Modeling a Within-School Contact Network to Understand Influenza Transmission

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http://arxiv.org/PS_cache/arxiv/pdf/1109/1109.0262v2.pdf

Background

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- Many influenza simulation models assume random mixing within mixing groups.
  - Within school
  - Within grade
- Schools are known to be a primary mechanism for influenza spread.

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We create a detailed contact network model based on friendship and contact data and perform simulations to answer these questions.

The National Longitudinal Study of Adolescent Health (Add Health)

- Representative sample of 80 high schools and 52 feeder schools in U.S. during 1994-95 school year
- We analyze data from one high school+feeder school combination.
- Students were given a school roster and identified up to 5 best male friends and 5 best female friends.
- We assume two students are friends if an un-reciprocated or reciprocated nomination occurred.
- We treat the friendship network data as complete (n=1074).

http://www.cpc.unc.edu/projects/addhealth
Carolina Population Center, University of North Carolina

Friendship-based contact network model

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  - Students are more likely to contact their friends.
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We supplement the Add Health data with a survey of contact behavior in schools to create a model capturing these two tendencies.

Social Contact Survey Data

A Survey on Epidemics in High Schools

- Survey administered in two Virginia high schools (2009)
  - 200 of 400 students surveyed
  - 120 of 1,000 students surveyed
- By a "contact," we mean being in close proximity for more than roughly five minutes.
  - Average number of contacts during each break between classes
  - Average number of contacts during lunch break
  - Percentage of contacts during school hours to friends

Huadong Xia, Jiangzhuo Chen, Madhav V. Marathe and Henning S. Mortveit, (2010). *Synthesis & Embedding of Subnetworks for Individual-based Epidemic Models.* NDSSL Technical Report 10-139.

Modeling the contact network

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- Define a "contact" to be a 10-minute face-to-face social contact.
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- Assume 7 classes (40 mins), 1 lunch break (50 mins), and 5 non-lunch breaks of 10 minutes each.
- The maximum number of contacts between any pair is 38.

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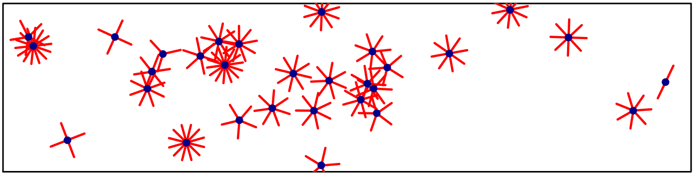
2. Model the contact network conditional on the friendship network.
    - Break/lunch contact network
    - Class contact network

Modeling break and lunch contacts

Definition: degree = number of contacts a student makes

- Let D_{bl} denote the vector of break/lunch contact degrees.
- Let Y_{bl} denote the sociomatrix of break/lunch contacts.
- $\mathrm{P}(Y_{bl} = y_{bl}) = \sum_{d_{bl}} \mathrm{P}(Y_{bl} = y_{bl} | D_{bl} = d_{bl}) \mathrm{P}(D_{bl} = d_{bl})$



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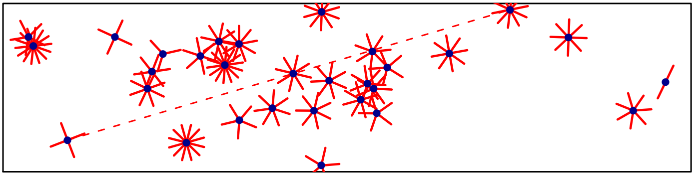

Modeling break and lunch contacts

- Model the break/lunch contact degree distribution by fitting negative binomial distributions to contact survey.
- Distribute 68% of contacts between friends

We use a similar approach to model the class contact network, but 50% of contacts are to friends.

Model Selection

- Dynamic contact network

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Influenza Simulations

- Incubation period has 2, 3, or 4 days with probability 0.3, 0.5, and 0.2.
- Infectiousness is proportional to viral load (sampled from challenge study data).
- 67% of infected students become symptomatic.
- 75% of symptomatic cases withdraw to home:
  - 20% on first day
  - 40% on second
  - 15% on third

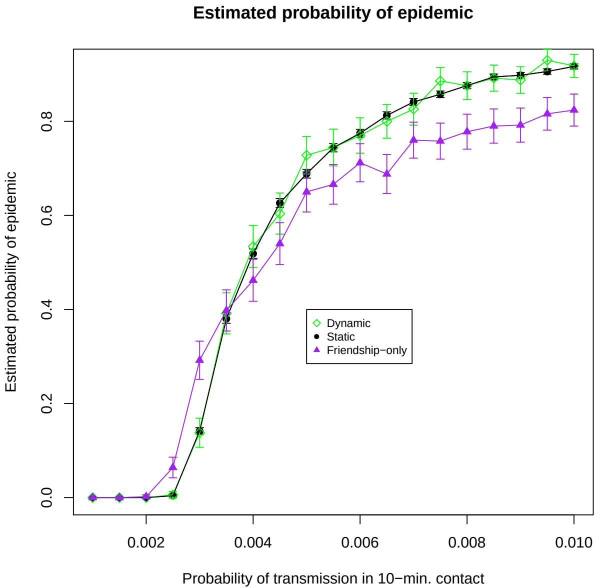
Chao, DE, Halloran, ME, Obenchain, VJ, and Longini, IM, (2010). "FluTE: a publicly available stochastic epidemic simulation model." *PLoS Computational Biology* vol.6, no.1

Influenza Simulations

- p_{ti} = per-10-minute transmission probability of person i on day t
- Y_{ij} = number of contacts between i and j on day t

$$\mathrm{P}(i \text{ infects } j \text{ on day } t) = 1 - (1 - p_{ti})^{Y_{ij}}$$

Comparison of three network models



Model Selection

- Dynamic contact network
- Static contact network
- Friendship-only network
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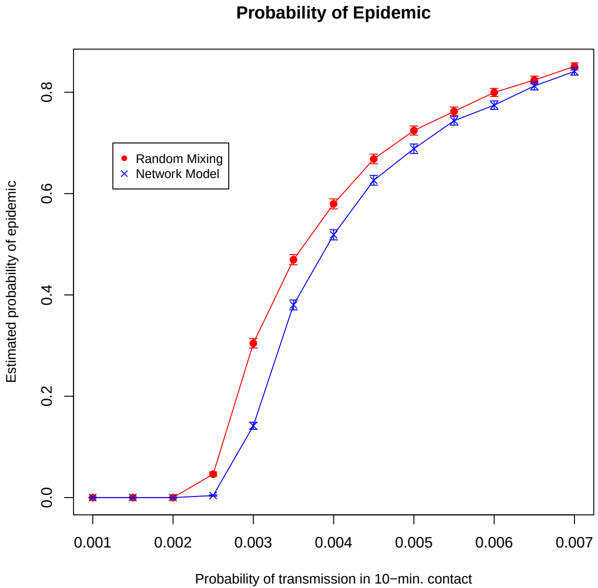
Influenza Simulations: Random Mixing

- Compare disease simulations over the contact network to those over a random mixing scenario.
- Calibrate so that the expected number of schoolmates contacted, as well as the total number of contacts, are the same in both models.

Influenza Simulation Results



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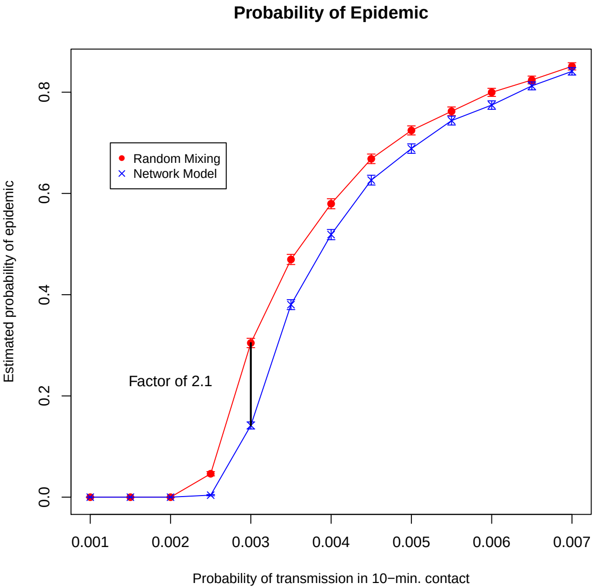

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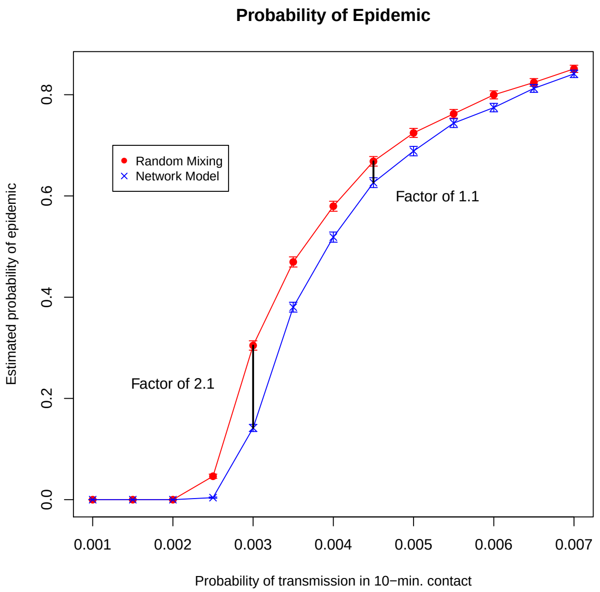

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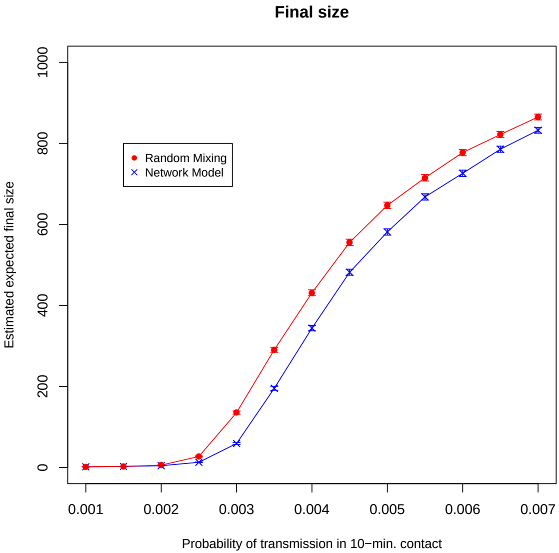

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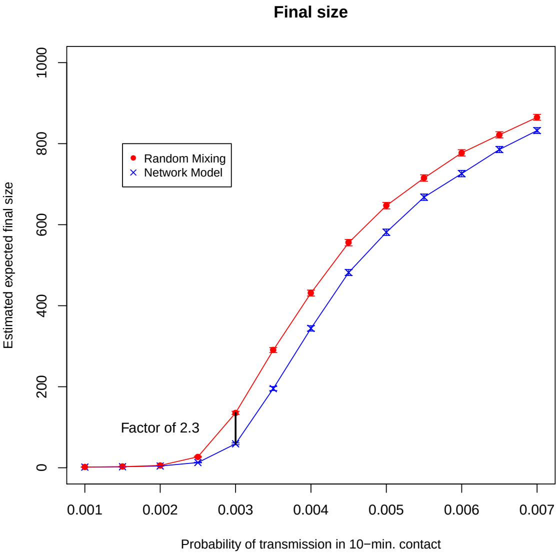

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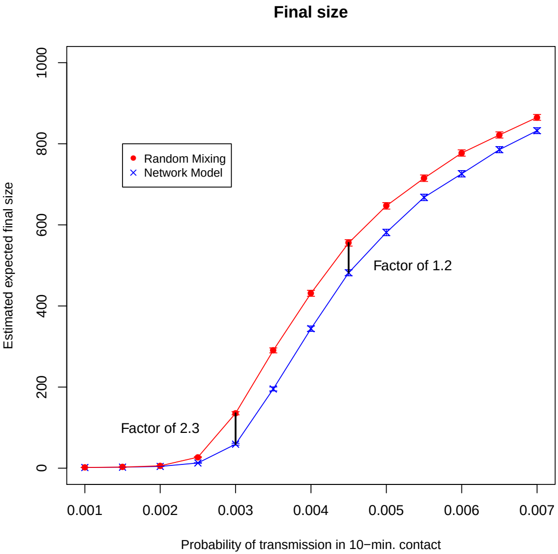

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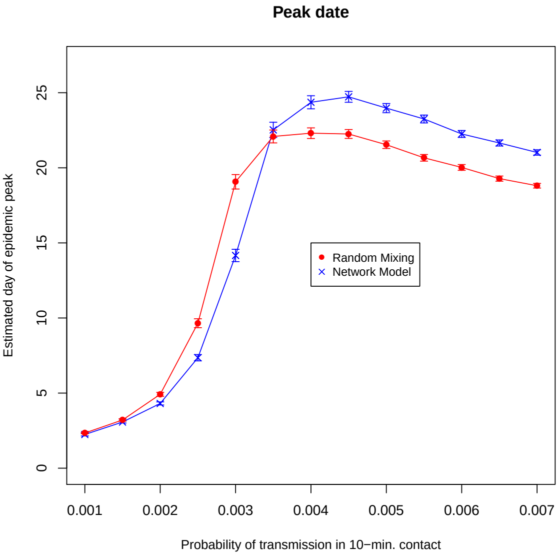

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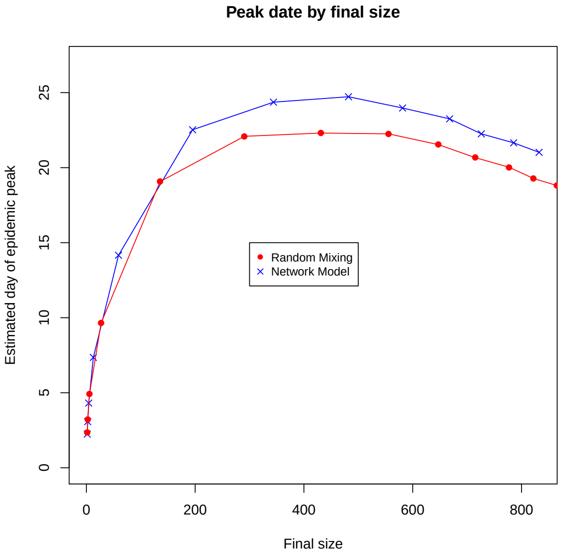

Intervention simulations

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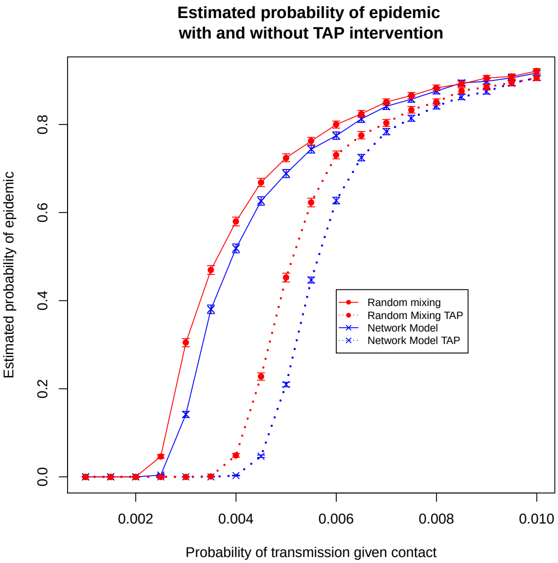
  - Assume 67% of infected students are symptomatic.
- Targeted antiviral prophylaxis
  - Symptomatic students receive 5 days of treatment; their contacts receive 10 days of prophylaxis.
  - Assume $AVE_S = 0.63$, $AVE_I = 0.15$, $AVE_P = 0.56$

Halloran ME, Hayden FG, Yang Y, Longini, IM, Monto, AS (2007) *Antiviral Effects on Influenza Viral Transmission and Pathogenicity: Observations from Household-based Trials.* American Journal of Epidemiology 165(2): 212-221

TAP Intervention Results



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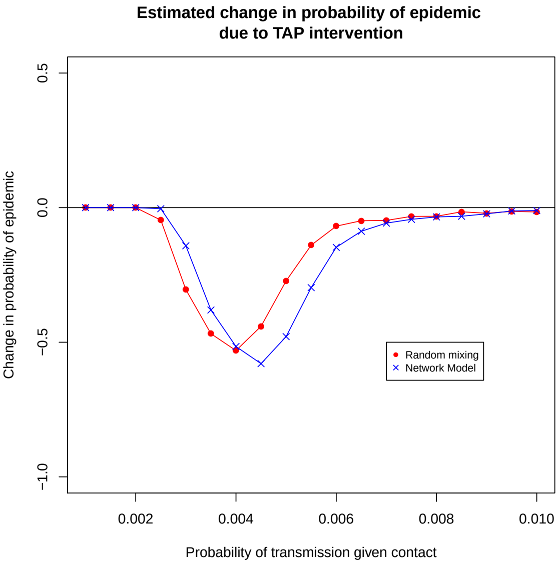

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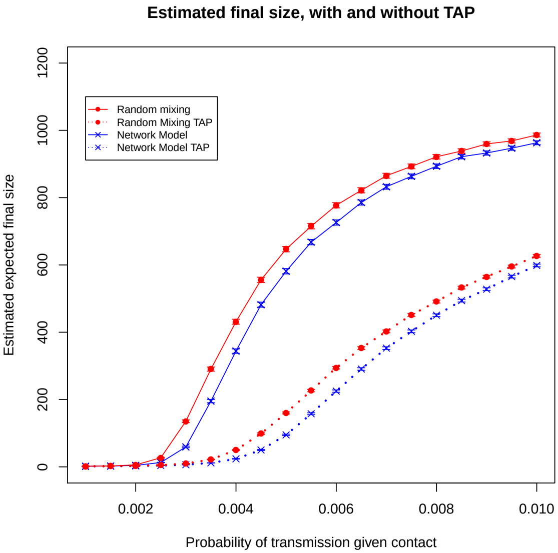

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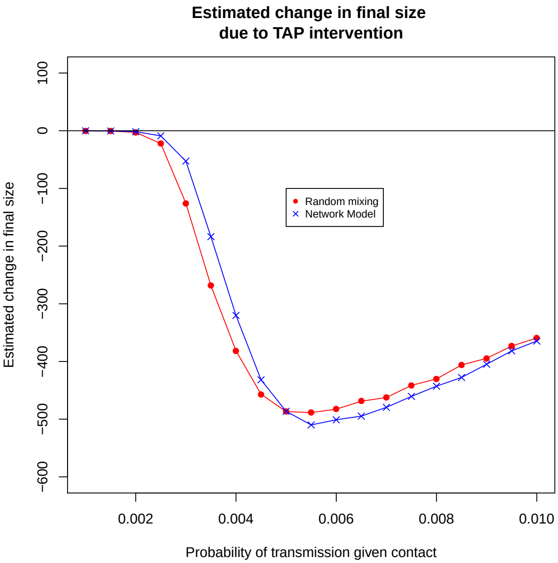

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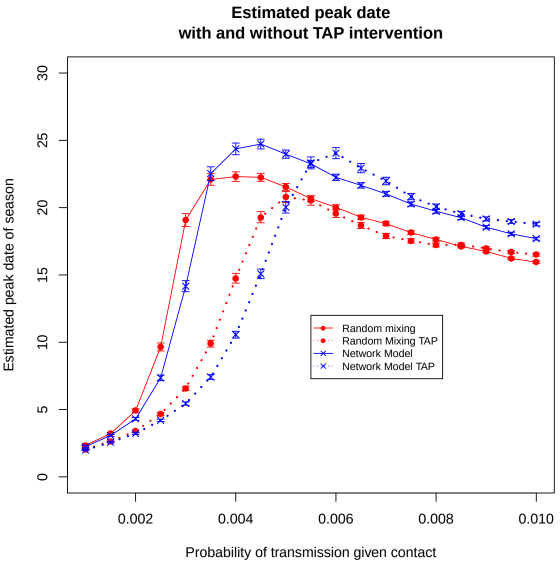

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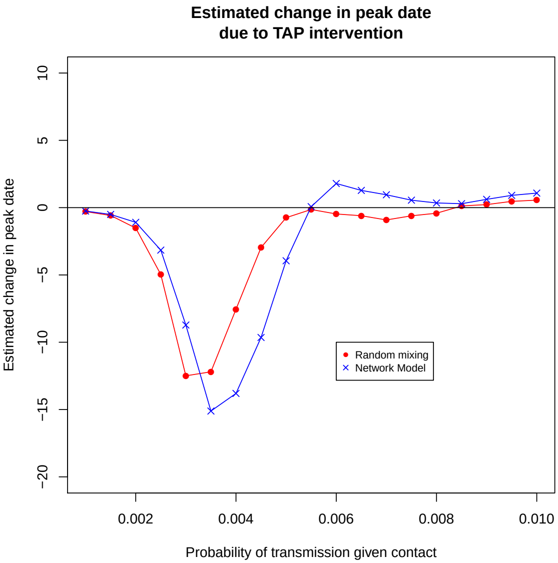
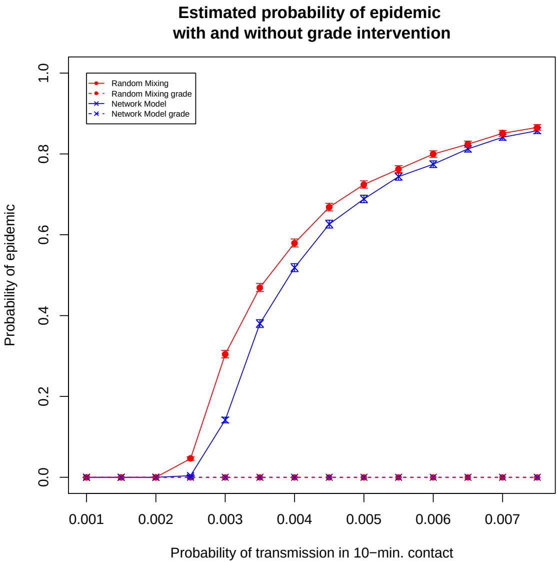


Grade Closure Intervention Results



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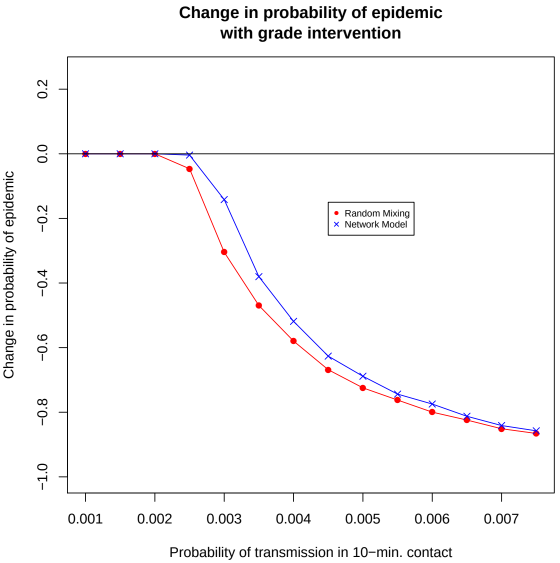

Limitations

- Measurement error in reports of "average number of contacts."
- Within-classroom contact frequencies not informed by data.
- We assumed perfect observation of symptoms and perfect reporting of contact behavior.
- We treated the Add Health friendship network data as a complete network.
- Model is for within-school contacts only. Friends may contact each other outside school.

Conclusions

- We developed a data-driven model of contact behavior in a school.
- Model allows us to estimate epidemic parameters and estimate the effectiveness of interventions.
- Epidemic outcomes, with and without interventions, differ substantively from a random mixing scenario.
- The dynamic contact network model and static contact network model produced identical epidemic predictions.

We recommend further exploration of contact network structure with the aim of improving existing simulation models.

Acknowledgments

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- CSQUID (Center for Statistics and Quantitative Infectious Disease)
- UW Social Network Modeling Group (Martina Morris and Steven Goodreau, PIs)
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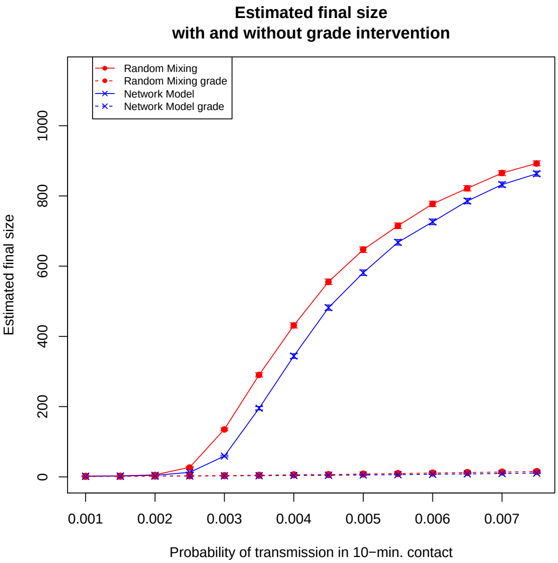

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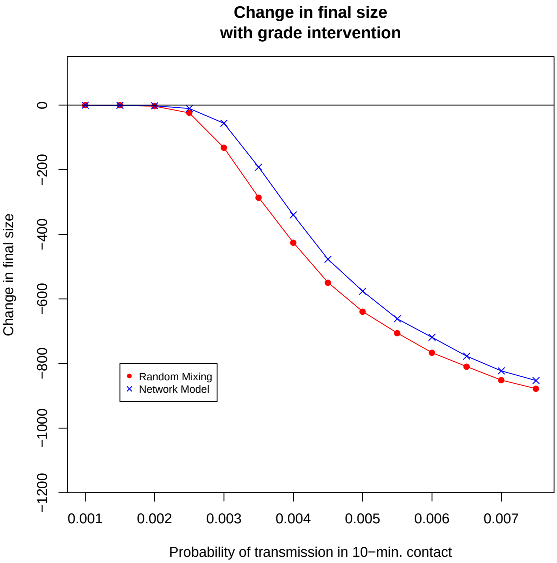

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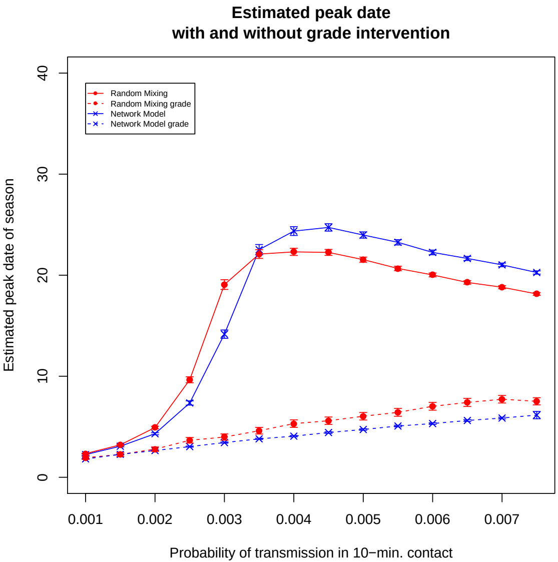

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