Modelling and Simulation in Public Health

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My talk today

• Need for analysis

• Four modeling/simulation studies
  - Disease modeling: Hepatitis B control
  - Epidemic modeling: HIV prevention and treatment
  - Network modeling: HIV prevention in Africa
  - Logistics modeling: Bioterror preparedness

• Concluding thoughts
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Challenges in global health

• High childhood mortality
• Epidemics of infectious diseases
• Poor health infrastructure
• Limited access to care
• Limited funds for disease prevention and treatment
Challenges in U.S. health

- Deaths from chronic disease
- Very high spending ...
Challenges in U.S. health

- Deaths from chronic disease
- Very high spending ...

$1,400 for GM employee health care!
Challenges in U.S. health

- Deaths from chronic disease
- Very high spending ...
- and rapidly growing
Challenges in U.S. health

- Deaths from chronic disease
- Very high spending ...
- and rapidly growing
- Worse health outcomes than many countries
- Limited funds for disease prevention and treatment

Japan – 82 years
Sweden – 81 years
US – 78 years
Key questions

What services should we pay for?

Who should receive these services?

How can these services be delivered most efficiently?
Key questions

What services should we pay for?

Who should receive these services?

How can these services be delivered most efficiently?
How is public policy different?

• No single decision maker
• Profit maximization is rarely the objective
• Political, social, legal, ethical factors are often very important
• Often great uncertainty about outcomes
• Typically, great need for reasoned, quantified analysis!
Need for analysis

“If we can just prevent one person from getting infected with HIV, it will have been worth it.”

“To receive Homeland Security funds, our county must develop a disaster response plan.”
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Hepatitis B prevention and treatment

- Bloodborne viral disease
  - 400 million infections worldwide (vs. 33 million with HIV)
  - 1.5 million in US
- Chronic infection is asymptomatic, incurable, treatable
- Without treatment, 1 in 4 will die of liver disease
- Vaccine preventable
First hepatitis project

- Hepatitis B among Asian and Pacific Islanders in the US
  - 10% prevalence among APIs, 0.1% in general population
  - Ad-hoc screening programs
  - CDC needed guidance

What is the cost-effectiveness of alternative hepatitis B screening, vaccination, and treatment policies for adult Asian and Pacific Islanders in the US?
Decision model of policies

Decision model of policies

Screen, Treat, and Vaccinate

Universal Vaccination

No Screen

Screen

Uninfected

Infected

Immune

Treat

No Treat

Vaccinate

No Vaccinate

Markov model of disease progression
Markov model of HBV infection

Susceptible

Acute Infection

Immune

Chronic Infection

Elevated ALT

Treatment Response

Cirrhosis

Liver Cancer

Liver Transplant

Deaths
Model instantiation

- Excel spreadsheet
- Discrete time increments
- Cohort of individuals, simulated over their lifetime
- Useful outcome measures for policymakers
  - Discounted lifetime costs
  - Deaths averted
  - Quality-adjusted life years (QALYs) gained
  - Cost/QALY gained
Results: US

• Screening and treatment
  - Cost-effective

• Vaccination
  - Cost-effective for close contacts
  - NOT cost-effective for other adults
Dissemination and impact

- Shared results with US CDC
- CDC changed screening recommendations in September 2008
- New guidelines will help eliminate a major US health disparity
Second hepatitis project

• HBV in China
  - 140 million children unprotected
  - China’s CDC contemplating nationwide catch-up vaccination
  - Wanted evidence of benefit

What is the cost-effectiveness of hepatitis B catch-up vaccination for children and adolescents in China?
Decision model of policies

Screen and Vaccinate

Screen

Infected

No Vaccinate

Vaccinate

No Screen

Uninfected

No Vaccinate

Vaccinate

Immune

No Treat

Vaccinate

Similar Markov model of disease progression

M

M

M

M

M
Results: China

- Catch-up vaccination provides
  - Better health outcomes
  - Lower overall costs

- Highly robust to assumptions

- Screening before vaccination is not cost-effective
Dissemination and impact

- Numerous meetings with officials in China
- April 2009: China changed its policy to provide free catch-up vaccination to all school age children
  - Prevent ~70,000 deaths
  - Net savings of $900 million in healthcare costs
  - Reduce social injustice from discrimination
- Model for other countries with high HBV burden
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Global HIV epidemic

Funds for prevention and treatment are far less than estimated need.
Policy questions

- **3 million** new infections per year
  
  *What programs should we invest in to prevent the spread of HIV?*

- **70%** of eligible infected individuals do not receive treatment
  
  *How should we allocate scarce treatment funds?*

- For every person entering treatment, **3 new infections** occur
  
  *What is the appropriate allocation of resources between prevention and treatment?*
Region-specific epidemics

- Prevalence
- Incidence
- Transmission modes
- Risk groups
- Available funding
- Political, social, cultural factors
HIV control in Eastern Europe

- Rapidly growing epidemic
- Fueled by injection drug use
- Also spread sexually
- Minimal funds for prevention and treatment
- Limited access to HIV treatment (ART)

Now, significant scale up of ART and methadone programs

What is the appropriate investment in methadone treatment vs. ART, given limited funds?
Evaluating control policies

Epidemic simulation model to evaluate costs and health outcomes for methadone expansion, ART expansion, or both.
Model instantiation

- Excel spreadsheet
- Discrete time increments, 20-year time horizon
- Calculate
  - Discounted net present costs of healthcare, methadone, ART
  - Discounted quality-adjusted life years (QALYs) experienced
- Calculate incremental cost-effectiveness ratios
  - Discounted cost/QALY gained
Results

- Excluding IDUs from ART and methadone is never effective
- Methadone and ART are both are cost effective, but methadone is more cost effective
- Treatment should be scaled up *in addition to* methadone
Dissemination and impact

- Will publish paper in a medical journal
- Will present results in Russia in May
- Results are applicable to the mixed HIV epidemics in Eastern Europe and Central Asia
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HIV in sub-Saharan Africa

- Sub-Saharan Africa accounts for 67% of global HIV cases.
- 1.9 million new HIV infections in 2007.
- Spread primarily via heterosexual contact.
- HIV/AIDS is avoidable & preventable. Abstain or Practice Safe Sex.
HIV prevention in Africa

• ABC Campaigns: Abstinence, Be faithful, Condom use

• Significant number of concurrent sexual partners in Africa

• Nationwide campaigns to reduce concurrency
Uganda's campaign

You might want the phone, meals out and fancy clothes...

...but do you need HIV?

You might want these material things...

...but do you need HIV?

Say no to Sugar Daddies.
Botswana’s campaign
Zambia’s campaign

More than one partner means many routes for HIV to travel. Your sexual network may be bigger than you think.

Do you know your sexual network?
Policy question

What is the effectiveness and cost-effectiveness of changes in concurrent partnership behavior in reducing the spread of HIV?
Model overview

- Simulation model of HIV spreading over a dynamic sexual partnership network
- Model has two parts
  - Sexual partnership network model
  - HIV disease microsimulation model
- Measurement of net present costs, quality-adjusted life years experienced
Evaluating concurrency reduction

Simulation of disease progression in each person

Network simulation model to evaluate costs and health outcomes
Partnership network model

- We model only partnerships between men and women
- Two types of partnerships
  - Spousal (only 1, long duration)
  - Non-spousal (multiple, short duration)
- We model partnership formation and dissolution (tricky)
HIV disease model

- Uninfected
- Acute HIV+
- HIV+ after 1 month

- Treatment initiated when CD4 < 200
- No access to treatment

- HIV+, with $T_x$
- HIV+, without $T_x$

Individuals’ characteristics:
Age, gender, HIV disease state, CD4 count
Model instantiation

- Matlab program
- Population of ~10,000 individuals
- Simulated in 1-month increments over 10 years
- Calculated a variety of outcomes
  - Deaths (from HIV, from other causes)
  - HIV incidence
  - HIV prevalence
  - Costs
Results

• Greatest number of infections are prevented by reducing concurrency among high-risk individuals

• … but concurrency reduction in other risk groups yields nearly as much benefit

• Complete elimination of concurrency will not stop HIV transmission

• Complementary HIV prevention programs are essential
Dissemination and impact

- Work is ongoing
- Will implement model with data from a national concurrency prevention program
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Bioterrorism preparedness

• Local health departments must plan for response to potential bioterror attacks

• No agreement on many important decisions
  - How much inventory to stockpile
  - How many dispensing centers are needed
  - Etc.
What is the effectiveness and cost-effectiveness of alternative policies for inventorying, distributing, and dispensing antibiotics, under different attack scenarios?
Evaluating preparedness plans

• Focus on one type of attack: anthrax

• Developed model of anthrax response supply chain

• Developed dynamic model of progression of anthrax in a population, given available antibiotic supplies, hospital beds, etc.

• Simulated alternative policies for inventorying, distributing, and dispensing antibiotics
Bioterror Attack

Exposed Population

Local Dispensing Sites

Local Hospitals

Local Inventories

Strategic National Stockpile
Bioterror Attack → Exposed Population → Local Dispensing Sites → Local Hospitals → Push Packs → Local Inventories → Vendor Managed Inventories
To what extent will quicker attack detection save lives?
What is the effect of large numbers of exposed and unexposed individuals requiring prophylaxis?
How much dispensing capacity should local communities have?

- Bioterror Attack
- Exposed Population
- Local Dispensing Sites
- Local Inventories
- Push Packs
- Vendor Managed Inventories
- Local Hospitals

How much dispensing capacity should local communities have?
How much inventory of medical/pharmaceutical supplies should be held locally vs. regionally?
How much should hospital capacity be enhanced via mutual aid agreements?
Dynamic model of disease progression, requests for prophylaxis

Queues for prophylaxis and treatment

DEATHS 🍀

RECOVERY ☀️

Population of exposed and potentially exposed individuals

Queues for prophylaxis and treatment

Model of available inventory, dispensing capacity, hospital capacity

Local Hospitals

Local Inventories

Vendor Managed Inventories

Push Packs

Local Dispensing Sites
Dissemination and impact

- Simulation-based scenario planning tool (Excel)
- Shared model with our local public health department
- Advisory group to the CDC Coordinating Office on Terrorism Preparedness and Response
  - Strategies for positioning and deploying the Strategic National Stockpile
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“You’re one tough cookie,” she said.
“You don’t learn fast, but you do learn.”
Concluding thoughts

• Many important decisions in public health could benefit from model-based analysis

• Elements of a successful analysis
  - Interdisciplinary collaboration
  - Focus on identifying good policies, not on developing overly sophisticated models
  - Dissemination of results to policy makers
Thank You

www.stanford.edu/dept/MSandE/people/faculty/brandeau/index.html