

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

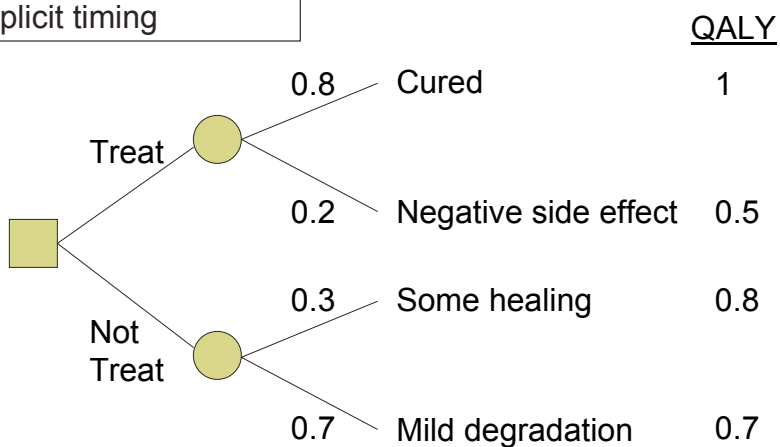
- ▲ Complexity aside, does choice of given type of model systematically influence decisions?
 - ▲ Brennan, Chick, Davies (2006), other examples

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*

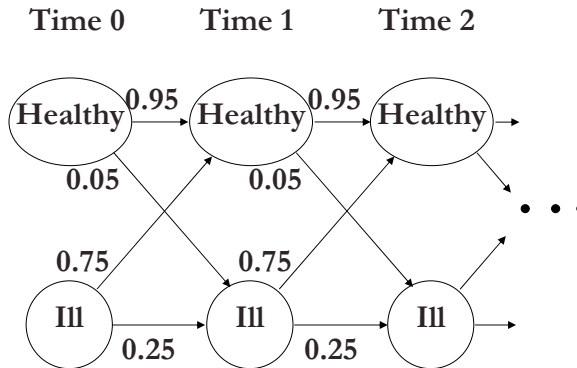
Decision Tree

Mean values
Independent outcomes
Implicit timing



Markov Model

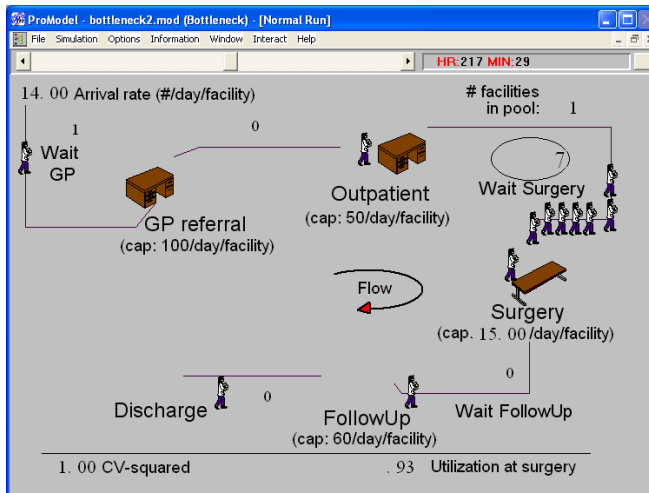
Stochastic cohort
Distributions
Timing



Discrete Event Simulation of Patients / Resources

Curse of dimensionality
Interaction, constraints

Rich randomness
Scheduling, operational...



Some Models

*Decision tree
(rollback)*

*Markov:
sample #
patients that
transition*

*Discrete
event
simulation*

Some Models

*System
dynamics
(ODE)*

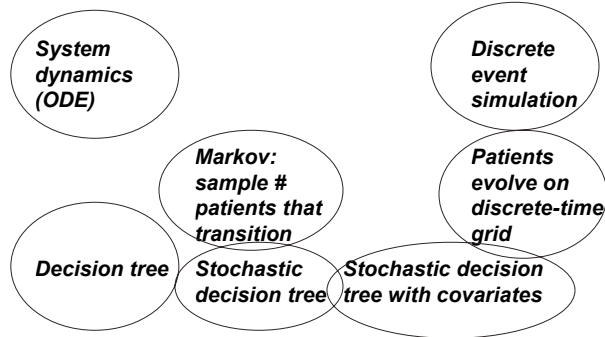
*Discrete
event
simulation*

*Markov:
sample #
patients that
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*Decision tree
(rollback)*

*Stochastic
decision tree*

Some Models



Model Hierarchy

	Aggregate level		Patient level	
	<i>Deterministic continuous state / mean value</i>	<i>Stochastic discrete counts</i>	<i>Stochastic Markovian individual</i>	<i>Stochastic general distribution individuals</i>
<i>Continuous time</i>	<i>System dynamics (ODE)</i>	<i>Stochastic Markov model (queue,...)</i>	<i>Patient-level simulation (interact)</i>	<i>Discrete event simulation</i>
<i>Discrete time</i>	<i>Finite difference model</i>	<i>Markov: sample # patients that transition</i>	<i>...</i>	<i>Patients evolve on discrete-time grid</i>
<i>Untimed</i>	<i>Decision tree</i>	<i>Stochastic decision tree</i>	<i>Stochastic decision tree with covariates</i>	

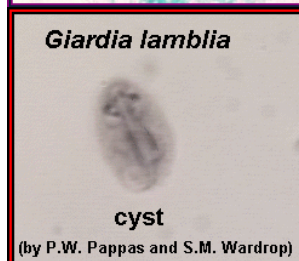
Timing / constraints

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 \Rightarrow 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?

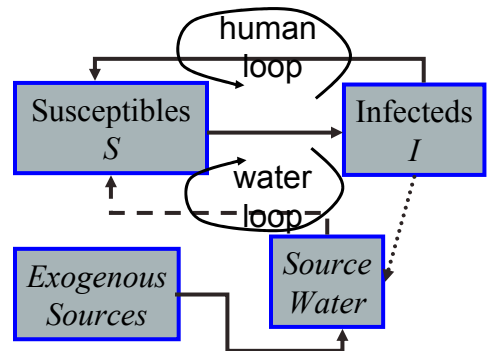
Simplified Transmission System: ODE Infection Transmission Model

▲ Infection dynamics

$$\begin{aligned} \frac{dS}{dt} &= -(\text{water} + \text{human loops}) \\ &\quad + \text{recovery rate} \\ &= -\left[r\phi W + c\beta \frac{I}{S+I} \right] S \\ &\quad + \frac{1}{D} I \end{aligned}$$

▲ Water contamination

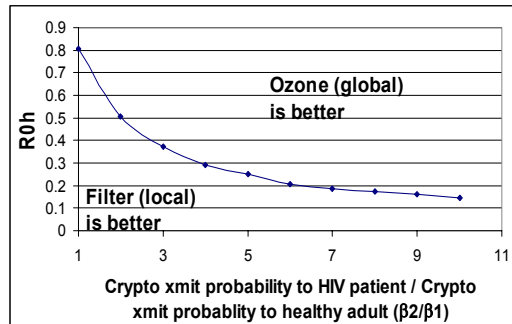
$$\frac{dW}{dt} = \gamma + \theta I - \alpha W$$



(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} = mean number secondary transmissions from human contact

Roadmap

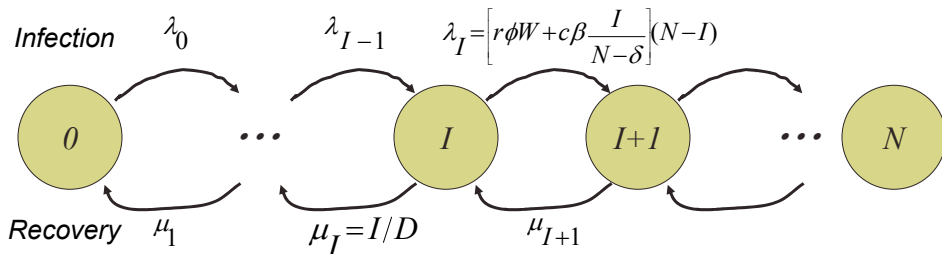
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Deterministic System Dynamics \Leftrightarrow Stochastic Markov Chain

▲ Deterministic System dynamics

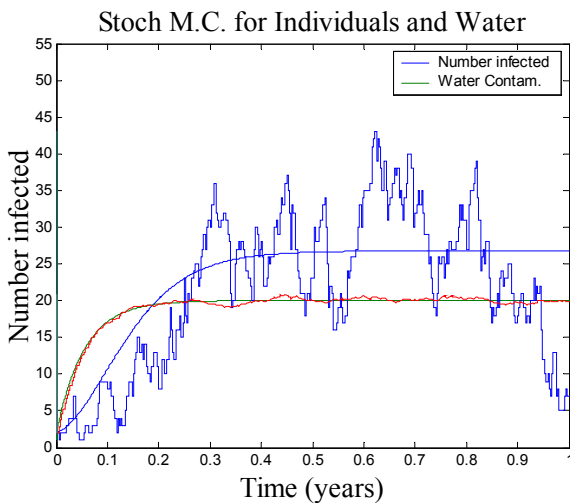
$$\begin{aligned} \frac{dI}{dt} &= - \text{recovery rate} + \text{infection rate} \\ &= -\frac{I}{D} + \left(r\phi W + c\beta \frac{I}{N} \right) (N - I) \end{aligned}$$

▲ Stochastic Markov chain: Variability



Stochastic Markov Chain

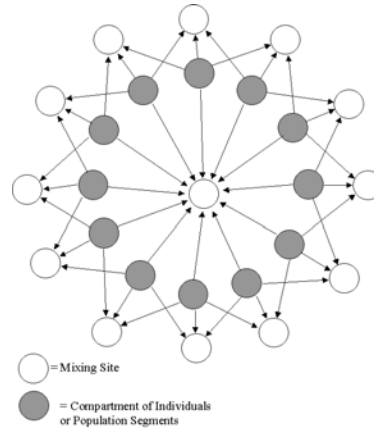
▲ “Shadow” count of # people, microbes, ...



▲ Apparent risk of local die-out of infection

Local and disseminating contact in NTHI model

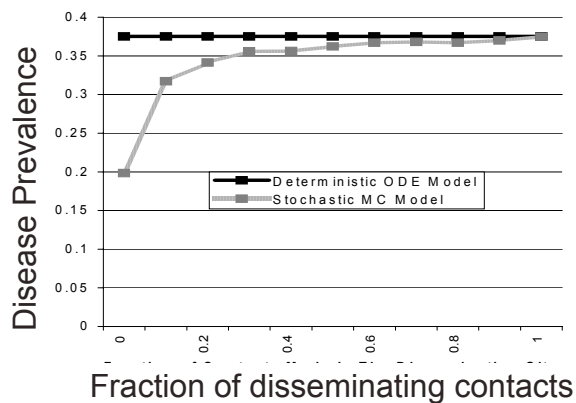
- Local:
 - Child care center room, family unit, classroom, small office, ...
- Disseminating:
 - Playground, contaminate source water, random mixing in street, ...
- What if fraction of “local” or “disseminating” contacts is varied?



(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

Roadmap

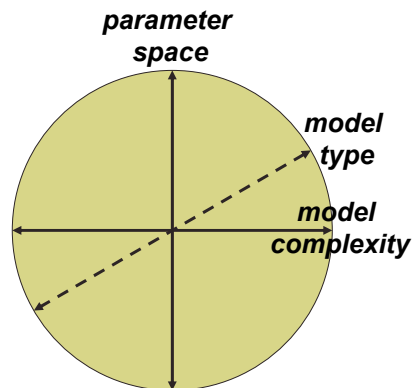
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Discrete-event simulations of patients, resources, ...

- ▲ 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 migrationthat 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

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.