Advanced Scientific Computing Research
Applied Mathematics
FY 2007 Accomplishment

"Choosing the best strategy to control epidemics"

Joel C. Miller
Los Alamos National Laboratory

Summary

We have developed techniques to calculate the size and probability of epidemics in a population in which the number of contacts is heterogeneous, the infectiousness per contact of individuals is heterogeneous, and the susceptibility per contact of individuals is heterogeneous. Our results give insight into the relative benefits of control strategies which achieve only partial coverage. We find that it is preferable to stop a small outbreak through measures targeting infected individuals, such as contact-tracing. However, if the outbreak is already large, the size is best controlled by measures targeting susceptible individuals, such as mass vaccination.

Outbreaks of infectious disease remain a threat to society. In some countries the adult prevalence of HIV is over 20%. Concurrently, malaria infects hundreds of millions annually worldwide, killing over a million, mostly young children. These diseases contribute to political and economic instability in many areas of the world.

In the first world, these diseases pose a lesser threat. However, the rapid emergence and spread of SARS shows our transportation system is highly effective at dispersing diseases. Other new diseases such as avian influenza could spread as quickly.

In designing control strategies, we inevitably face limited resources. Vaccines, education, or other protective measures do not reach the entire at-risk population. Similarly, some infected people receive limited or no treatment. Consequently some people are more susceptible or infectious than others.

Two questions arise: The first is "does the heterogeneity have any impact on the course of the outbreak?" If not, our models may safely use an average value. The second question is "if there is an effect, can we use it to our advantage?" If so, we can better allocate resources.

Our research shows that strategies with the same average effect on the *transmissibility*, the probability that a contact between an infectious and susceptible person spreads disease, have differing impacts on the size or probability of an epidemic. Heterogeneities in infectiousness reduce the probability of an epidemic while heterogeneities in susceptibility reduce the size of an epidemic if it happens. This suggests that to prevent an epidemic, a strategy which significantly reduces infectiousness for a moderate fraction of the population is more likely to prevent an epidemic than a strategy which moderately reduces the infectiousness of a

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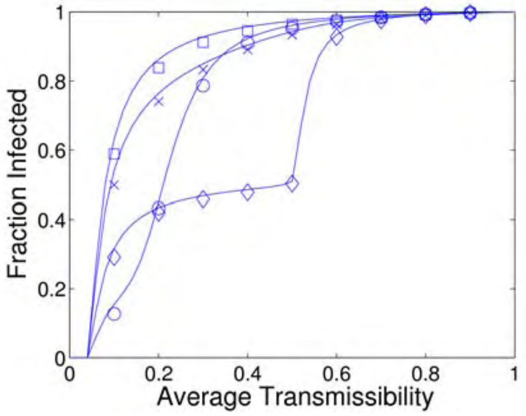
[*] 505-606-2051, jomiller@lanl.gov LA-UR-06-8193

large fraction of the population. Similarly a strategy which significantly reduces the susceptibility of a moderate fraction of the population reduces the size of an epidemic more than a strategy which is moderately effective for a large fraction of the population.

These observations can be understood through the following scenario: consider a disease for which infected individuals infect all contacts. Such a disease spreads widely, eventually infecting the entire population. If we reduce the transmissibility by half, then about half of the contacts of the first individual are infected, and they in turn spread the disease to half of their contacts. The outbreak quickly becomes an epidemic. Eventually each susceptible person comes into contact with many infected people, and is very likely to be infected eventually. In contrast, if half of the population has its infectiousness reduced to zero, the transmissibility has the same average, but with probability 0.5, the first infection spreads to no-one and an epidemic does not occur. Similarly, if half of the population has its susceptibility reduced to zero, then the epidemic spreads through the remainder of the population, but will not reach any of the protected people.

We caution that these comparisons are for strategies which have the same average effect. Clearly the average impact on the spread of malaria from giving two bed nets to one child is less than that of giving a bed net to each of two children. More careful consideration must be given to strategies which have different average effects and different levels of heterogeneity.



A comparison of size from simulations (symbols) in the EpiSimS Portland network with predictions (curves) for various types of heterogeneities in susceptibility.

To test our results, we consider the spread of diseases on the EpiSimS network, used to model the interactions of people in Portland, Oregon. We consider a number of different distributions of infectiousness and susceptibility and find good agreement between theory and simulation in the figure.

Full details have been published in *Physical Review E*, Vol 76, 010101, 2007.

For further information on this subject contact:

Dr. Joel C Miller
Los Alamos National Laboratory
jomiller@lanl.gov
505-606-2051

Or

Dr. Anil Deane
Applied Mathematics Research Program
Office of Advanced Scientific Computing
Phone: 301-903-1465
deane@ascr.doe.gov