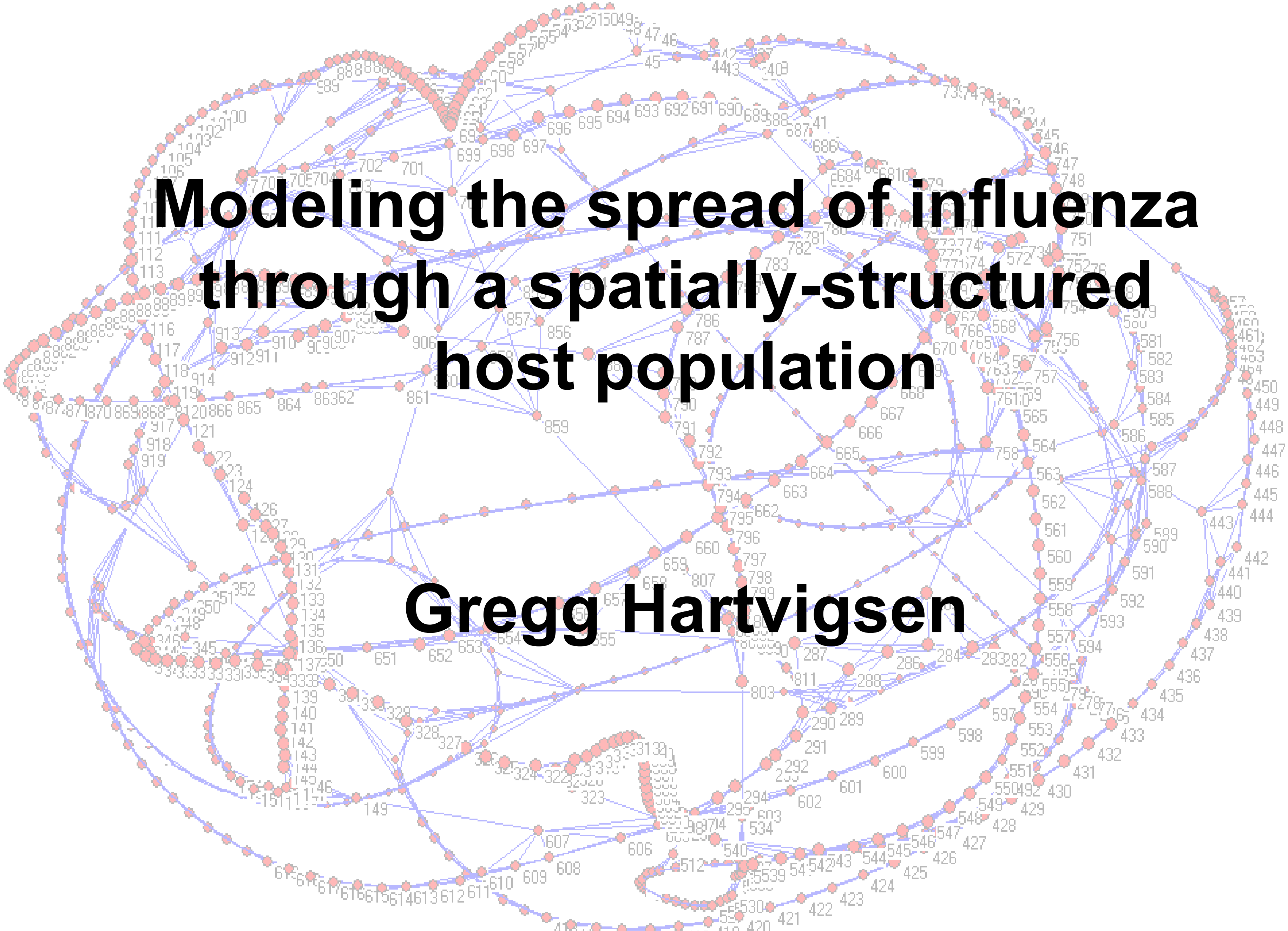
Modeling the spread of influenza through a spatially-structured host population

Gregg Hartvigsen



Thursday, February 24, 2005
Posted: 1324 GMT (2124 HKT)

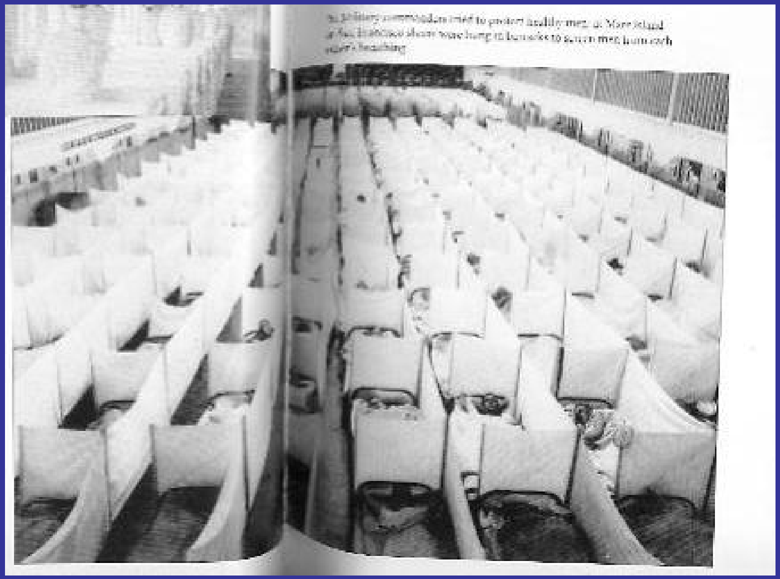
VATICAN CITY (CNN) -- Pope John Paul II has been rushed to hospital by ambulance after suffering a recurrence of the flu that forced him to be hospitalized for 10 days earlier this month.

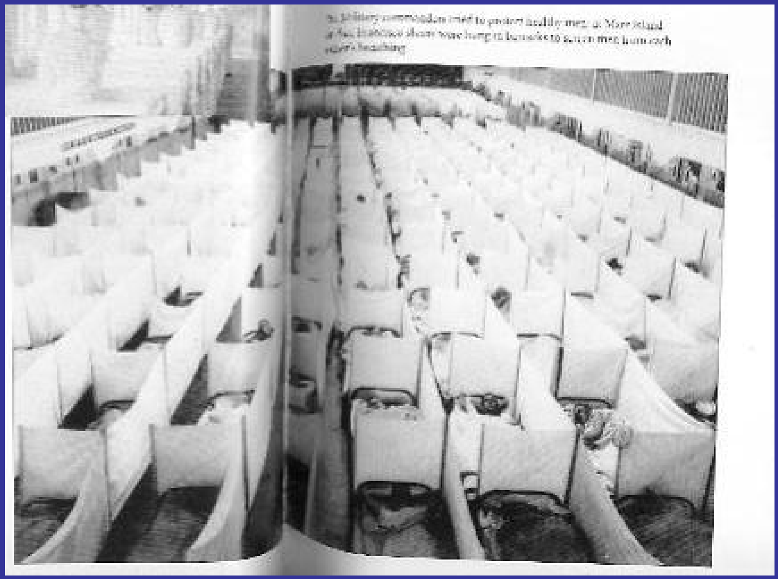
Modeling the Spread of Influenza

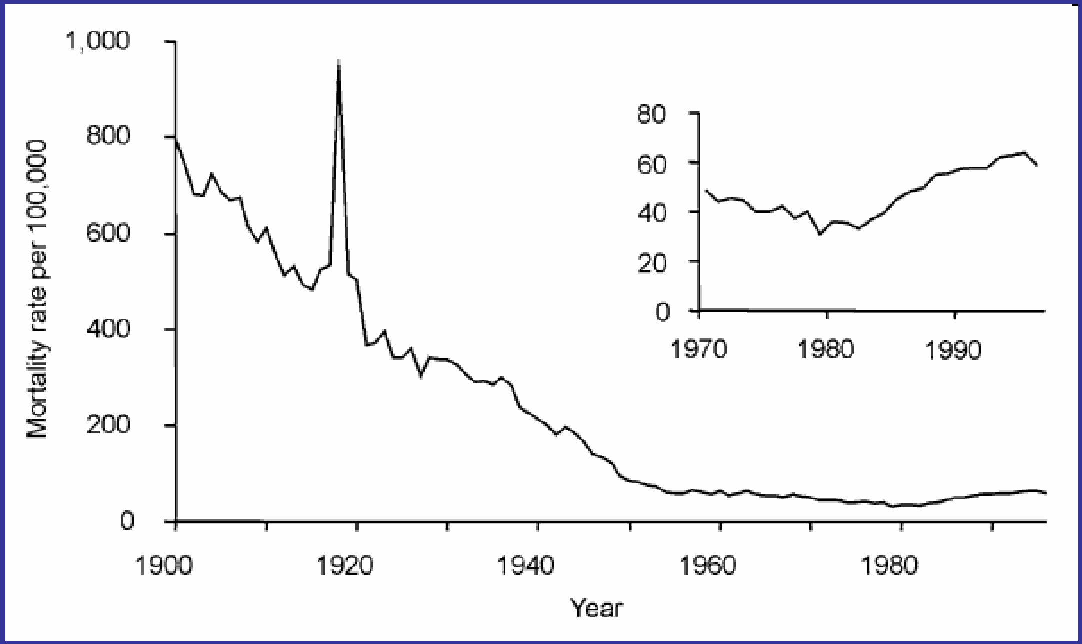
Overview of the Problem
Structure of the Host Network
Modeling Influenza
Results
Conclusions

Modeling the Spread of Influenza

Overview of the Problem
Structure of the Host Network
Modeling Influenza
Results
Conclusions







Presentation from the 2000 Emerging Infectious Diseases Conference in Atlanta, Georgia
Emerging Infectious Diseases: A CDC Perspective. James M. Hughes, M.D.
Centers for Disease Control and Prevention, Atlanta, Georgia, USA

CDC’s Eight Priority Groups for Vaccination (All of Equal Importance)

2004 Vaccine Shortage

Who should get a flu vaccination?

People who are 65 years old or older —
Even if you’re in great health!

Children 6 to 23 months old —
Children younger than 2 years old have one of the highest rates of hospitalization from influenza

Adults and children with a chronic health condition —
Like heart disease, diabetes, kidney disease, asthma, cancer, or HIV/AIDS

Women who will be pregnant during flu season —
Flu season is typically November through March

Residents of nursing homes and long-term care facilities

Children aged 6 months to 18 years on chronic aspirin therapy

Healthcare workers involved in direct patient care

Out-of-home caregivers and household contacts of children younger than 6 months

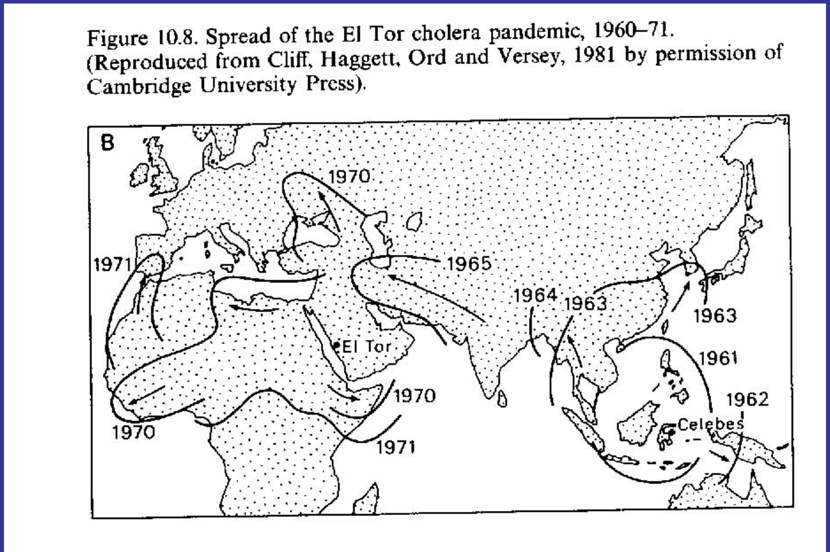
If you’re not in one of these groups, you should not get vaccinated, to allow those at highest risk to get a shot.

Department of Health and Human Services
Centers for Disease Control and Prevention

For more information, ask your healthcare provider or call the CDC Immunization Hotline
English and Español **800-CDC-INFO** Website **www.cdc.gov/flu**

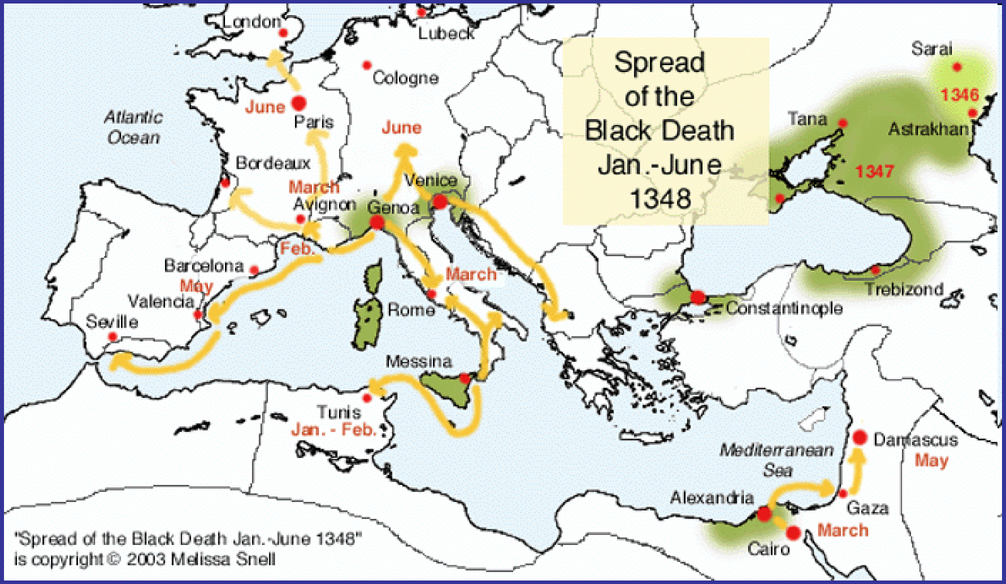
http://www.cdc.gov/flu
November 12, 2004

The Progression of Diseases

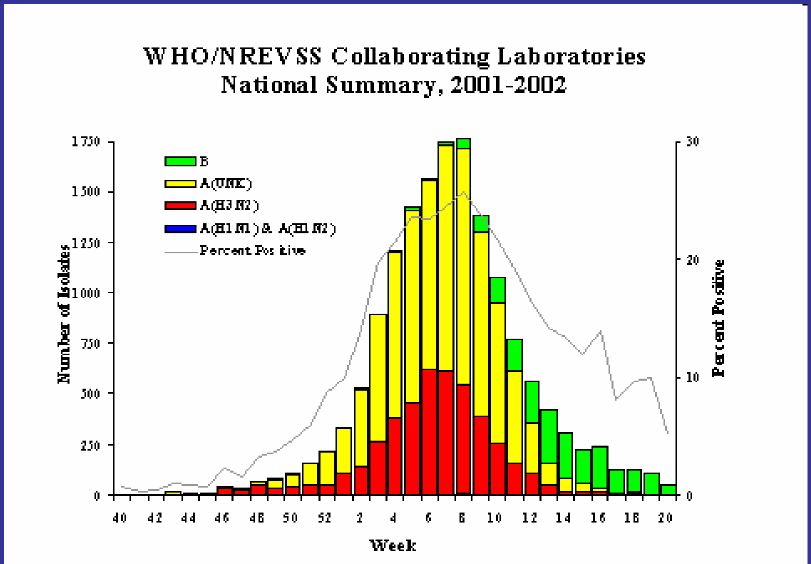


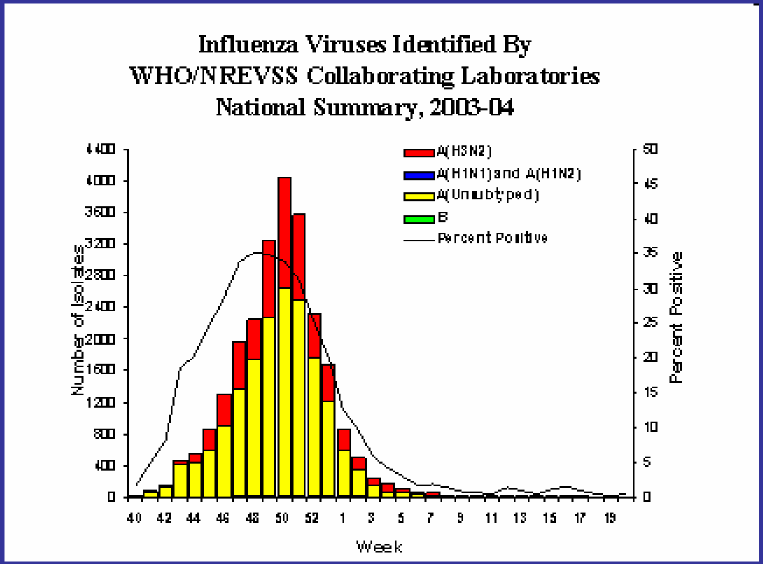
Cholera

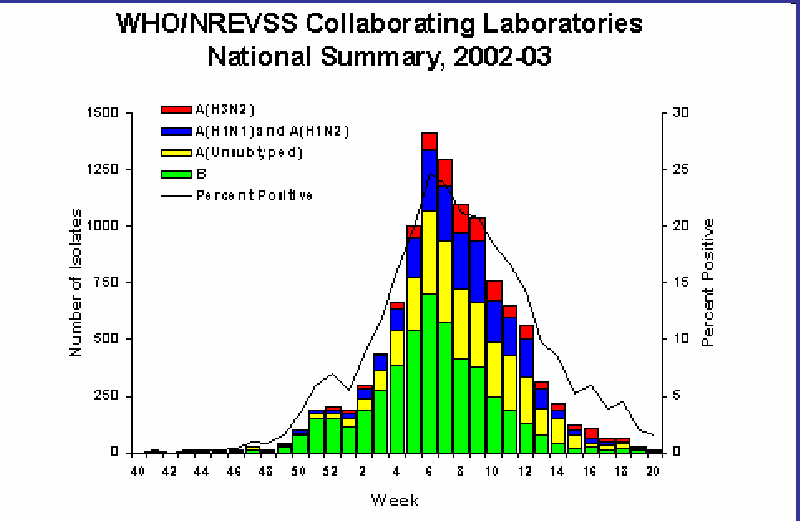
1348
Black Death

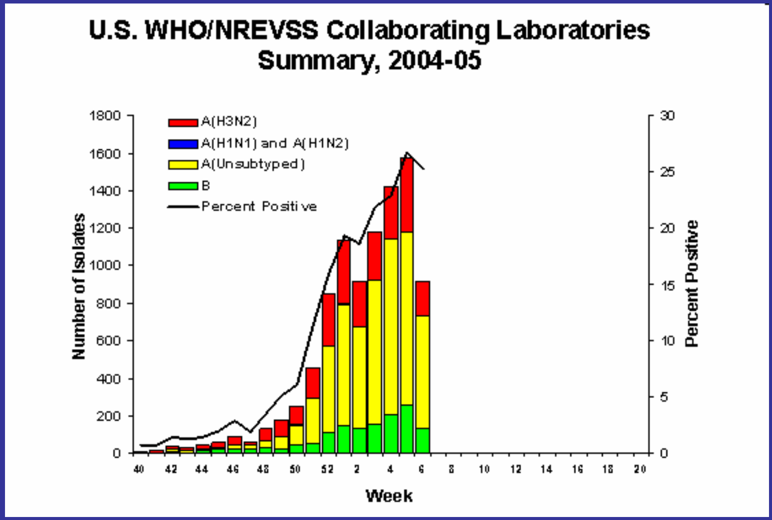


The Progression of Flu





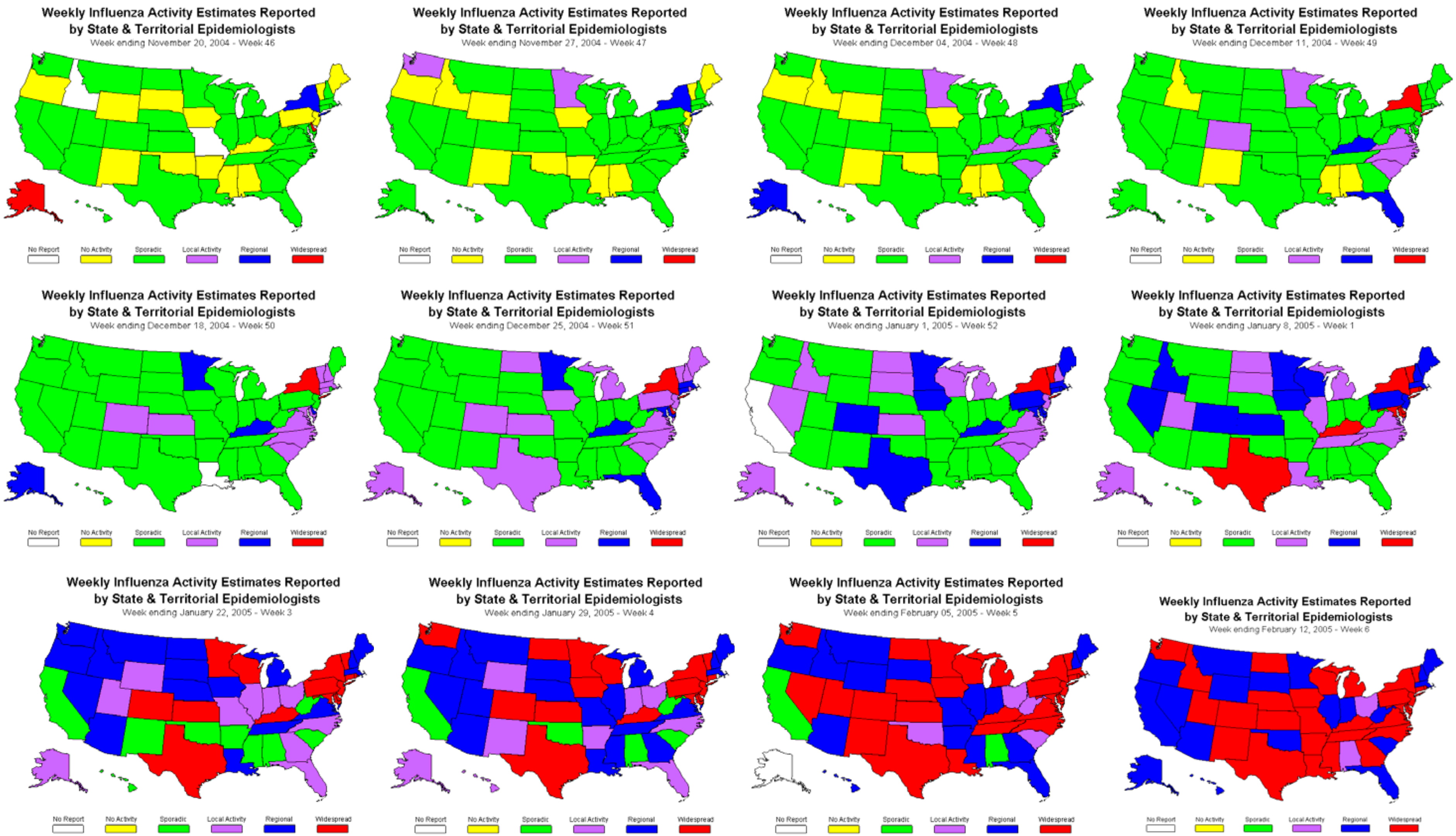




http://www.cdc.gov/flu

Nov. 20, 2004

http://www.cdc.gov/flu

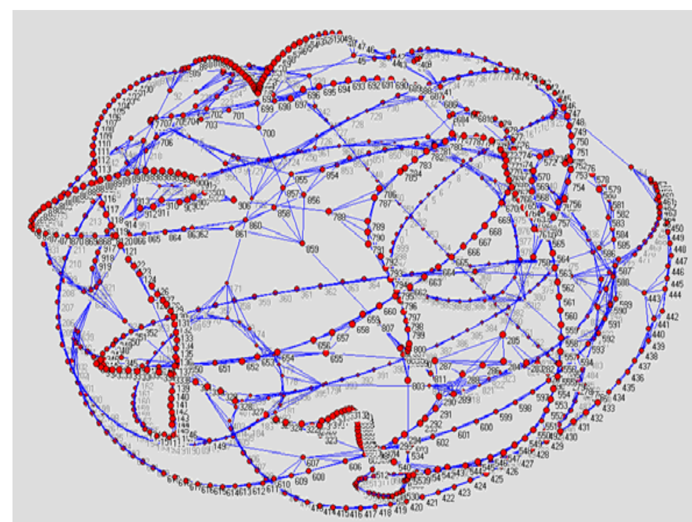


No Report	No Activity	Sporadic	Local Activity	Regional	Widespread

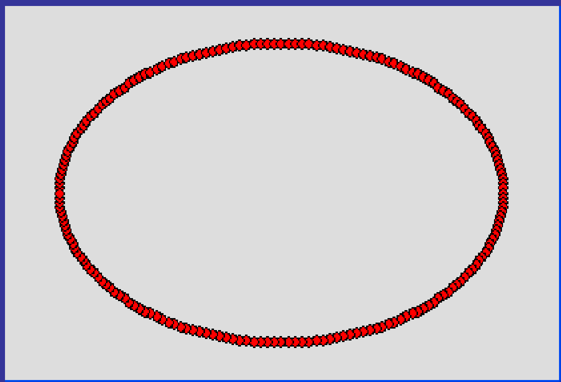
Feb. 12, 2005

Modeling the Spread of Influenza

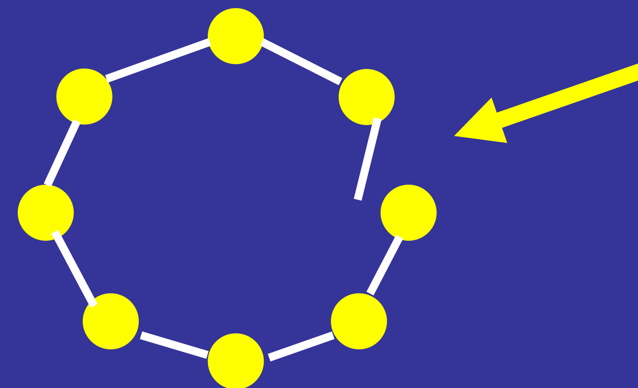
Overview of the Problem
Structure of the Host Network
Modeling Influenza
Results
Conclusions



Small-World Networks



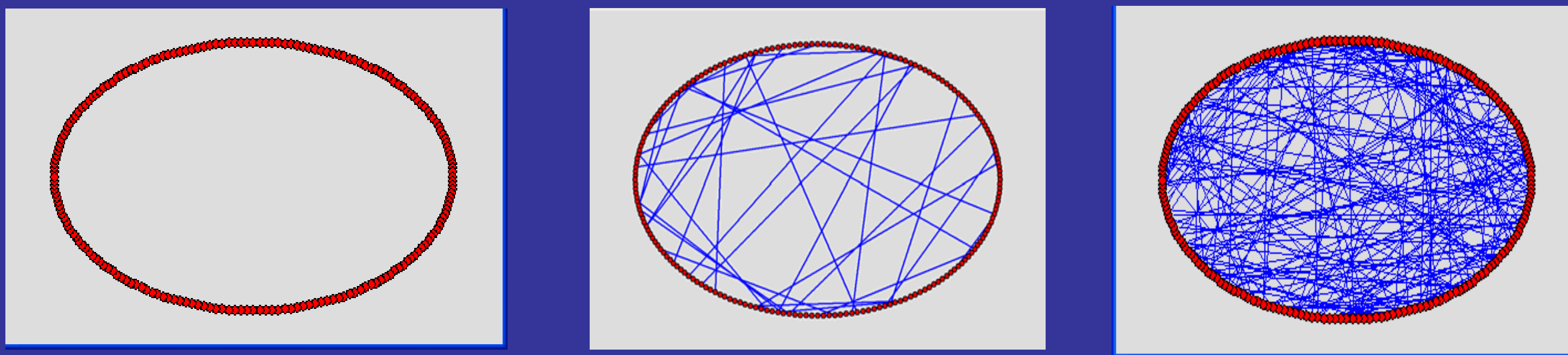
swn-P = 0.00



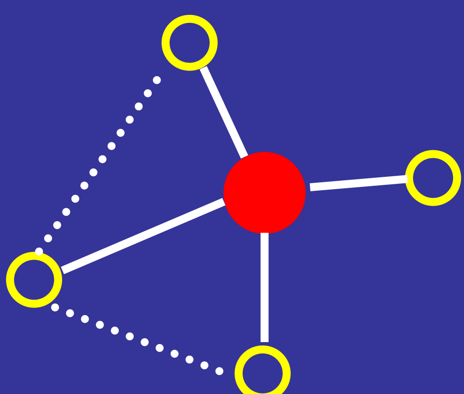
swn-P = probability that each host’s edge is broken and rewired to a randomly chosen host from the population.

Watts and Strogatz. 1998. Collective dynamics of ‘small-world’ networks. Nature 393: 440-442.

Small-World Networks



swn-P = 0.00 0.01 0.05



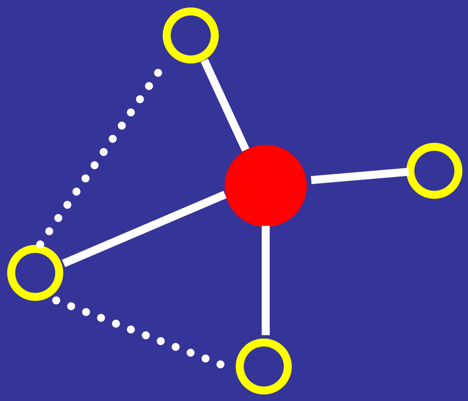
Use Networks with 1K, 10K, and 100K

Hosts begin with four neighbors (k)

(transmission network)

One unlucky host gets inoculated

Structure of a Network



k = degree

NCR = Neighbor Contact Rate

Population Size

swn-P

Modeling the Spread of Influenza

Overview of the Problem

Structure of the Host Network

Modeling Influenza

Results

Conclusions

$$C.C. = \frac{|E(T_v)|}{\binom{k_v}{2}}$$

Vaccination Strategies

1. Vaccinating Random Nodes
2. Vaccinating Hubs (nodes with the highest degree)
3. Vaccinating Nodes with Lowest Clustering Coefficient
4. Vaccinating Nodes with Highest Clustering Coefficient
5. Vaccinating Nodes Containing Cross-Cut Edges

Vaccination Strategies

1. Vaccinating Random Nodes
2. Vaccinating Hubs (nodes with the highest degree)
3. Vaccinating Nodes with Lowest Clustering Coefficient
4. Vaccinating Nodes with Highest Clustering Coefficient
5. Vaccinating Nodes Containing Cross-Cut Edges

Clustering Coefficient:

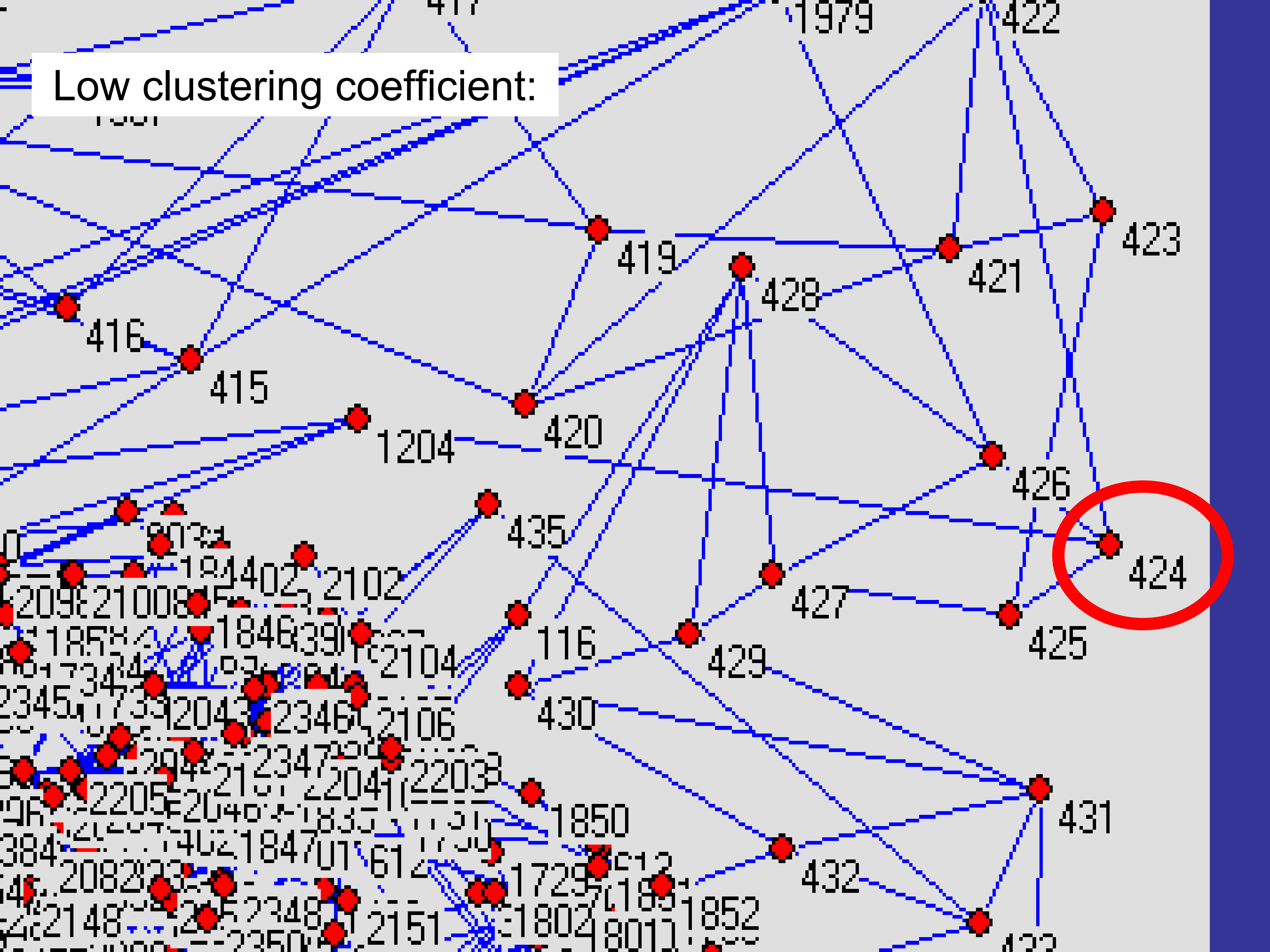
$$\text{C.C.} = \frac{|E(T_v)|}{\binom{k_v}{2}}$$

$|E(T_v)|$ = # of edges in the neighborhood of v

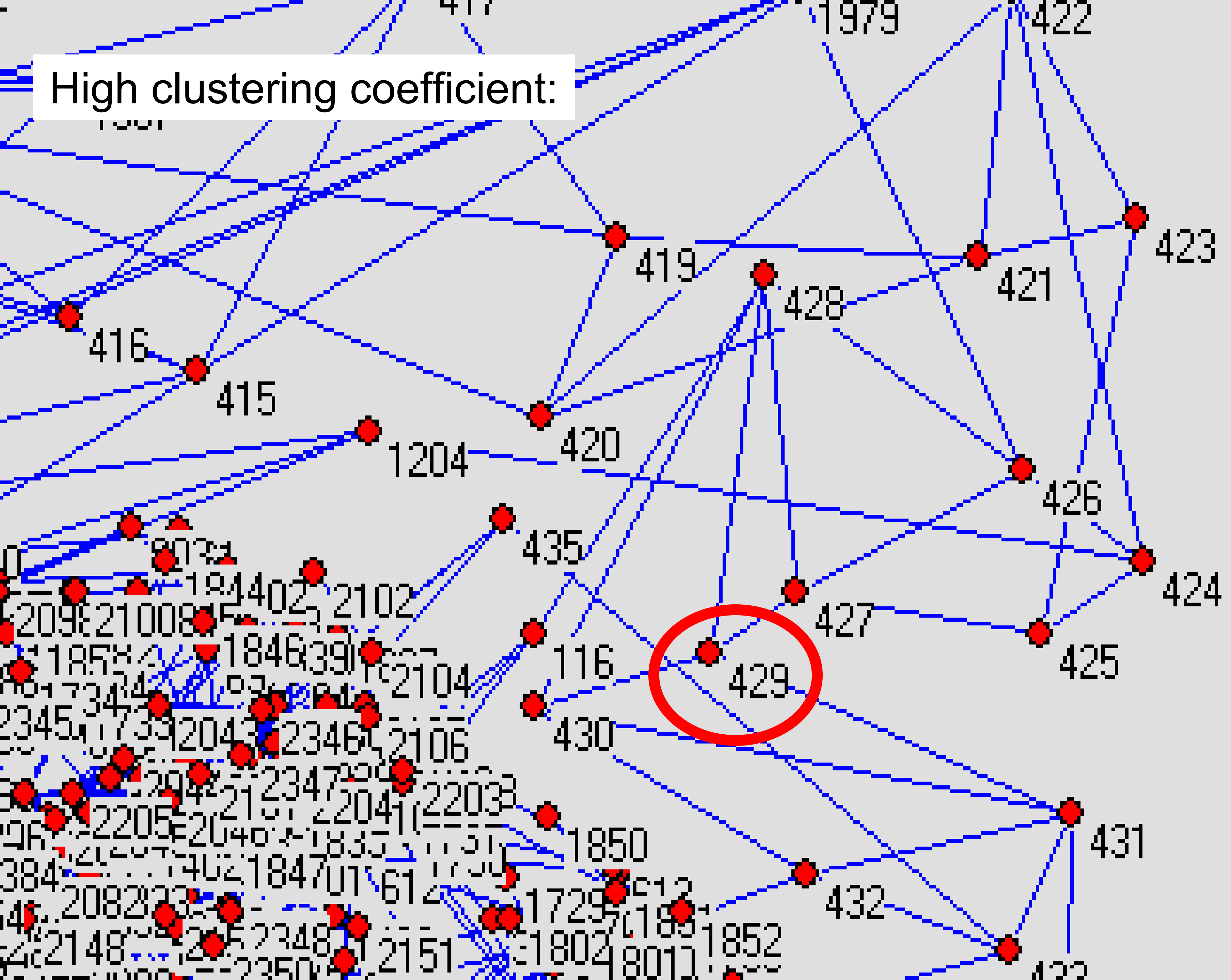
$\binom{k_v}{2}$ = total # of possible edges in T_v

Watts, 1999, *The Small-World Phenomenon*

Low clustering coefficient:



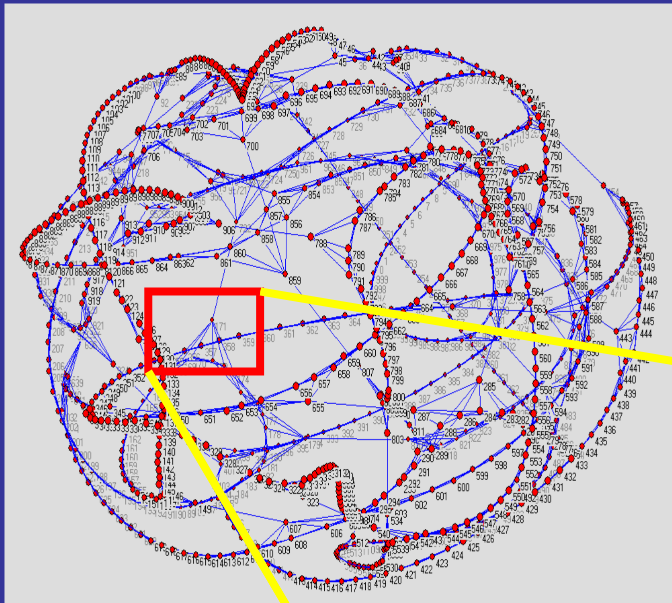
High clustering coefficient:

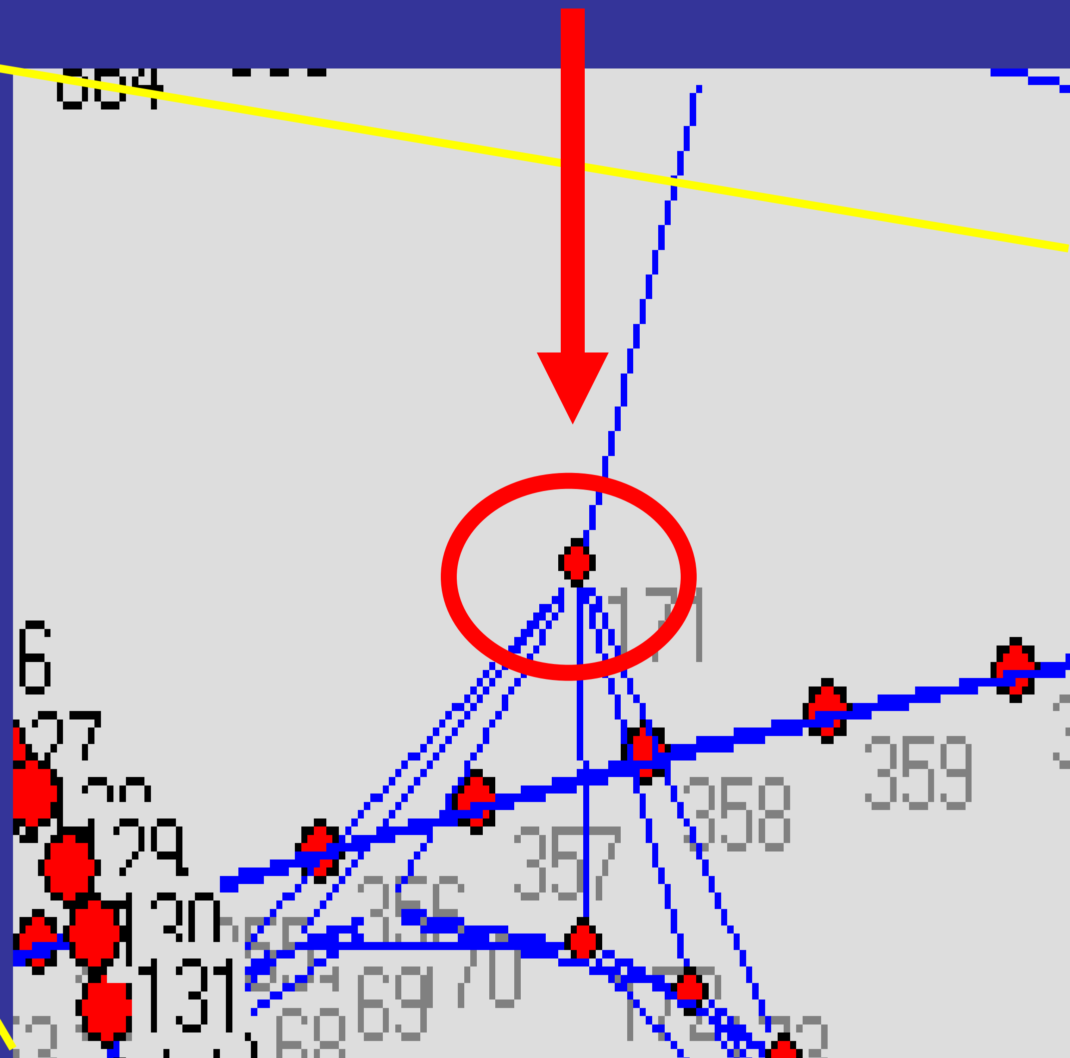


Vaccination Strategies

1. Vaccinating Random Nodes
2. Vaccinating Hubs (nodes with the highest degree)
3. Vaccinating Nodes with Lowest Clustering Coefficient
4. Vaccinating Nodes with Highest Clustering Coefficient
5. Vaccinating Nodes Containing Cross-Cut Edges

Vaccinating nodes with cross-cut edges



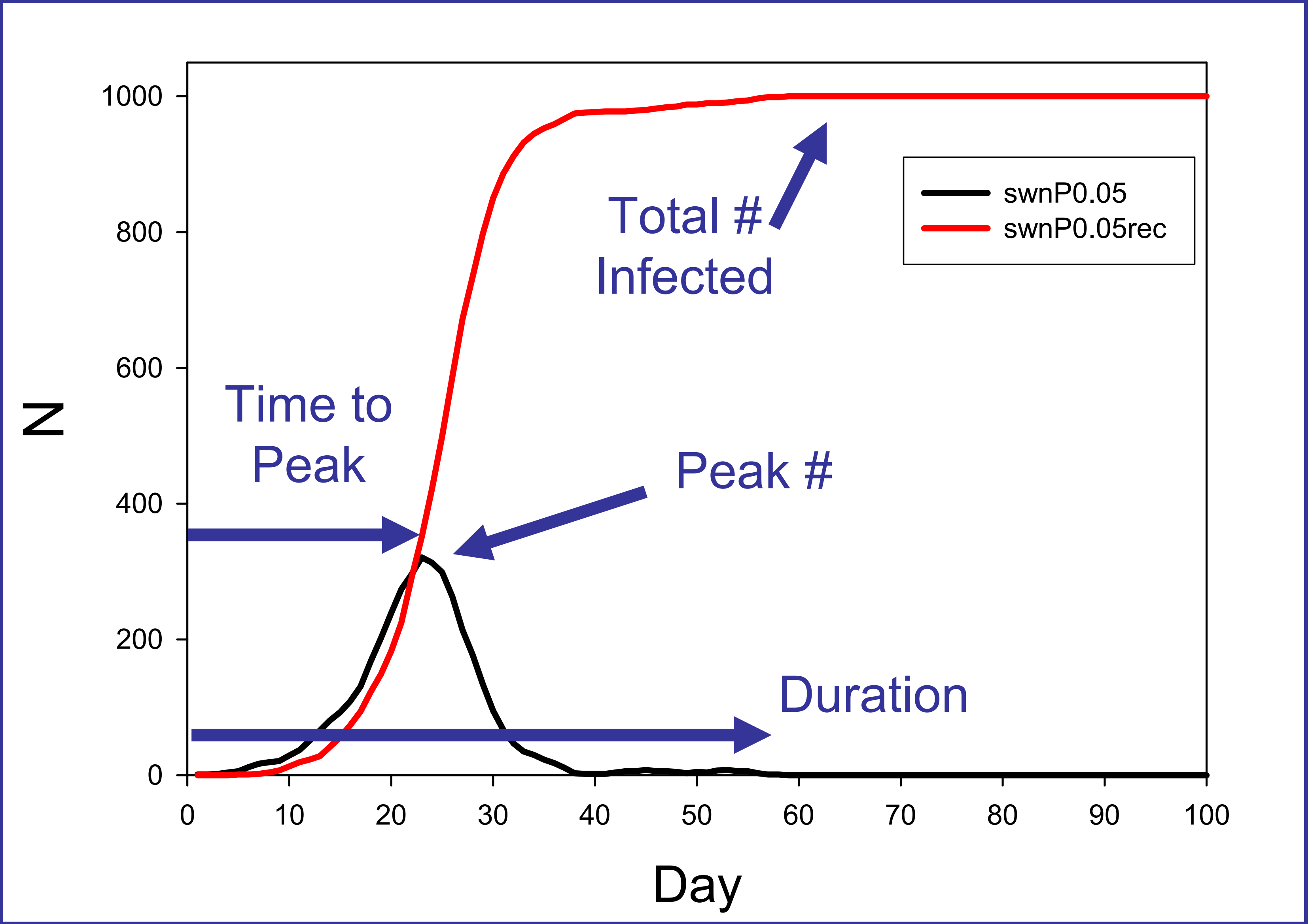


Design = 4-Way Factorial

Factors	Levels
SWN – P	9
Vaccination Strategy	5
Percent Vaccinated	7
Population size	3

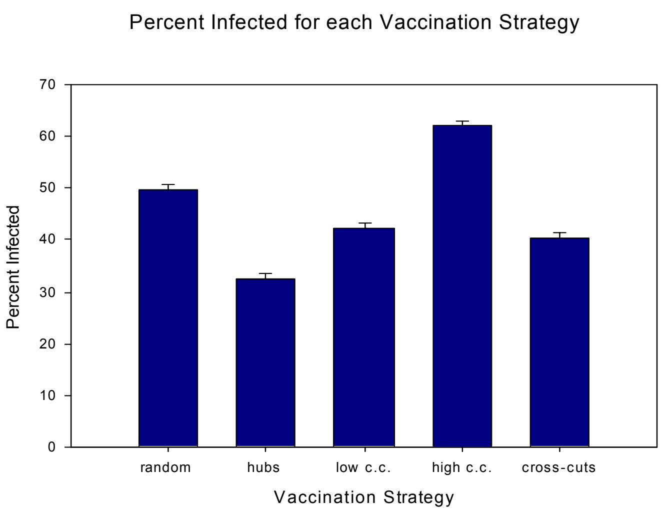
9 x 5 x 7 x 3 x 10 replicates = 9450 simulations

What do we measure?



Modeling the Spread of Influenza

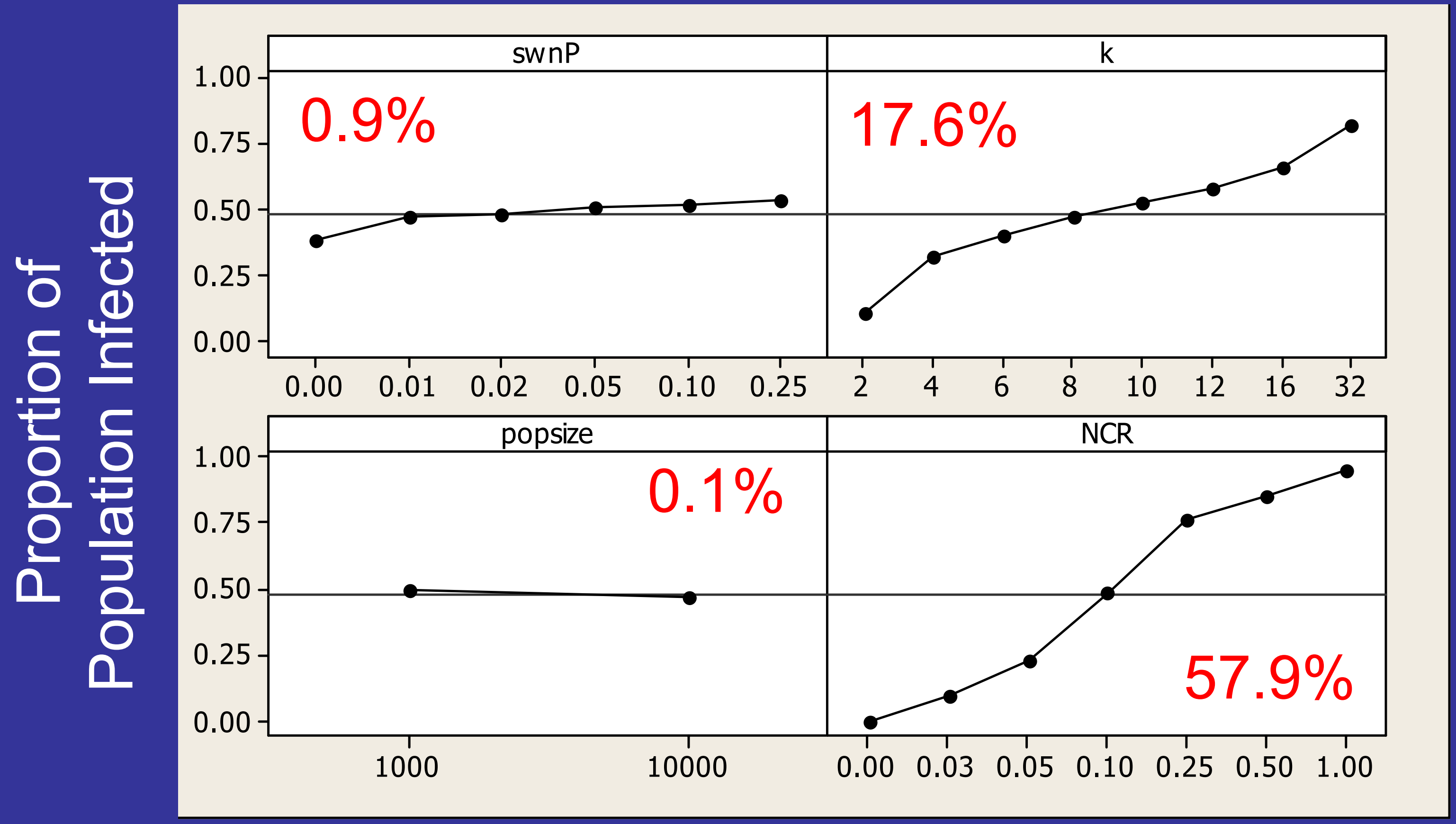
Overview of the Problem
Structure of the Host Network
Modeling Influenza
Results
Conclusions

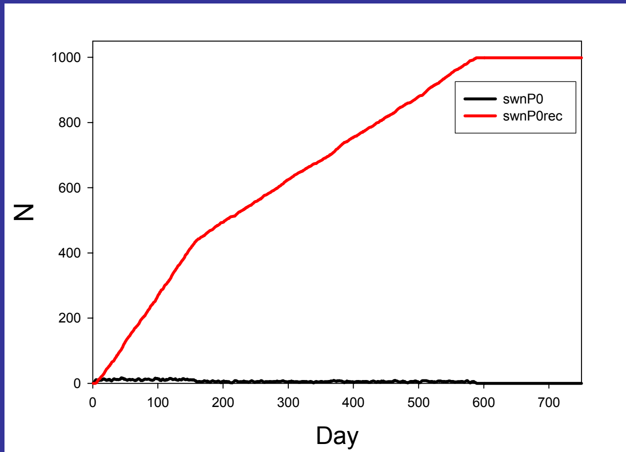


Two experiments:

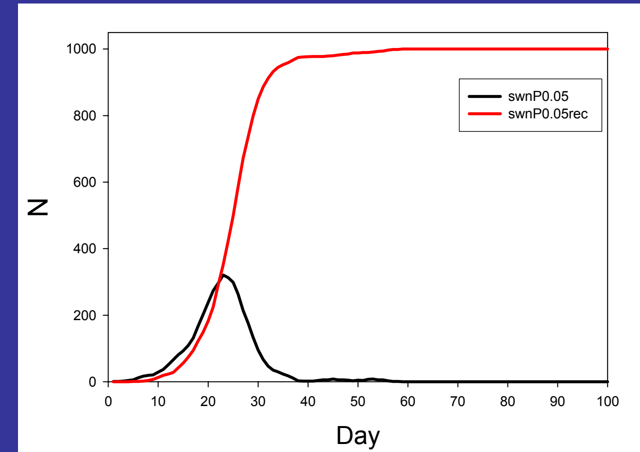
1. Test spread across network
2. Investigate vaccination rates and strategies on the slowing of influenza

Structure of the Transmission Network Influences the Extent of the Epidemic



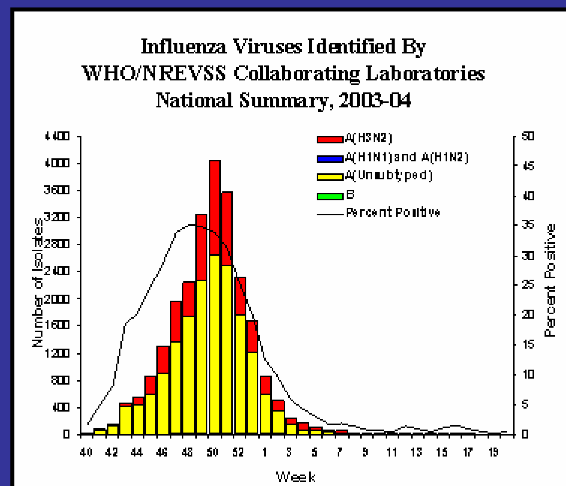


?



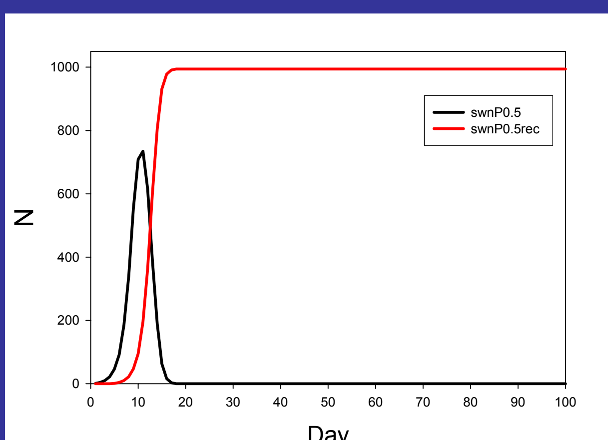
swnP = 0

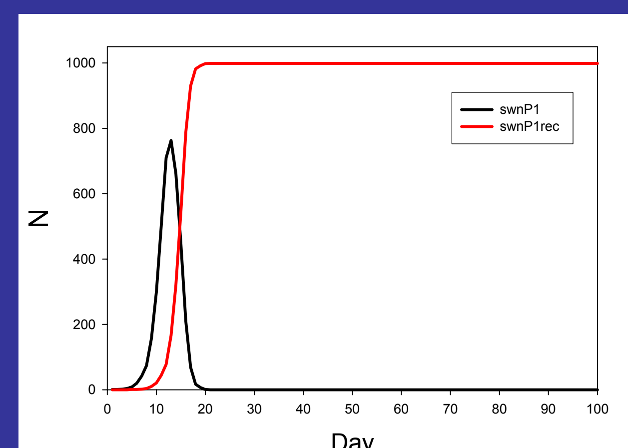
swnP = 0.05



swnP = 0.5

swnP = 1.0



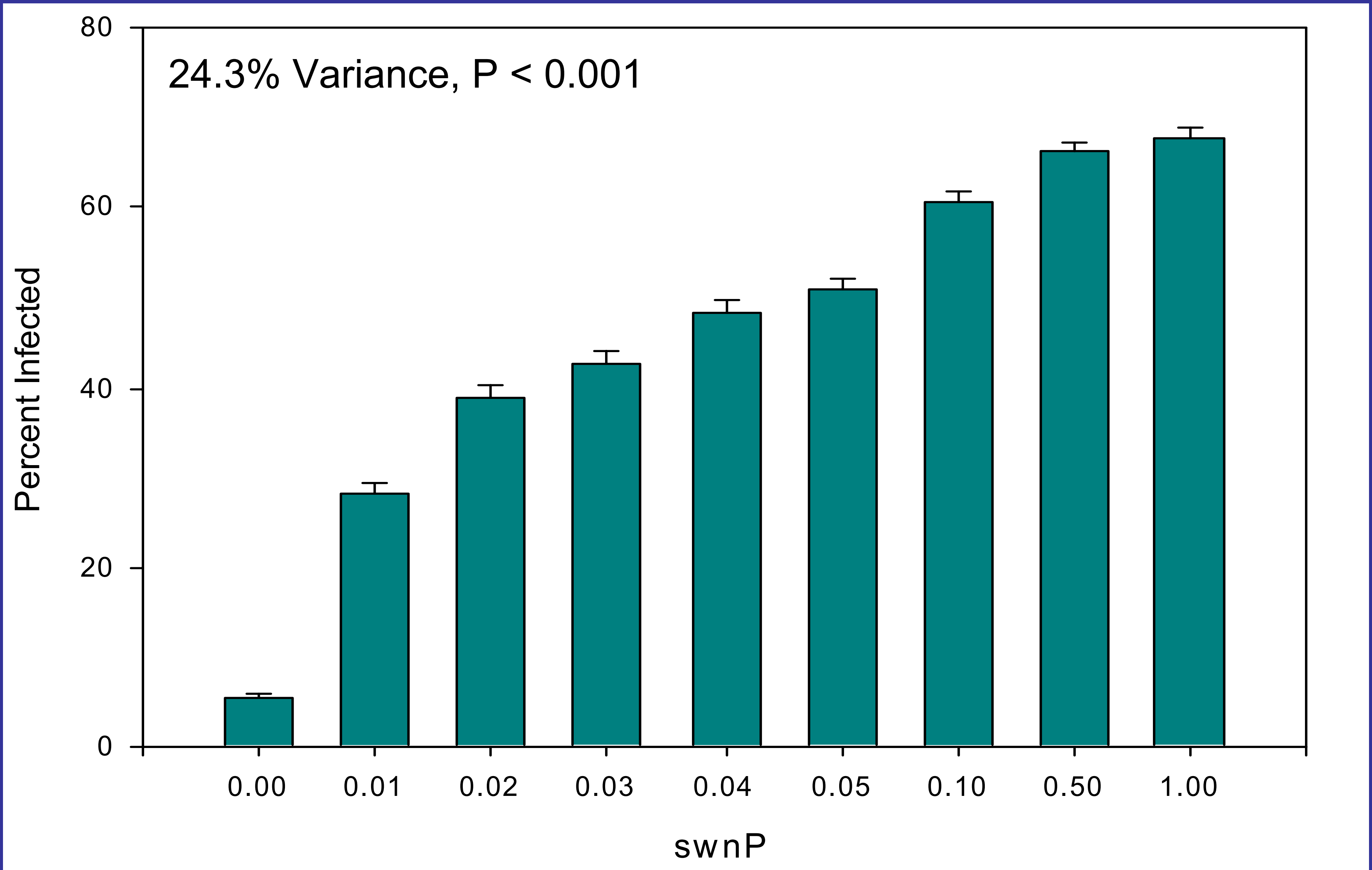


Response Variable = ArcSin Proportion of Population Infected

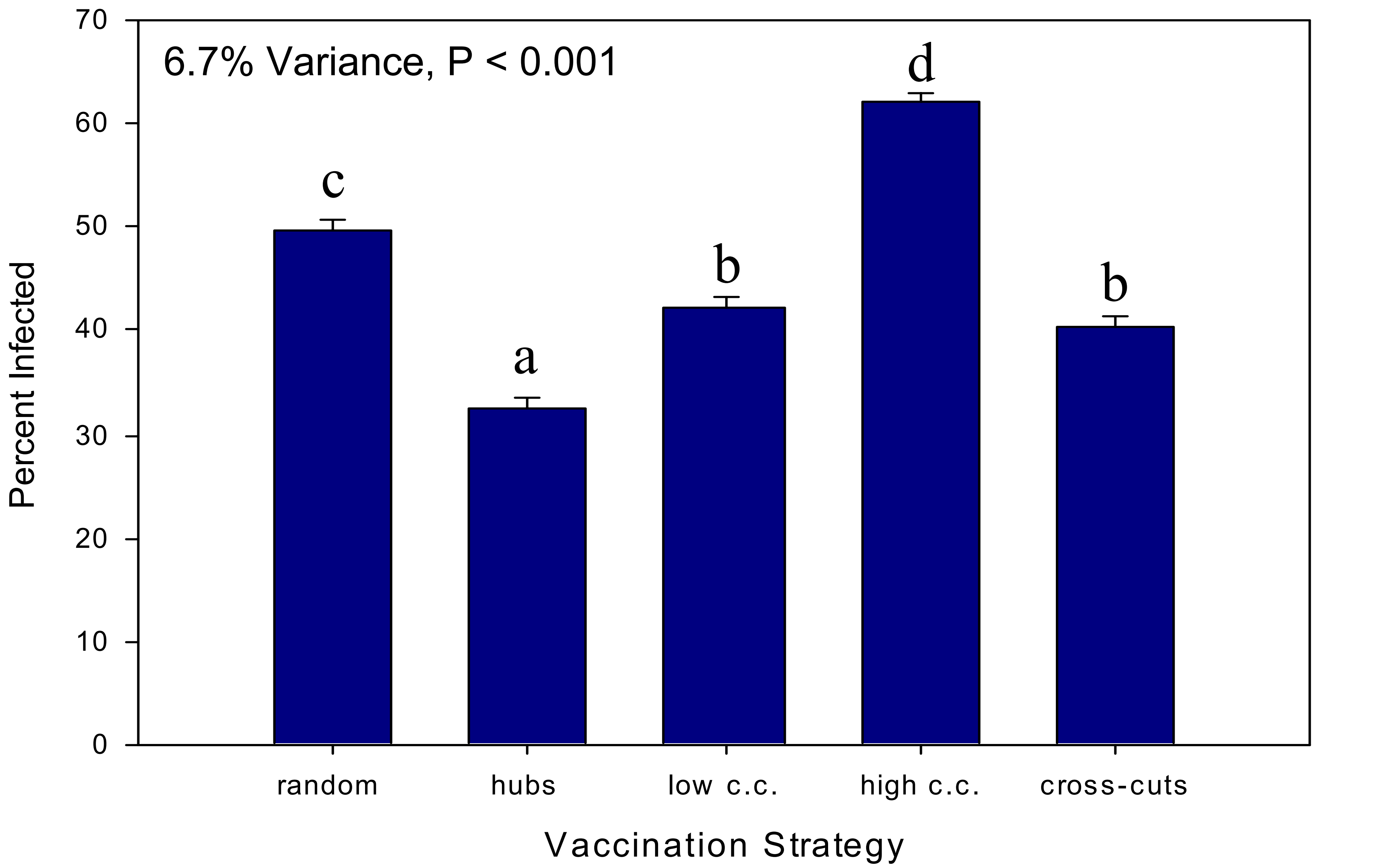
Source	DF	MS	F	P
swnP	8	72.053	996.50	<0.001
vacstrat	4	46.822	647.55	<0.001
per_vacc	6	253.705	3508.75	<0.001
popsize	2	12.832	177.46	<0.001
swnP*vacstrat	32	2.663	36.82	<0.001
swnP*per_vacc	48	4.035	55.80	<0.001
swnP*popsize	16	0.640	8.86	<0.001
vacstrat*per_vacc	24	2.359	32.62	<0.001
vacstrat*popsize	8	3.035	41.98	<0.001
per_vacc*popsize	12	0.160	2.22	0.009
swnP*vacstrat*per_vacc	192	0.555	7.68	<0.001
swnP*vacstrat*popsize	64	0.261	3.61	<0.001
swnP*per_vacc*popsize	96	0.325	4.50	<0.001
vacstrat*per_vacc*popsize	48	0.227	3.14	<0.001
swnP*vacstrat*per_vacc*popsize	384	0.092	1.27	<0.001
Error	8504	0.072		
Total	9448			

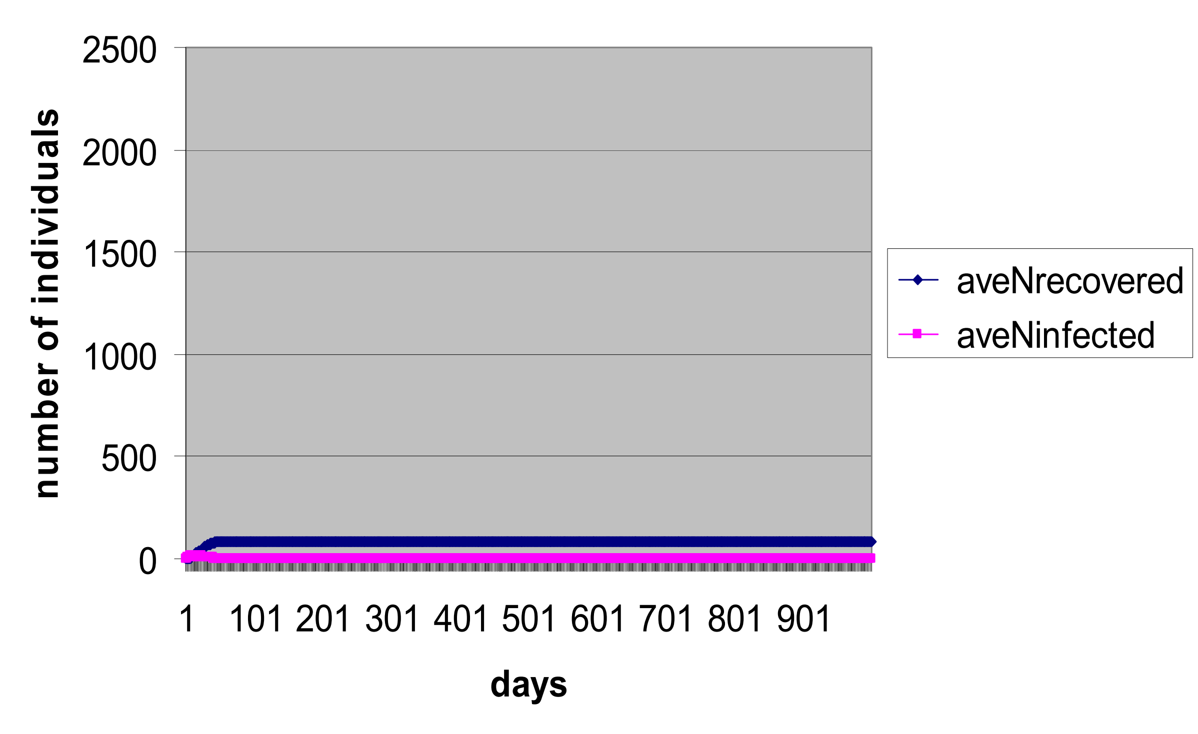
r^2 = 93.9

Main Effect of swnP



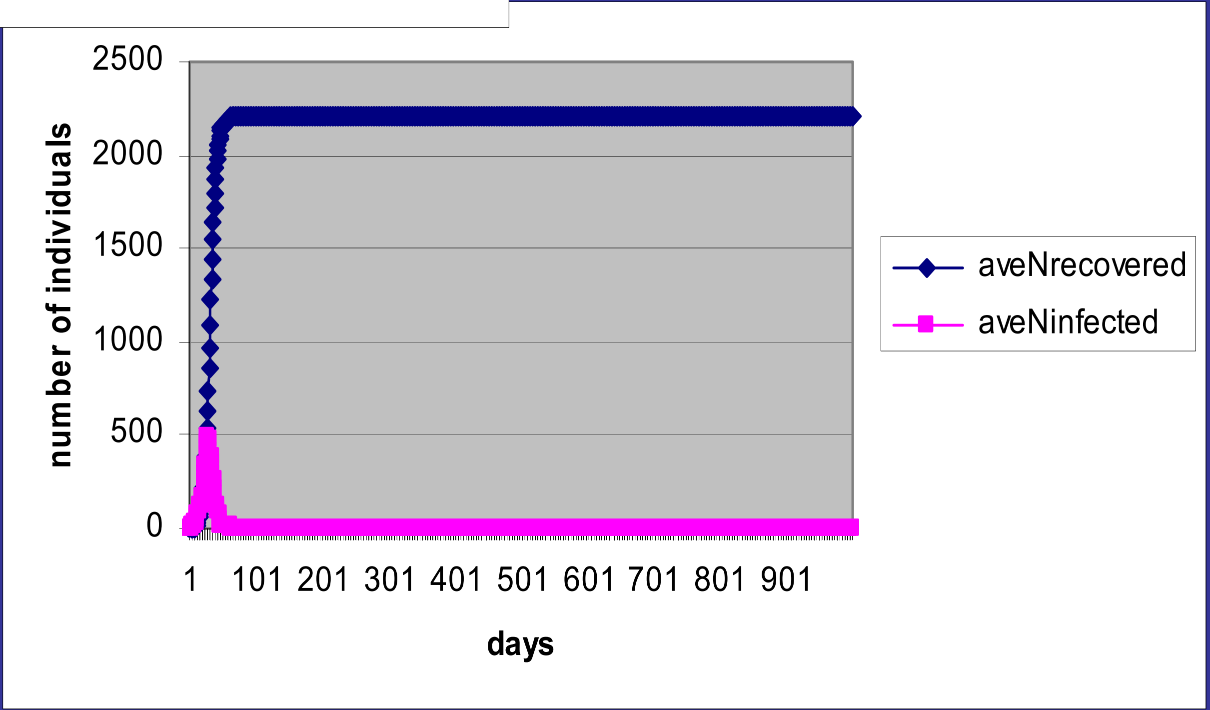
Main Effect of Vaccination Strategy



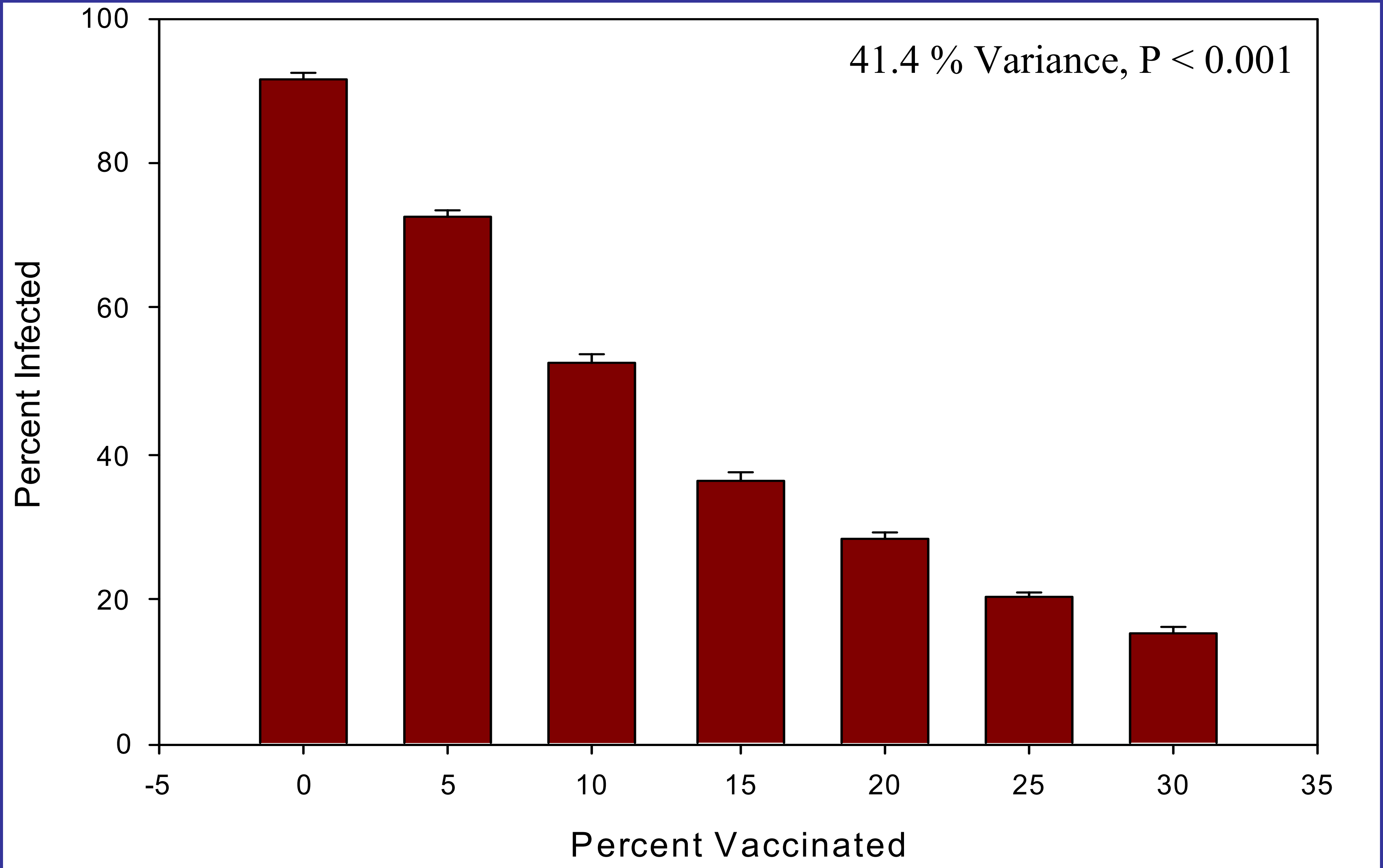


Vaccinate 10% Low Clustering Coefficient

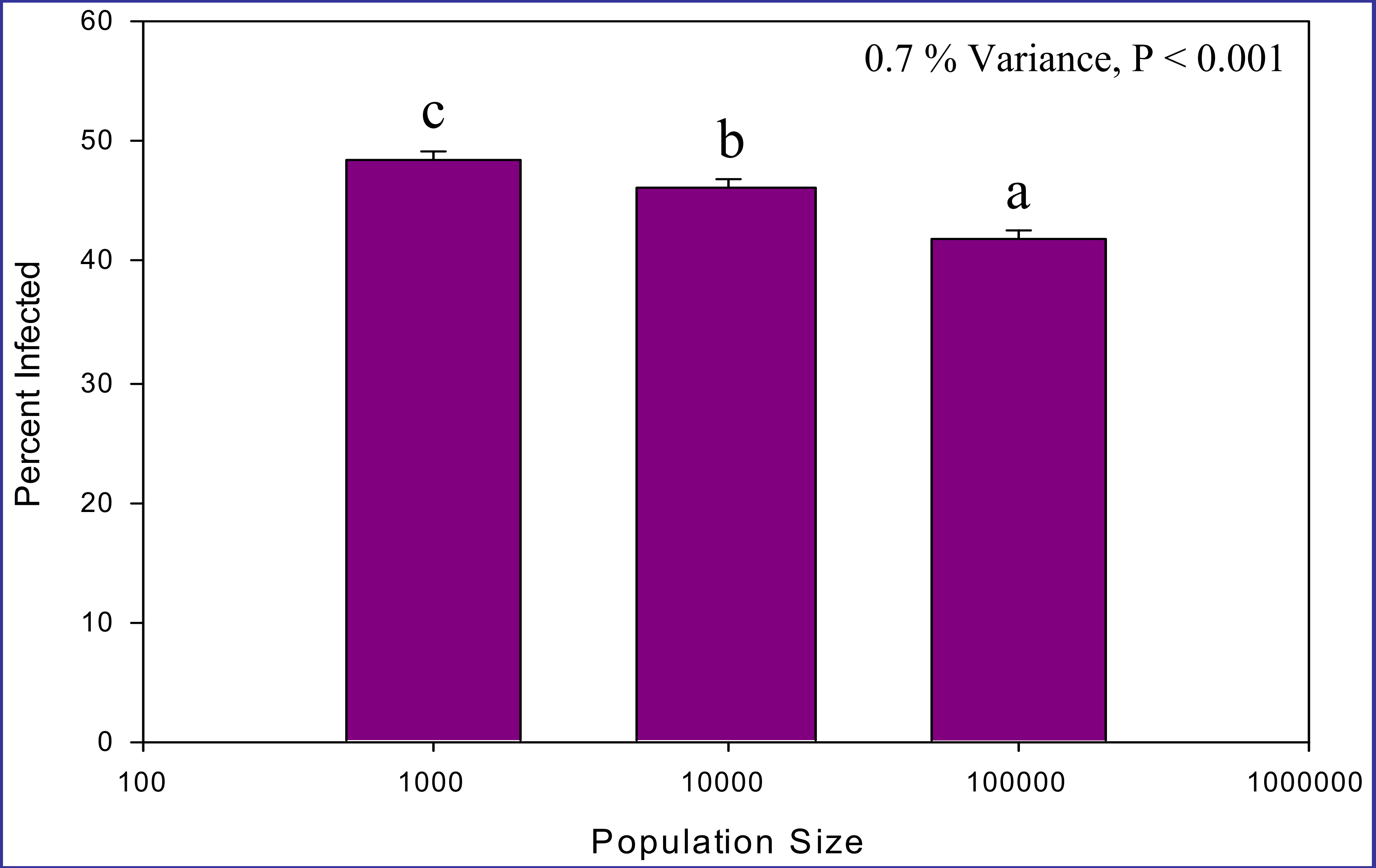
Vaccinate 10% High Clustering Coefficient



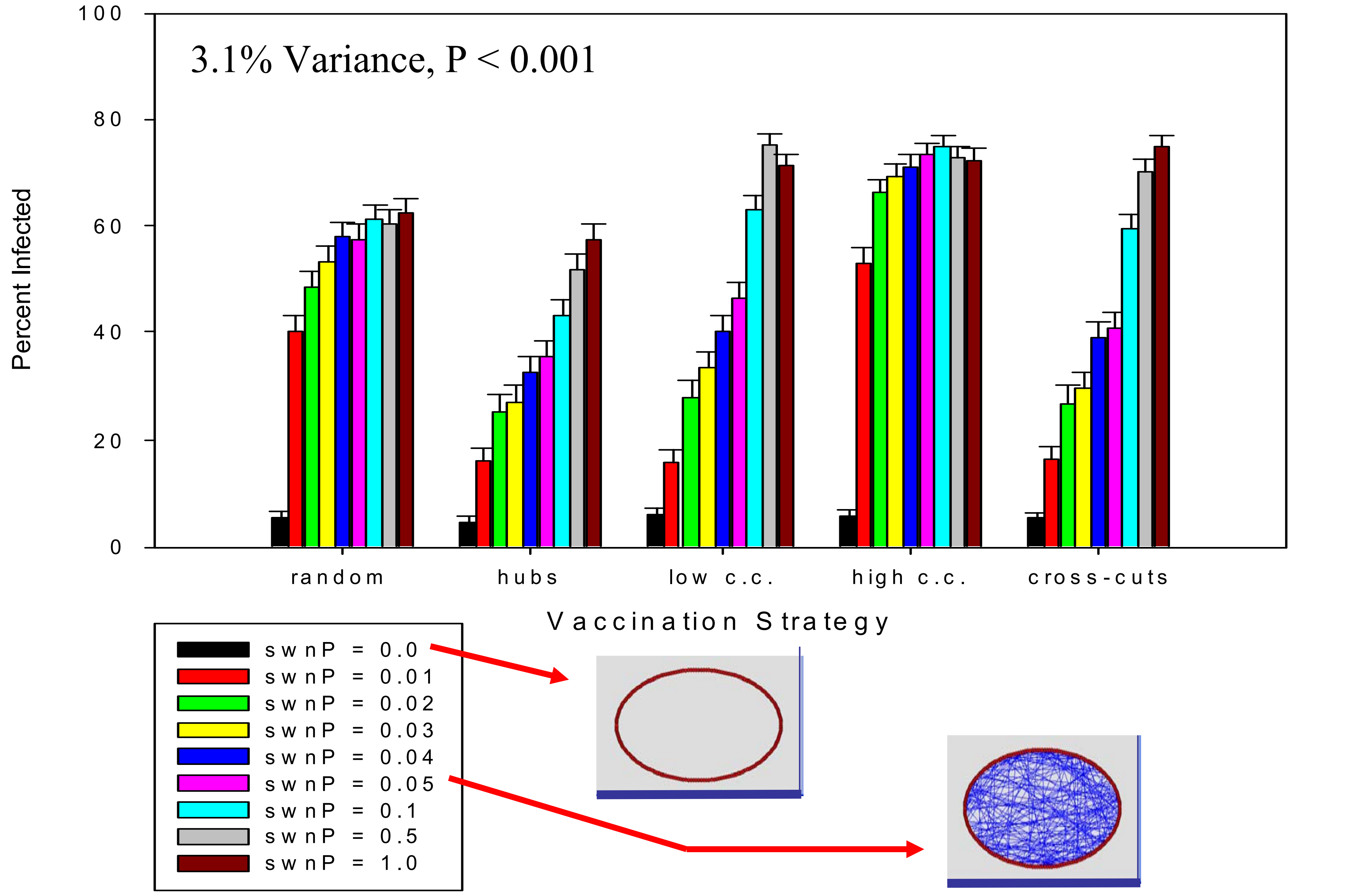
Main Effect of Percent Vaccinated



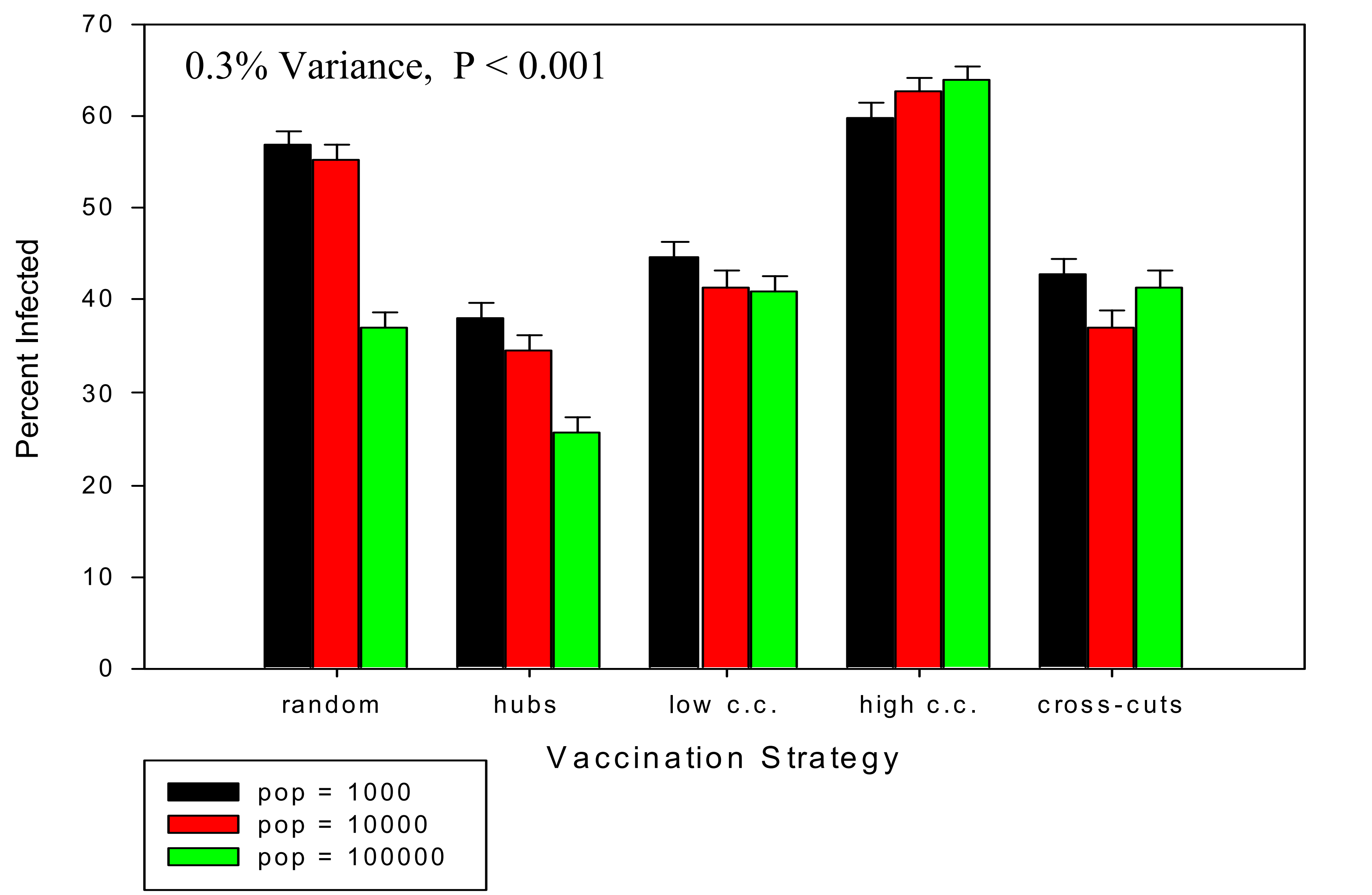
Main Effect of Population Size



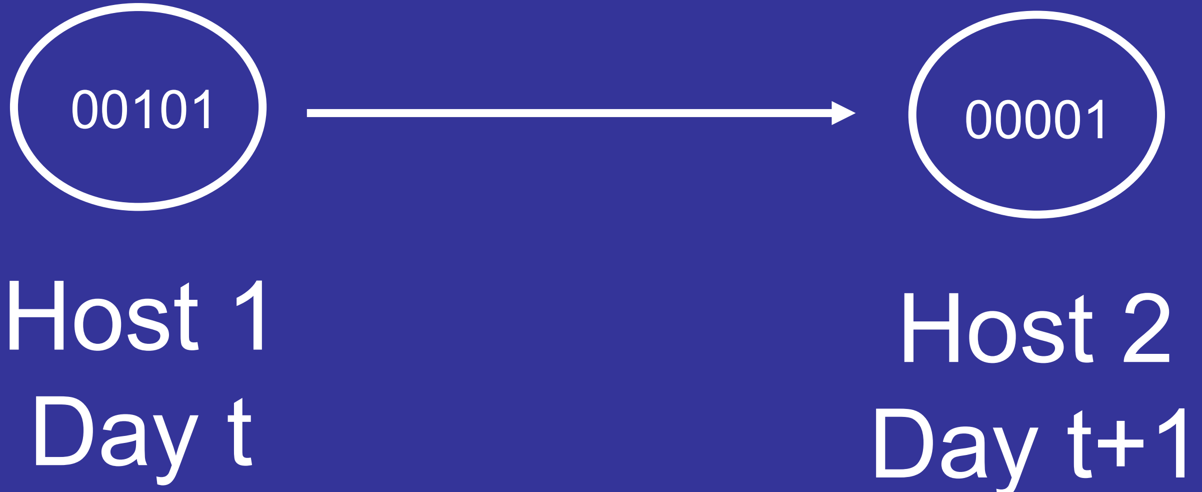
Vaccination Strategy x swnP



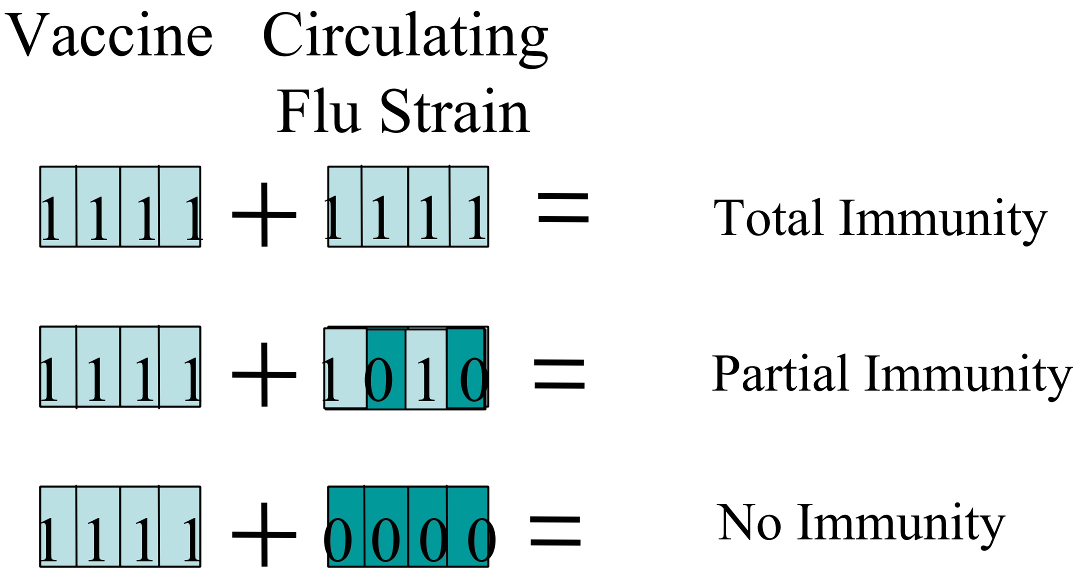
Vaccination Strategy x Population Size



Antigenetic Evolution

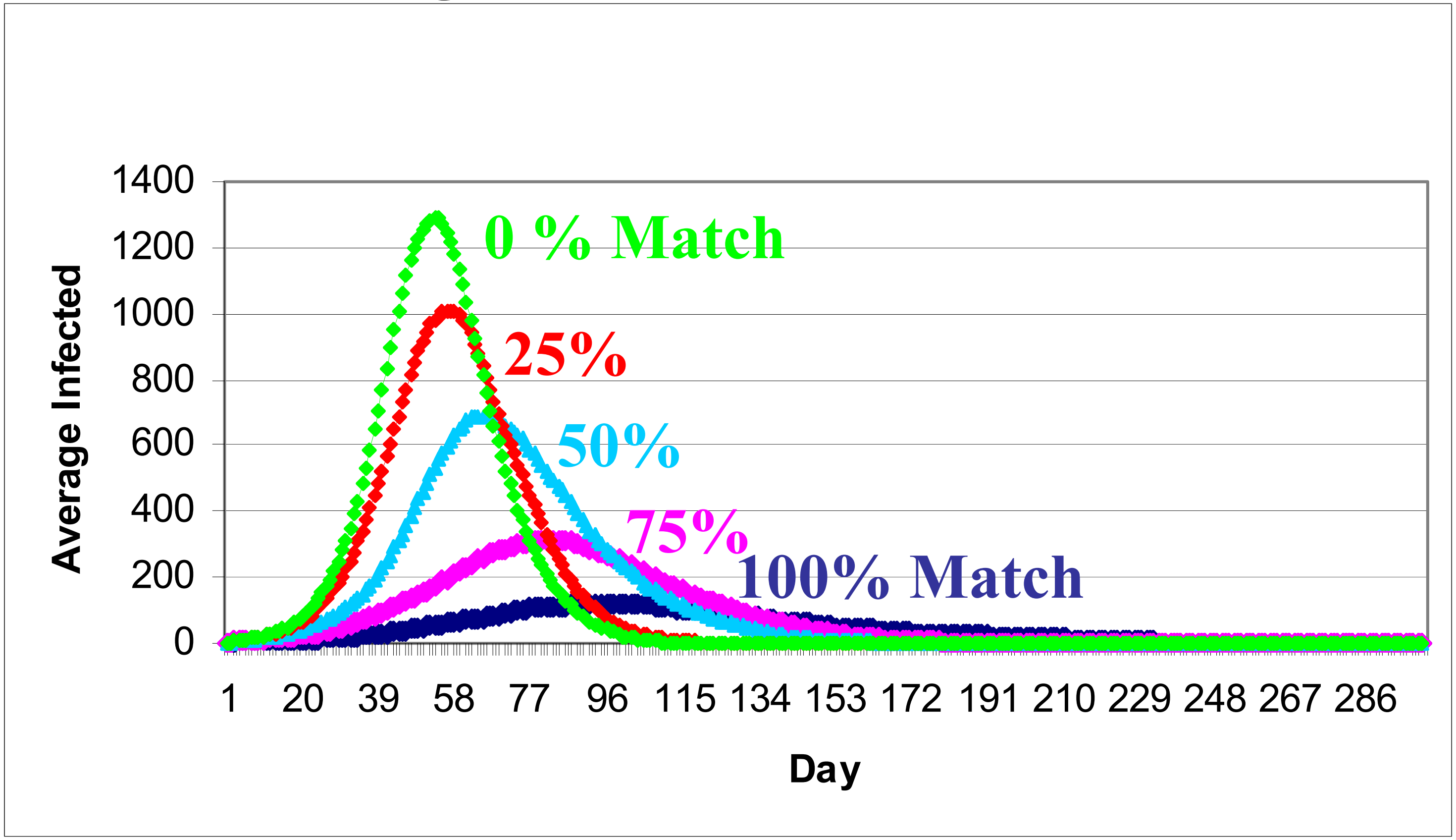


Cross Immunity

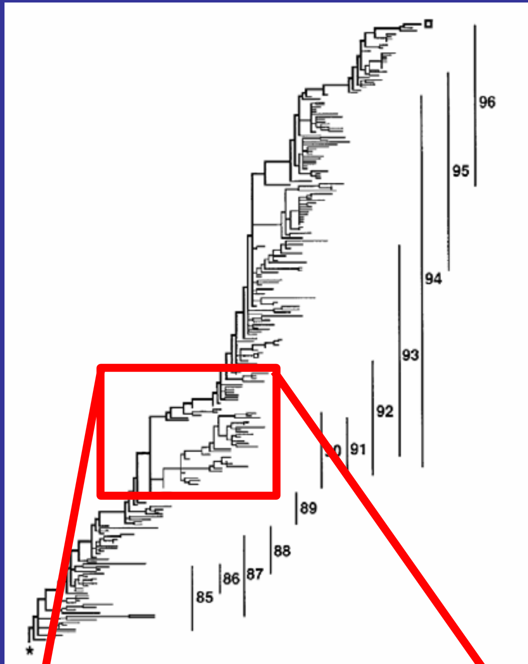


- The percent match between flu strains determines the degree of cross immunity observed

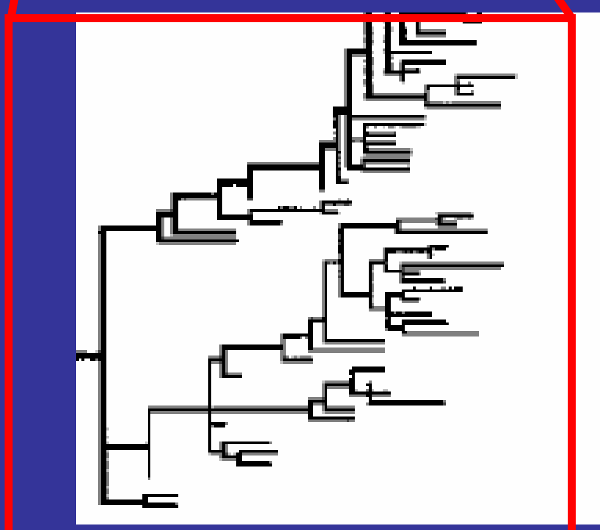
Closer matches of vaccine to circulating flu reduces epidemic

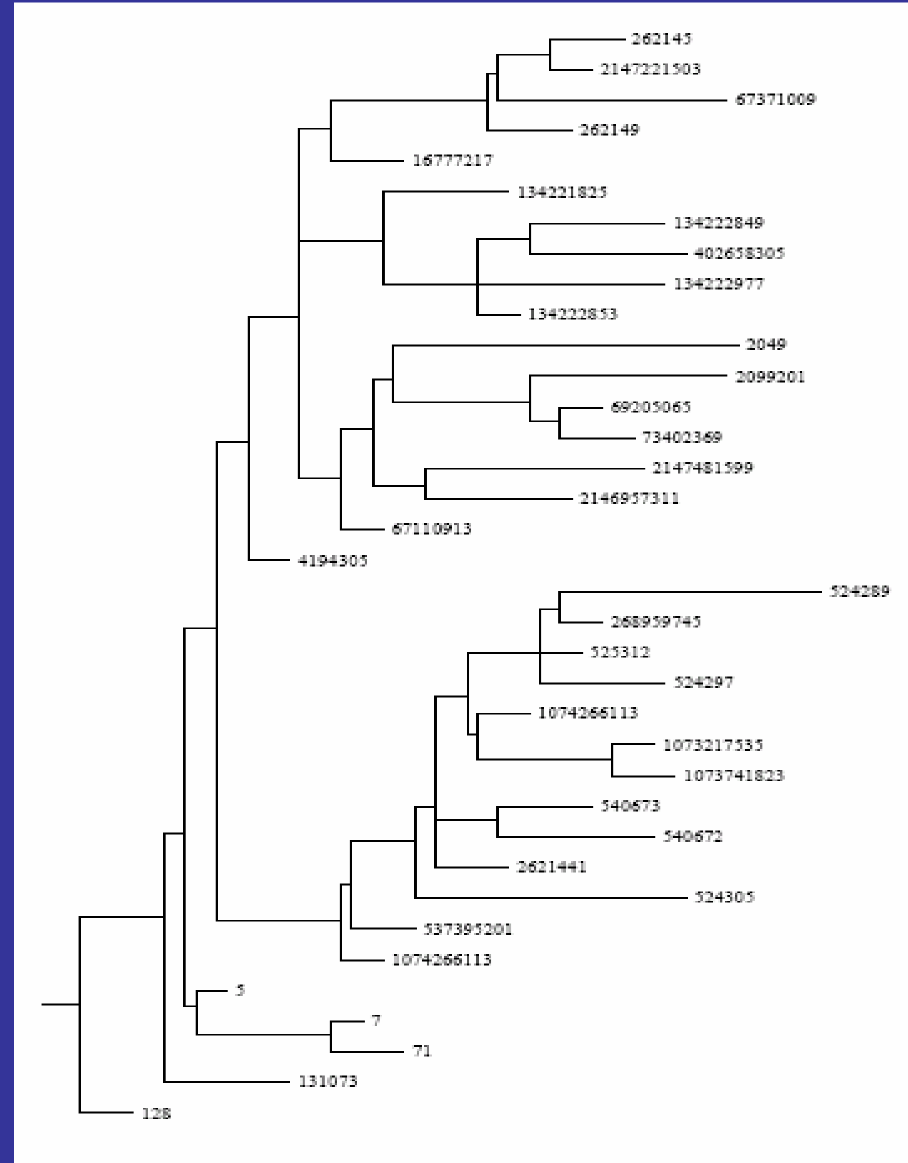


20 % population (N=10,000) vaccinated



IG. 1. Overall structure of the most parsimonious trees. The thic li e running from the lower left (* = root) to the upper right (open s uare) is called the trunk and represents the successful H3N2 lineage. T e vertical lines indicate the range of isolates from the flu years ctober 1 to September 30).





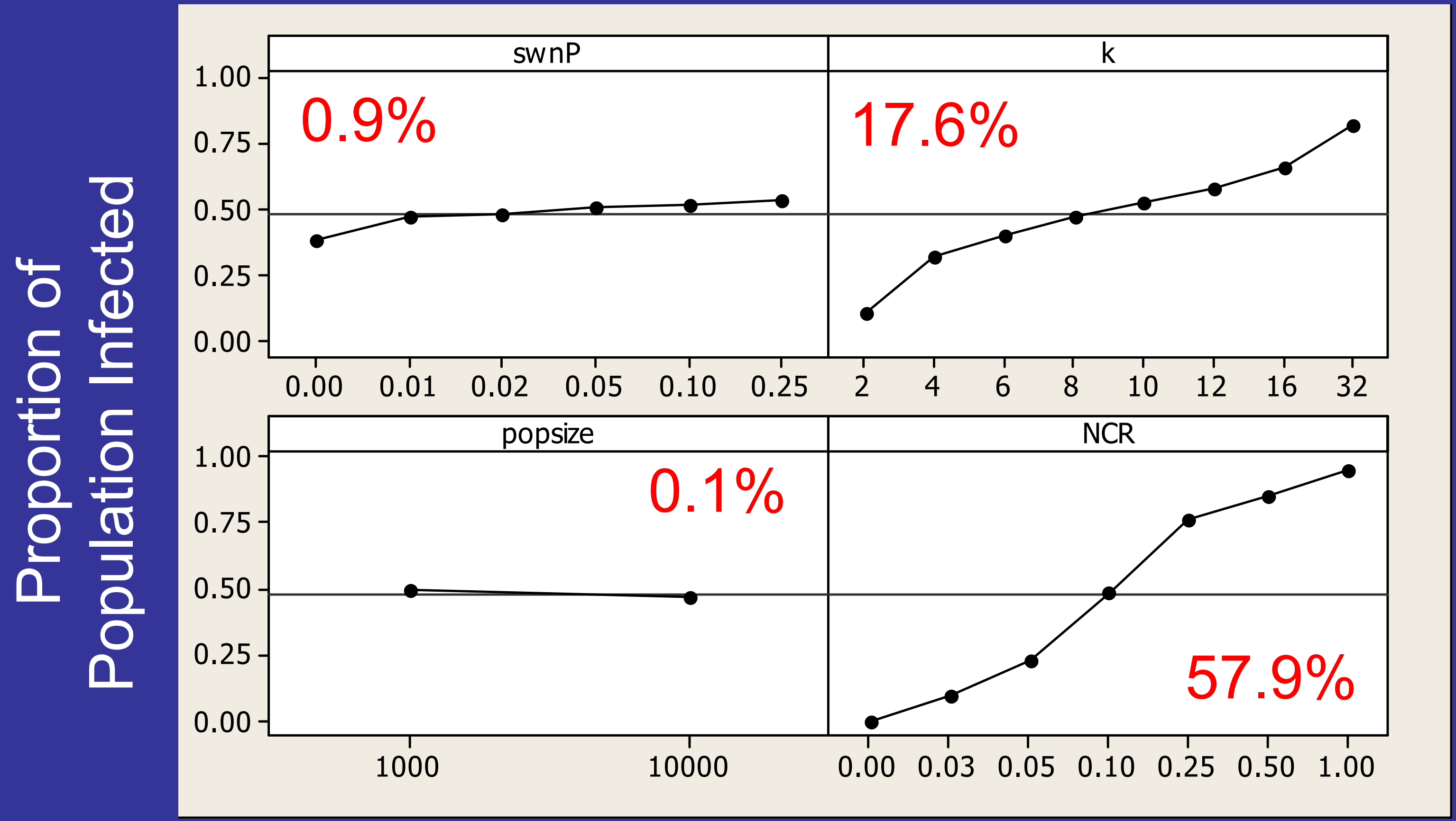
Fitch et al. 1997. PNAS 94: 7712-7718

Modeling the Spread of Influenza

Overview of the Problem
Structure of the Host Network
Modeling Influenza
Results
Conclusions

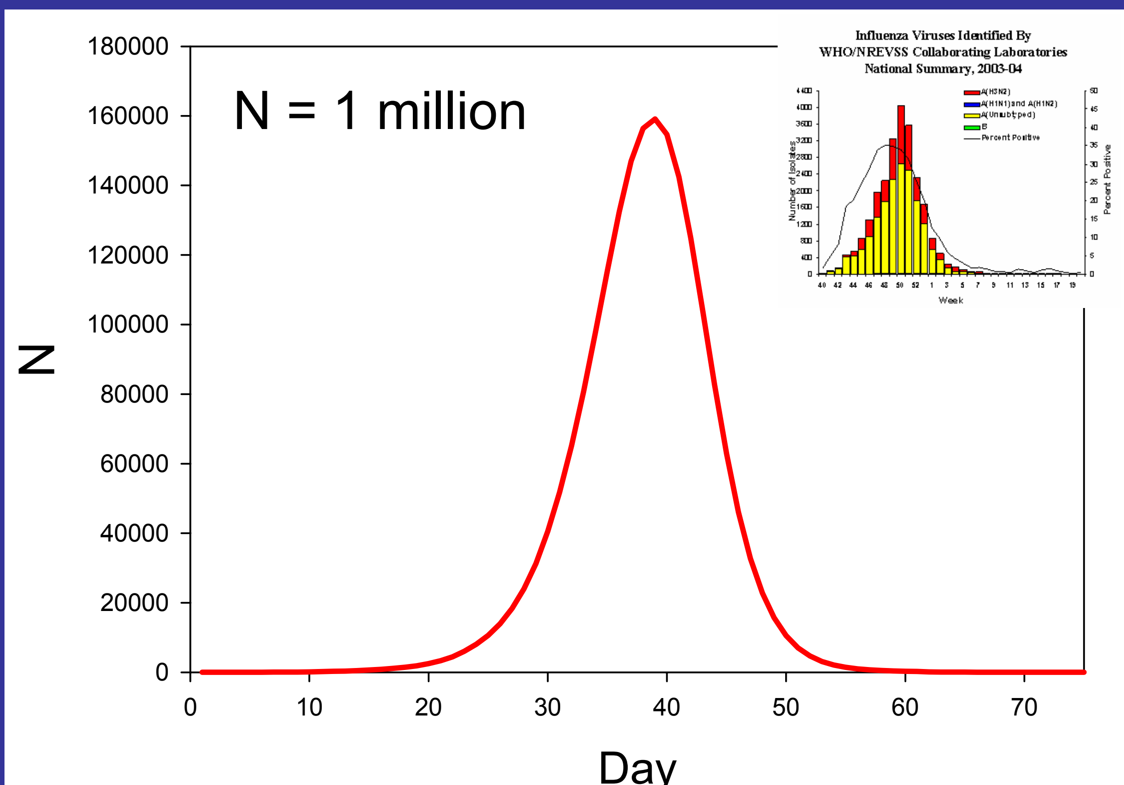
Conclusions (5)

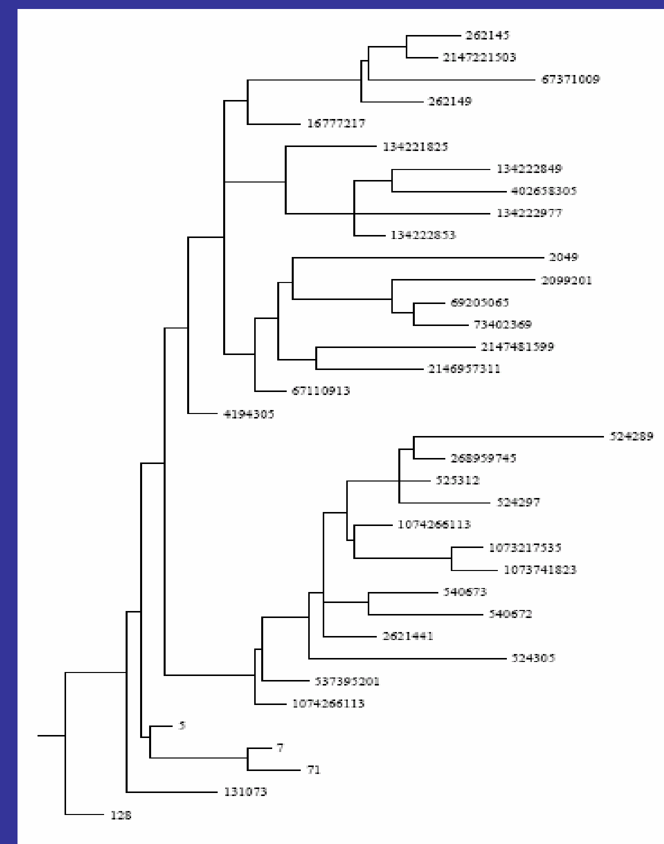
1. Structure of the transmission network influences the extent of the epidemic



Conclusions (5)

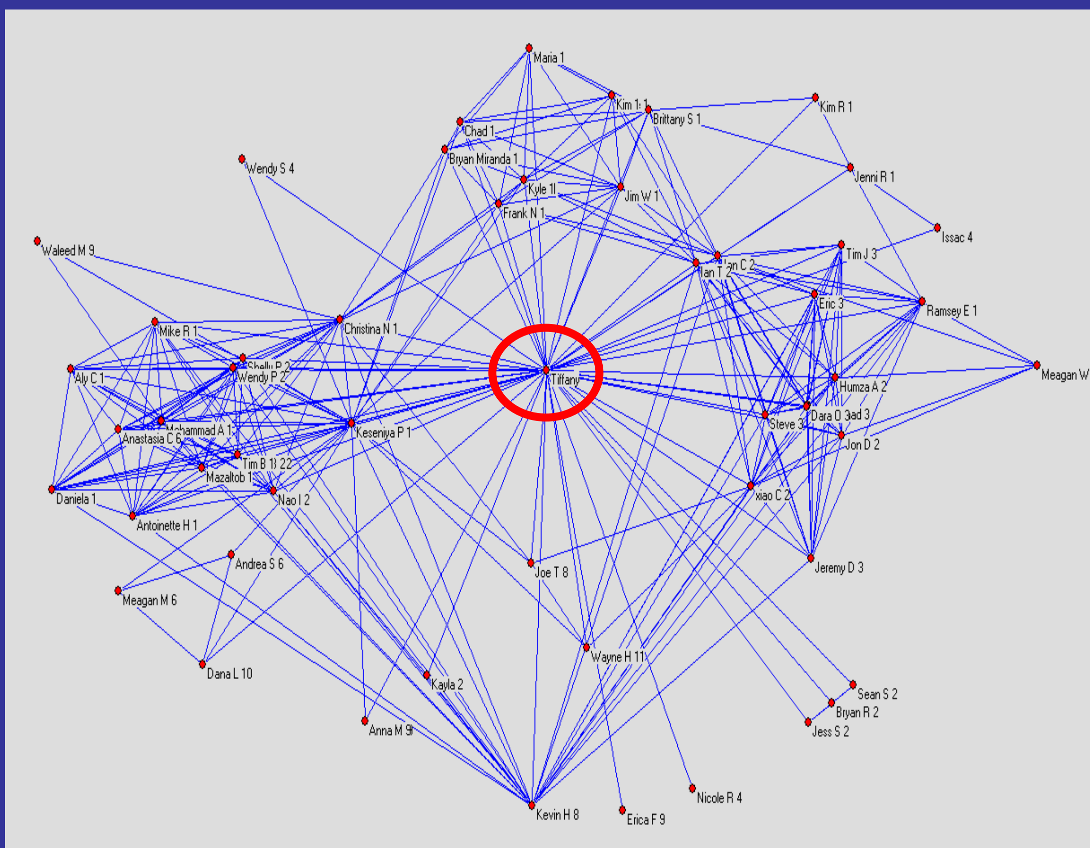
2. Model appears to simulate both the dynamics and evolution of influenza.

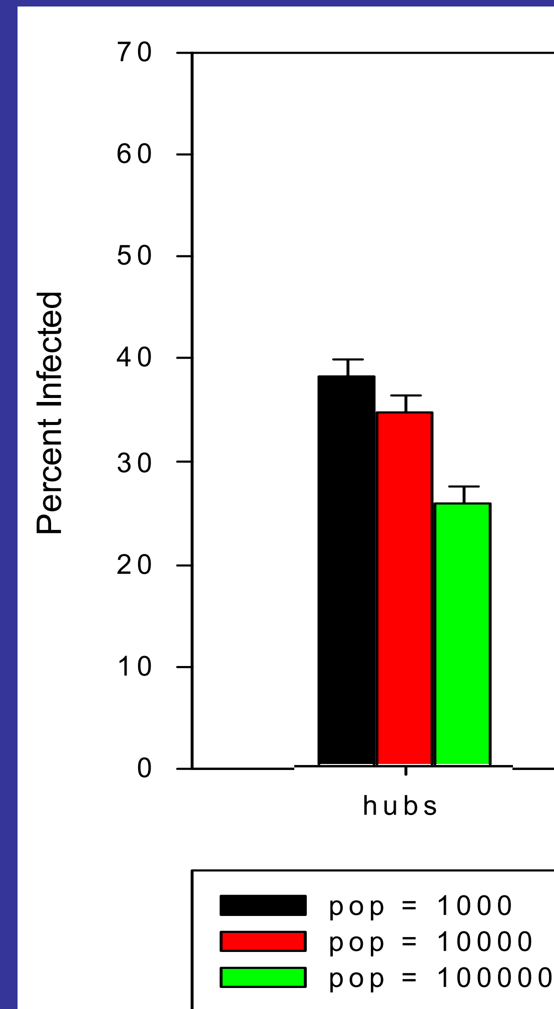




Conclusions (5)

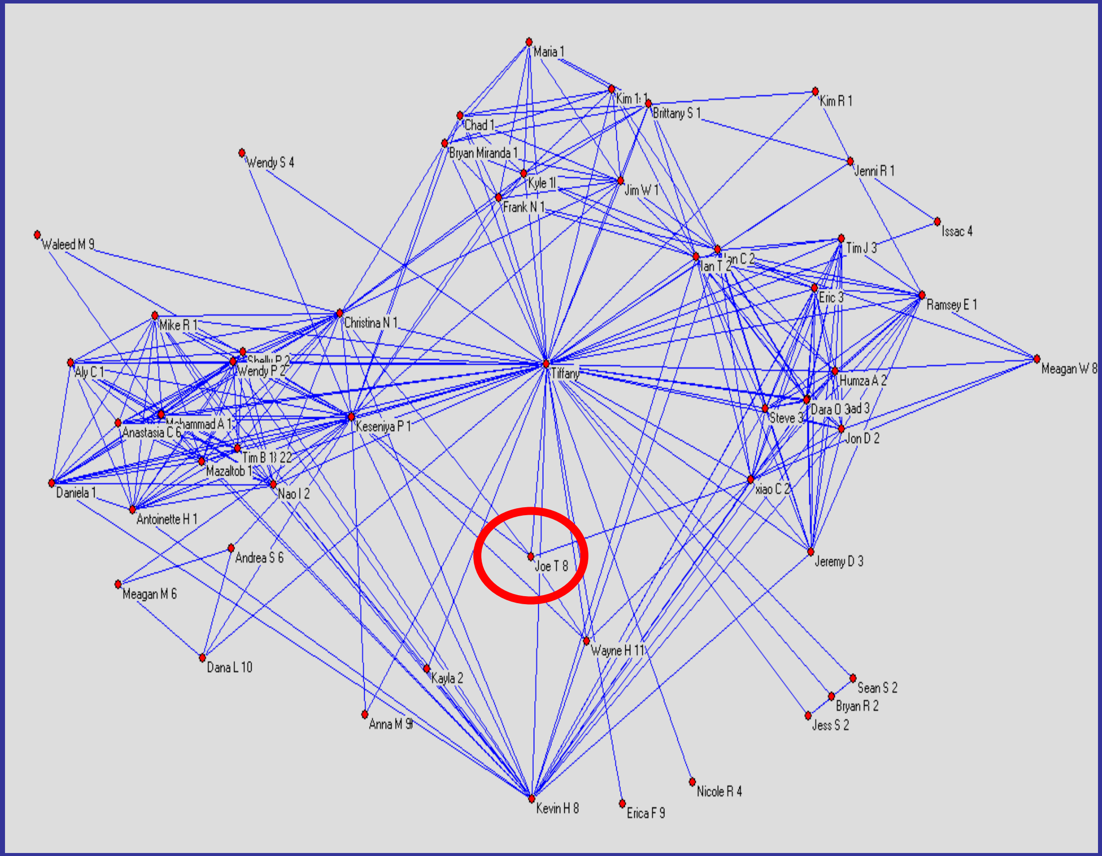
3. Best to vaccinate hubs. And this gets better as population size increases.

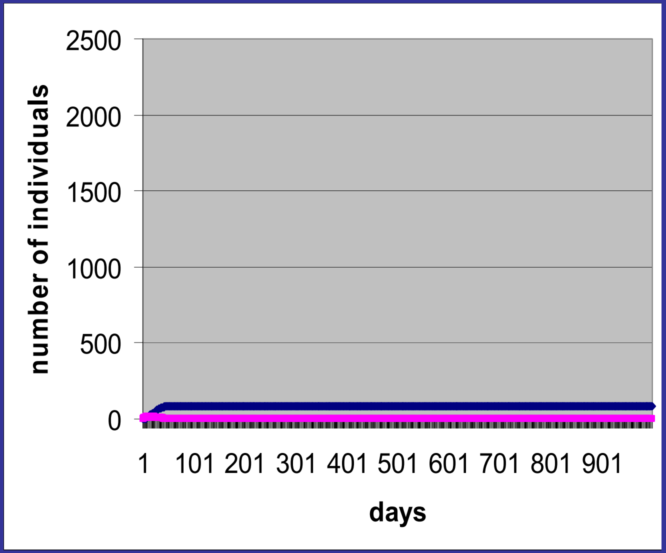




Conclusions (5)

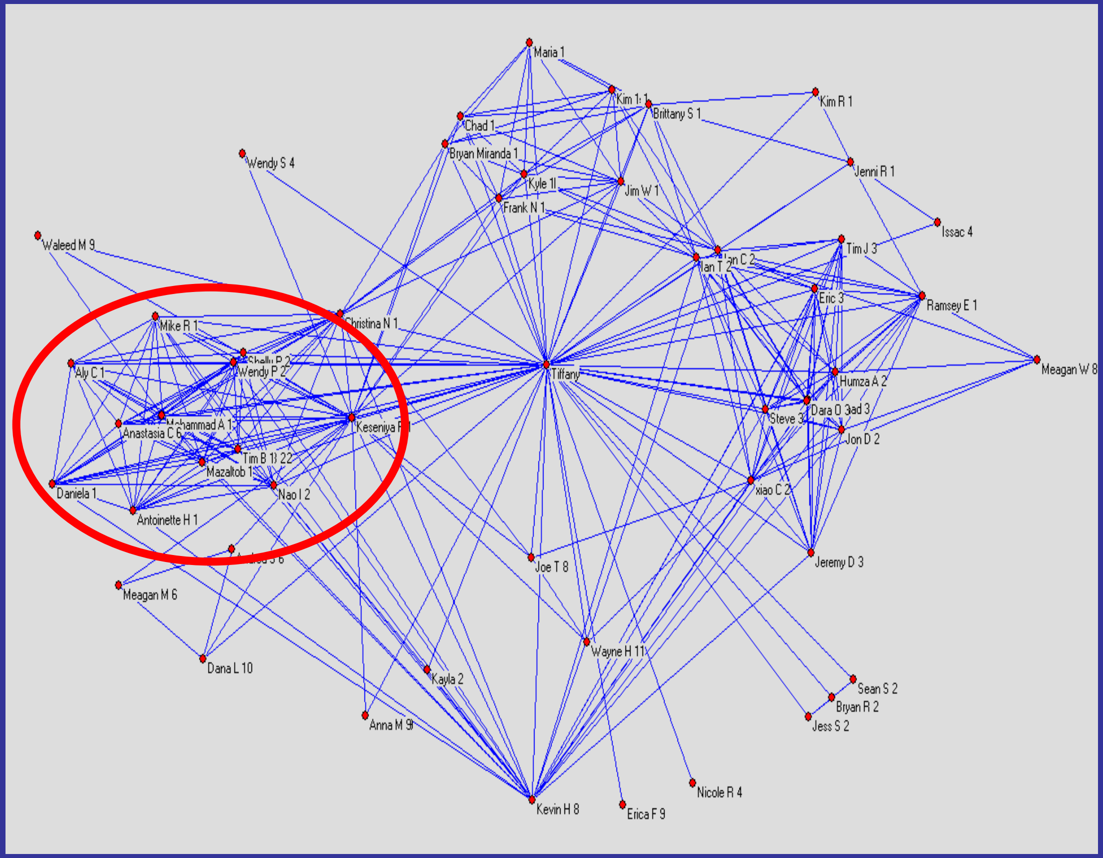
4. It’s good to vaccinate people whose friends don’t know each other.

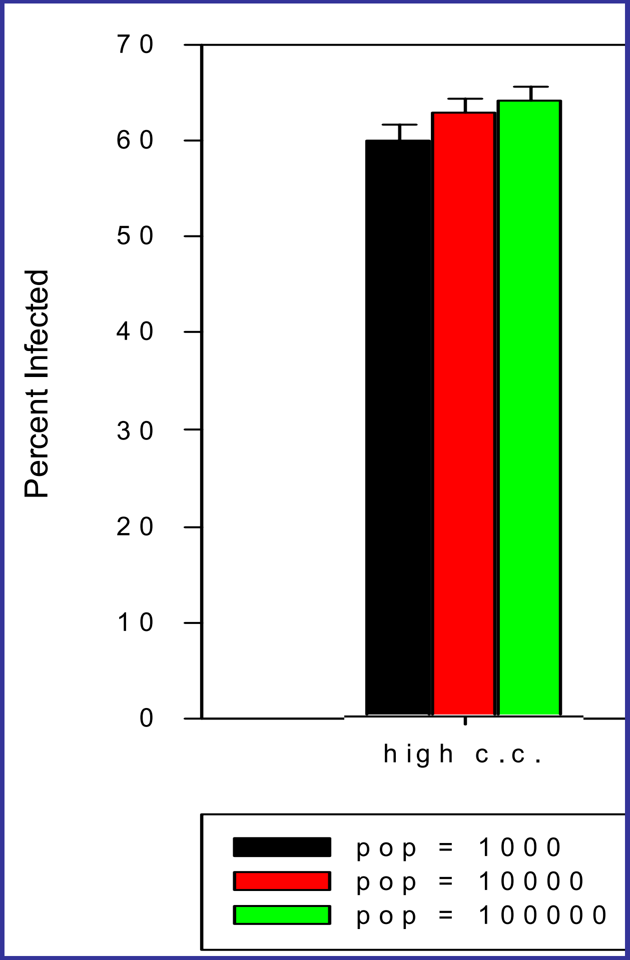




Conclusions (5)

5. Worst (worse than random) - vaccinate people whose friends all know each other (high clustering coef.)





CDC's Eight Priority Groups for Vaccination (All of Equal Importance)

2004 Vaccine Shortage

Who should get a flu vaccination?

People who are 65 years old or older —
Even if you're in great health!

Children 6 to 23 months old —
Children younger than 2 years old have one of the highest rates of hospitalization from influenza

Adults and children with a chronic health condition —
Like heart disease, diabetes, kidney disease, asthma, cancer, or HIV/AIDS

Women who will be pregnant during flu season —
Flu season is typically November through March

Residents of nursing homes and long-term care facilities

Children aged 6 months to 18 years on chronic aspirin therapy

Healthcare workers involved in direct patient care

Out-of-home caregivers and household contacts of children younger than 6 months

If you're not in one of these groups, you should not get vaccinated, to allow those at highest risk to get a shot.

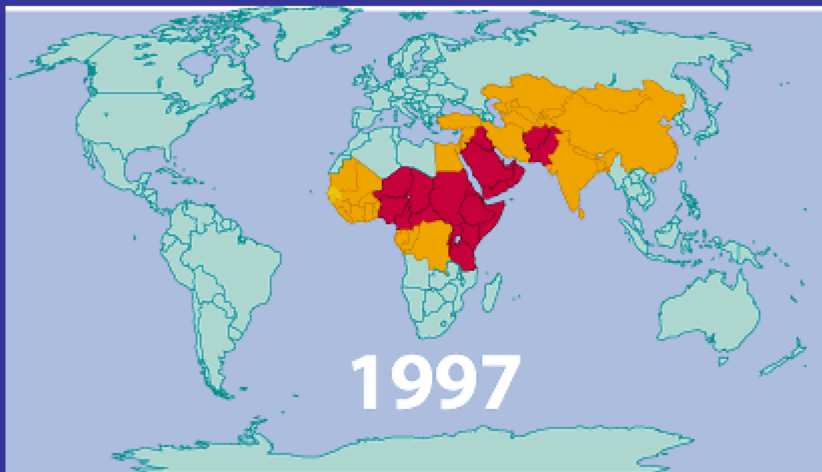
Department of Health and Human Services
Centers for Disease Control and Prevention

For more information, ask your healthcare provider or call the CDC Immunization Hotline
English and Español 800-CDC-INFO Website www.cdc.gov/flu

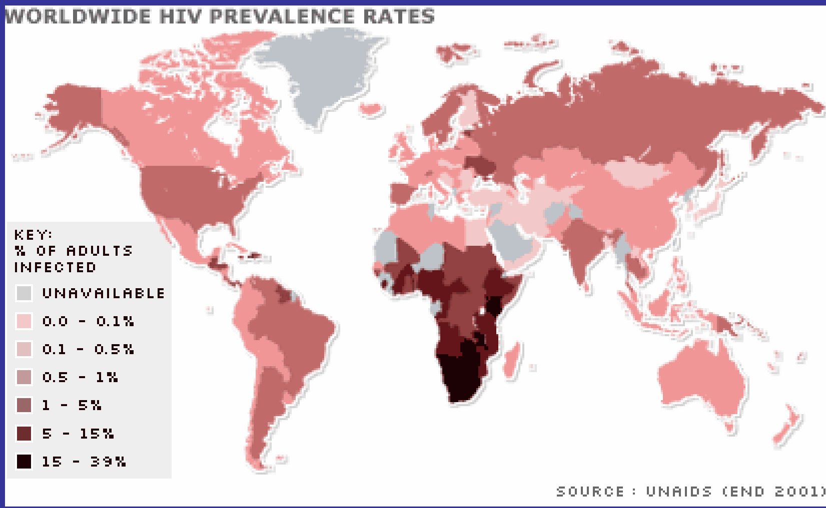
http://www.cdc.gov/flu
November 12, 2004

Modeling Other Systems?

Rinderpest

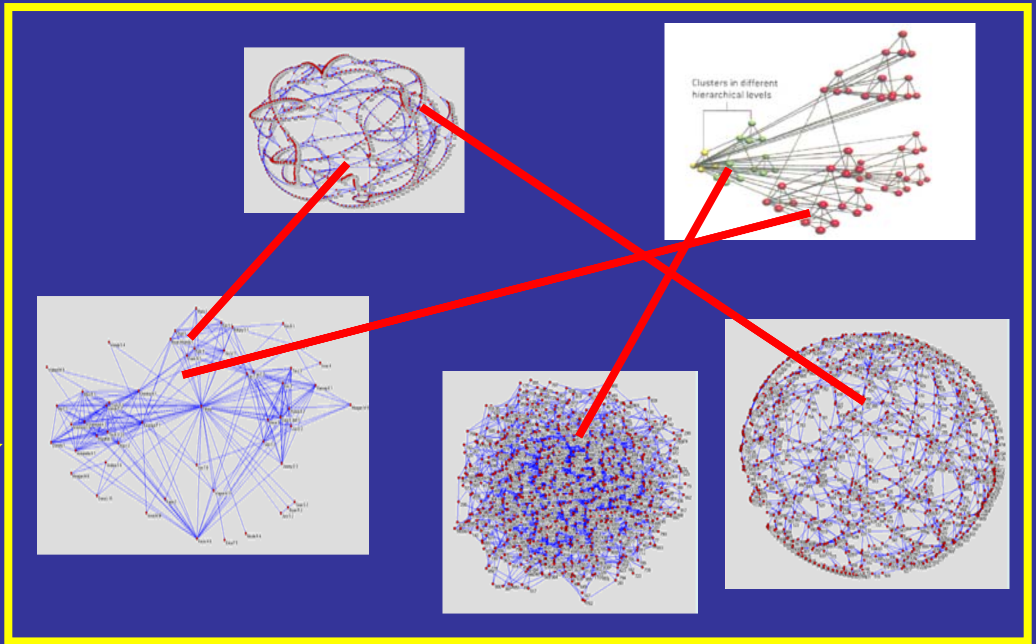


FAO - UN

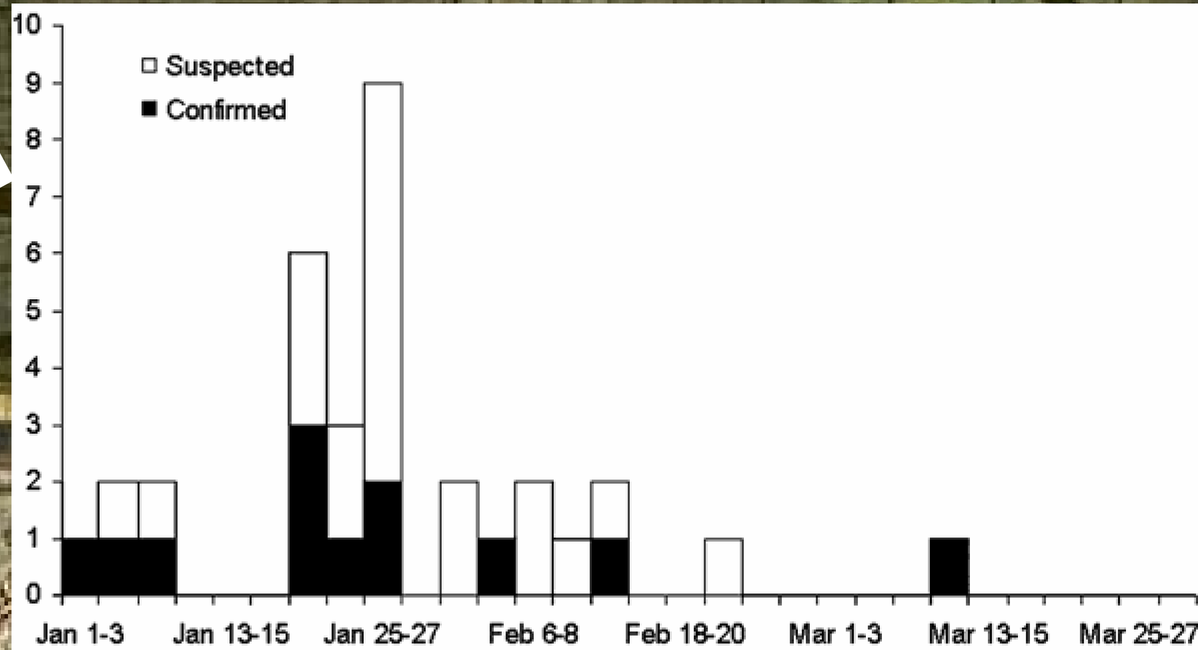


SARS (work by
Sarah Olscamp)

Homma Farian
Matthew Haas et al.



23 of 34 (68%) patients died



Epidemic curve showing the dates of onset for 12 confirmed and 21 suspected human cases of avian influenza A (H5N1) infection, Thailand, 2004.

Chotpitayasunondh, T. et al. 2005. Human disease from influenza A (H5N1), Thailand 2004. Emerging Infectious Disease 11(2): 201-209.

Acknowledgements:

Students

Amy Zielinski (Bio '06)
Jackie Dresch (Math '06)
Michelle Amsler (Biochem '05)
Shuya Kyu (Biochem '06)
Katrina Button (Bio/Math '04)
[**now a grad student at Mich State U.**]

Co-PIs

Chris Leary (Math)
Tony Macula (Math)
Wendy Pogozelski (Biochemistry)

NSF: DMS – Computational Mathematics
NSF: Undergraduate Training Grant in Mathematics and Biology
The Geneseo Foundation
SUNY Geneseo Biology Dept.
SUNY Geneseo Mathematics Dept.
SUNY Geneseo Computer Science Dept.