Designing and Evaluating Disease Control Policies

CS: 4980 Spring 2020

Tue, March 31st

Where we are in the course

- **Part I**: Models (e.g., compartmental models, contact network models) and disease dynamics
- **Part II**: Inference problems (e.g., inferring disease parameters, inferring patient zero, inferring asymptomatic spreaders, etc.)

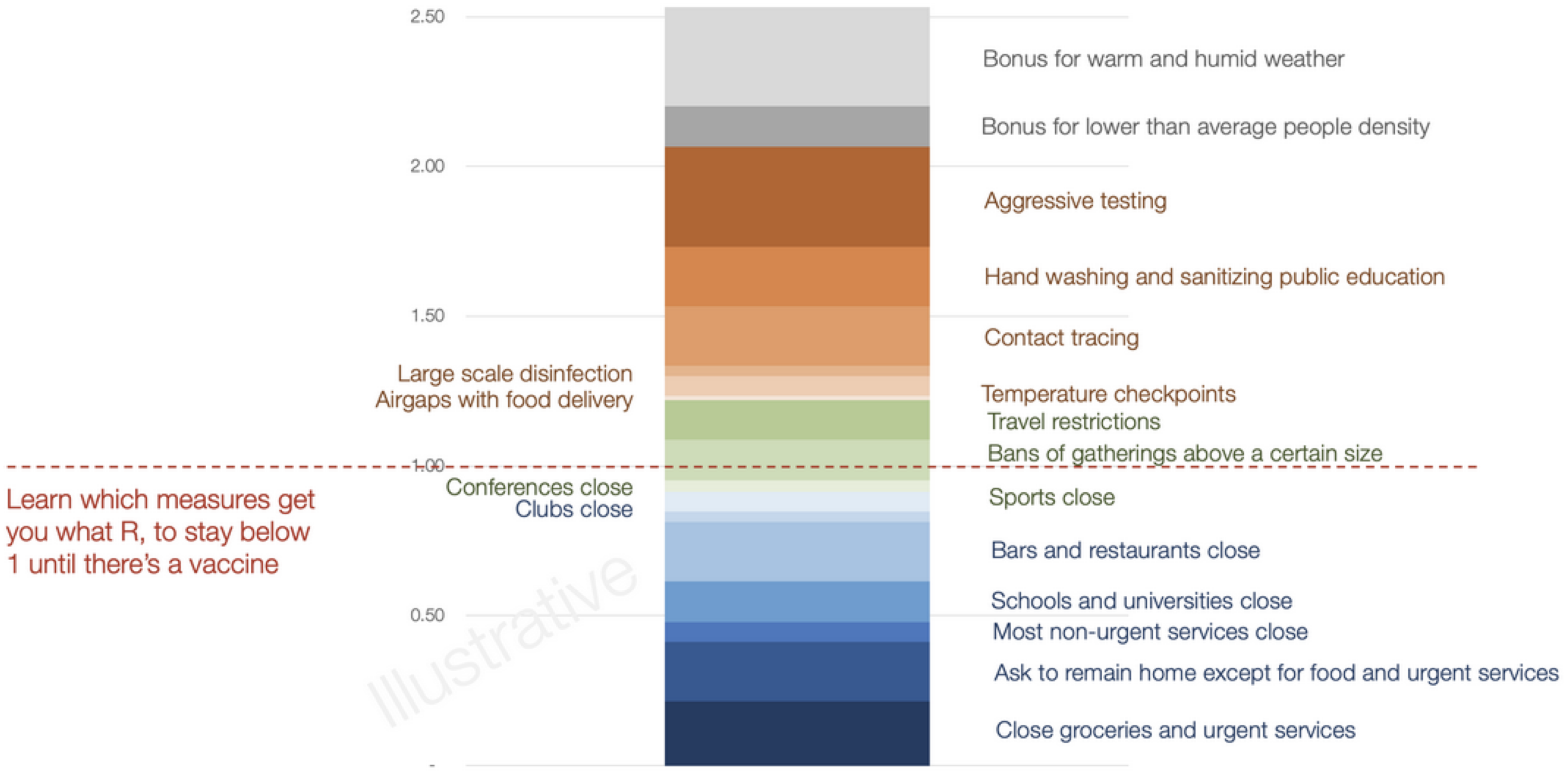
- **Part III**: Designing and Evaluating Disease Control Policies

Examples of Disease Control Policies

- Social Distancing, including closing of schools, banning of large gatherings, closing country borders, banning travel, etc.
- Quarantining and Isolation
- Hand washing, use of personal protective equipment (PPEs) (e.g., masks)
- The use of antivirals
- Vaccinations
- Surveillance

Chart 15: Building Up to R = 1

*Illustrative Example of How Politicians Could Make Decisions during the Dance Phase**



Source: Tomas Pueyo

Note: None of these numbers are known today. But in one month, we might have enough data to quantify them. Furthermore, this graph suggests that these measures add up, when in fact they don't. For example, mandating at least 2m of distance between people would capture much of the benefit of other social distancing measures

But Disease Control is not free!

Often disease control involves allocation of *limited* resources.

Who: If we allocate resources in one location (or to one group of individuals), we may not have resources available for other locations/groups.

When: If we allocate resources now, we may not have resources available for later, when we might have more information.

Limited Resources

Hospital Beds, Ventilators, and Respirators

CDC Centers for Disease Control and Prevention
CDC 24/7: Saving Lives, Protecting People™

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Coronavirus Disease 2019 (COVID-19)

How to Prepare +

Strategies for Optimizing the Supply of N95 Respirators: Crisis/Alternate Strategies

https://www.cdc.gov/coronavirus/2019-ncov/hcp/respirators-strategy/crisis-alternate-strategies.html

Optimization problems

- Problems of allocating limited resources can be modeled as *optimization problems.*

- Features of optimization problems
  - **Choice variables**: variables to which we must assign values.
  - **Objective function**: a function of the choice variables that needs to be minimized or maximized.
  - **Constraints**: Constraints on the values the choice variables can take.

Example: Vaccine Allocation problem

Input: Contact network $G = (V, E)$, vaccination budget $B > 0$

Choice variables: $x_v \in \{0, 1\}$ for each $v \in V$ (x_v indicates if individual v is to be vaccinated.)

Possible objective function: Expected number of individuals infected by an infection (e.g., SIR model) that starts at a random individual and spreads on G with *vaccinated individuals removed*.

Constraints: $\sum_{v \in V} x_v \leq B$ (number of vaccines cannot exceed the budget)

Reading [1]

PLOS ONE

RESEARCH ARTICLE

Healthcare Worker Contact Networks and the Prevention of Hospital-Acquired Infections

Donald E. Curtis, Christopher S. Hlady, Gaurav Kanade, Sriram V. Pemmaraju, Philip M. Polgreen, Alberto M. Segre

Published: December 30, 2013 • https://doi.org/10.1371/journal.pone.0079906

Results section: read the subsection on “Design of Effective Vaccination Policies” (Figures 4 and 5).
Discussion section: read the subsection on “Modeling vaccination policies and their effectiveness” (Figure 6)

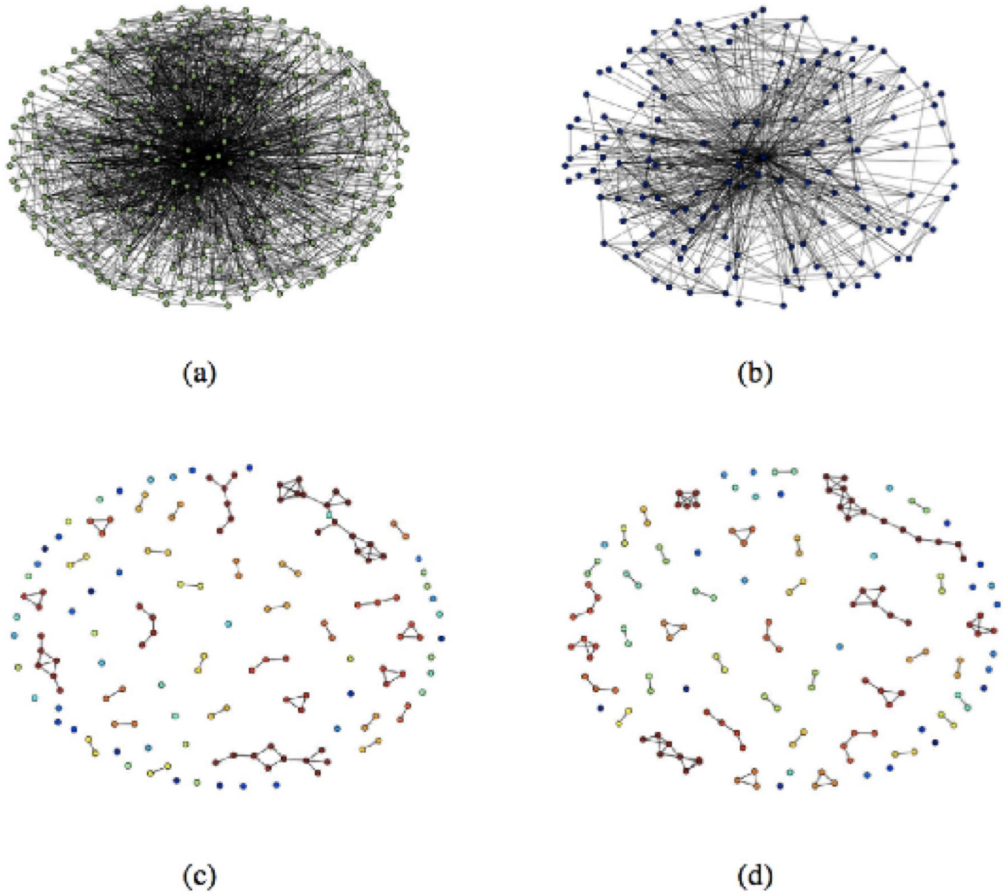
Effects of deleting nodes [1]

Recall: HCW login network constructed from Electronic Medical record (EMR) login data from the UIHC (a).

(b) 50% of nodes are chosen at random and deleted.

(c) 50% of nodes with highest degrees are chosen and deleted.

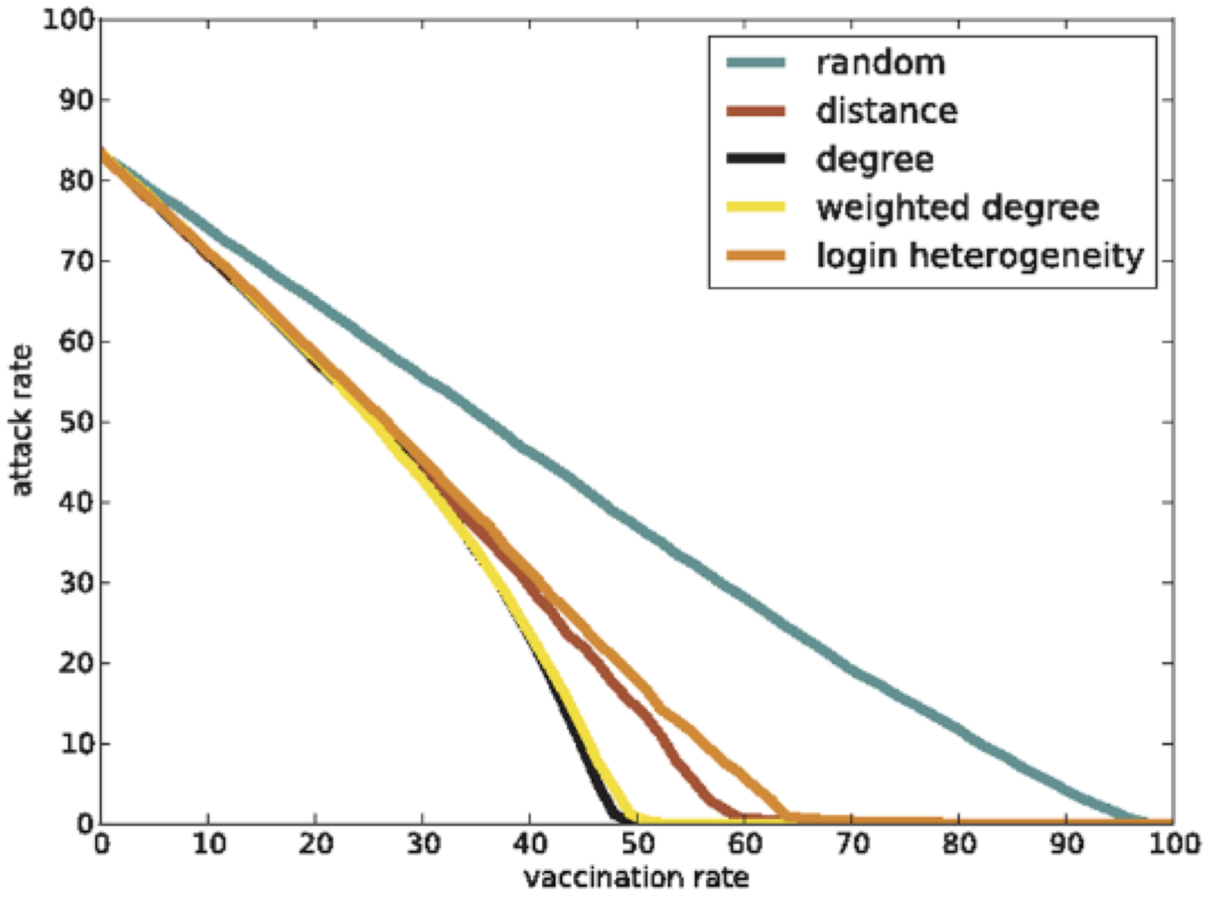
(d) 50% of nodes with highest distance traveled are chosen and deleted.



Effects of vaccination policies [1]

- We simulate the SIR model on HCW login contact network using influenza parameters.

- **Login heterogeneity policy**: vaccinate individuals in decreasing order of number of distinct computers they have logged into.



Further work

- Include patients.
- How does the fact that this login network is just a “sample” of the actual contact network, affect results? How should we include missing HCWs and missing edges into this model?
- Use the SEIR model and COVID-19 parameters.

Reading [2]

TUTORIALS IN
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Mathematical Approaches to Infectious Disease Prediction and Control

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Read: Section 6 “Disease Control”

Recall the SIR model equation

$$E[I(t+1)] - I(t) = \frac{\beta\, S(t)\, I(t)}{N} - \gamma\, I(t) - \mu\, I(t)$$

β: prob. contacting/infecting, γ: prob. recovering , μ: prob. dying

Goal: To ensure $\frac{\beta\, S(t)\, I(t)}{N} - \gamma\, I(t) - \mu\, I(t) < 0$. ("Bend the curve")

Equivalently,

$$\frac{\beta\, S(t)}{N\,(\gamma + \mu)} < 1$$

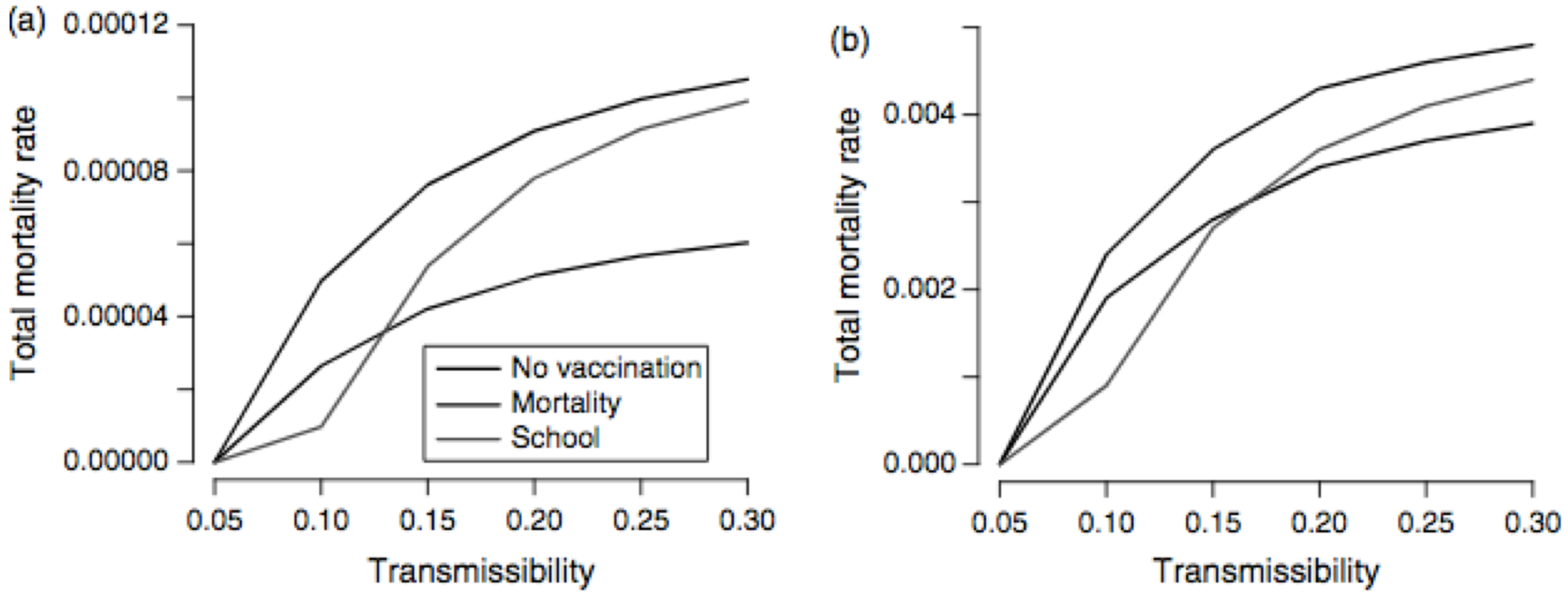
Connecting parameters to policies

$$\frac{\beta\ S(t)}{N\ (\gamma +\ \mu)} < 1$$

- **Reducing $\boldsymbol{\beta}$**: social distancing, hand washing, masks
- **Reducing $\boldsymbol{S(t)}$**: vaccinating
- **Increasing $\boldsymbol{\gamma}$**: administering anti-microbials
- **Increasing $\boldsymbol{\mu}$**: we won't discuss this for humans, but it has been used on cattle during the mad-cow disease.

Example from Reading [2]

FIGURE 8. Prioritizing flu vaccines under limited supplies.



(a) Seasonal flu model in which high-risk groups = {infants, elderly}, (b) 1918–1919 flu: adults have the highest mortality rates followed by infants.

In both cases, top curve = no interventions, middle curve (for small Trans.) = vaccinations prioritized for high-risk groups, bottom curve (for small Trans.) = vaccinations prioritized for school children.

Topics

- How to model disease-control problems as optimization problems, both in compartmental and contact network models?

- How to algorithmically solve these problems, given that they are usually NP-complete?

- **Example problems**: vaccination allocation, locating sentinel sites for surveillance.