}{S + I} \right) S + \frac{1}{D} I
  \]
- Water contamination
  \[
  \frac{dW}{dt} = \gamma + \theta I - \alpha W
  \]

(Chick, Koopman, Soorapanth et al. 2001 2003)
Ozone pretreatment (global) & Filter (local, target to HIV subpopulation)

Added subpopulations/disease progression…

“better” = fewer cryptosporidiosis cases in HIV subpopulation

\[ R_{0h} = \text{mean number secondary transmissions from human contact} \]

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Deterministic System Dynamics ⇔ Stochastic Markov Chain

Deterministic System dynamics
\[
\frac{dI}{dt} = -\text{rate of recovery} + \text{rate of infection}
\]
\[
= -\frac{I}{D} + \left( r \phi W + c \beta \frac{I}{N} \right) (N - I)
\]

Stochastic Markov chain: Variability

Infection

Recovery

\[\lambda_0 \quad \lambda_{I-1} \quad \lambda_I = \left[ r \phi W + c \beta \frac{I}{N-I} \right] (N-I) \]

Stochastic Markov Chain

“Shadow” count of # people, microbes, ...

Stoch M.C. for Individuals and Water

Apparent risk of local die-out of infection
Local and disseminating contact in NTHI model

- Local:
  - Child care center room, family unit, classroom, small office, …

- Disseminating:
  - Playground, contaminate source water, random mixing in street, …

- What if fraction of “local” or “disseminating” contacts is varied?

(Koopman, et al. 2002)

ODE and MC give different mean prevalence if…

… most contacts are local
… or local groups are small
Summary: Stochastic versus deterministic model types

- Markov chain behavior differs on two levels
  - Random outcomes
  - Long-run averages may differ! (local effects)

- Prevention:
  - Disseminating: municipal water treatment, SARS masks, vaccine
  - Local: hygiene in families, behavioral, vaccines

- “Best” depends on contacts
  - 10% decrease in disseminating contact reduces prevalence more than 10% decrease in local contact

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Discrete-event simulations of patients, resources, …

- Infection dynamics and scarce resources
  - vCJD transmission via surgical instruments, “usual” ODE models may not adequately model
    (i) stochastic contamination in small sets of instruments,
    (ii) instrument migration
    that strongly influence the outcomes of instrument replacement policies (Stevenson et al., http://www.nice.org.uk/guidance/IPG196)

- Smallpox preparedness
- Social networks?

Sensitivity analysis to model choice

- Outcomes & conclusions may depend upon the type of model, not just to parameters

- Stochastic effects and small or large numbers
- Operational constraints
- Systems view and nonlinear dynamics

parameter space
model type
model complexity
Conclusions

- **Modeling as decision support tool:**
  - The choice of model *can* influence estimated costs, benefits, and decisions

- **Modeling as science:**
  - Complete specification of specific model
  - Analysis to compare across model structures – sensitivity to model type?

- **Modeling as art:**
  - Wide palette of related models in our toolkit.