A Dynamic Patient Network Model of Hospital-Acquired Infections

Sean Barnes | Bruce Golden | University of Maryland, College Park

Edward Wasil | American University

Presented at the 2010 Winter Simulation Conference in Baltimore, MD

Motivation

The spread of infection is a huge problem, particularly in large, tertiary-care hospitals across the world

One approach: Ensure an 'adequate' ratio of health care workers (HCWs) to patients

<u>Objectives</u>

- Examine the contact network of patients within a hospital and determine how it affects transmission
- Quantify the effect of patient sharing between HCWs

Conceptual Model – Patient Network

Patients are connected by sharing a nurse and/or physician

Patient assignments can lead to various network configurations (i.e., densities) that effect transmission

Key parameters: # of patients, nurses, and physicians, sharing, alignment

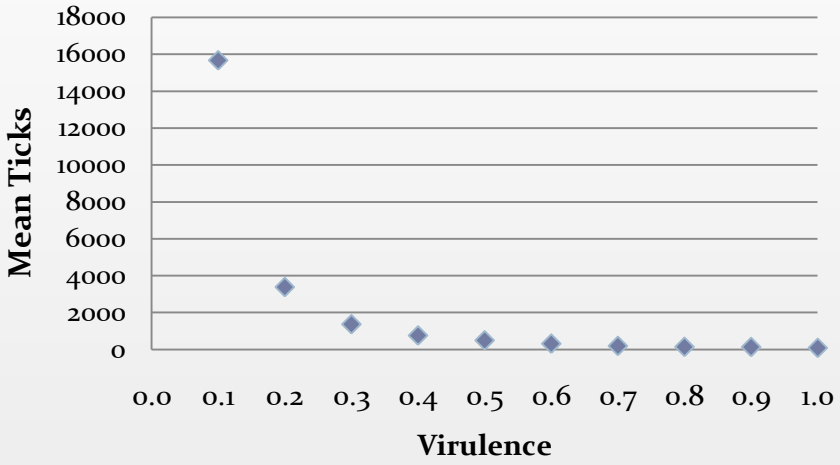
Conceptual Model – Transmission Dynamics

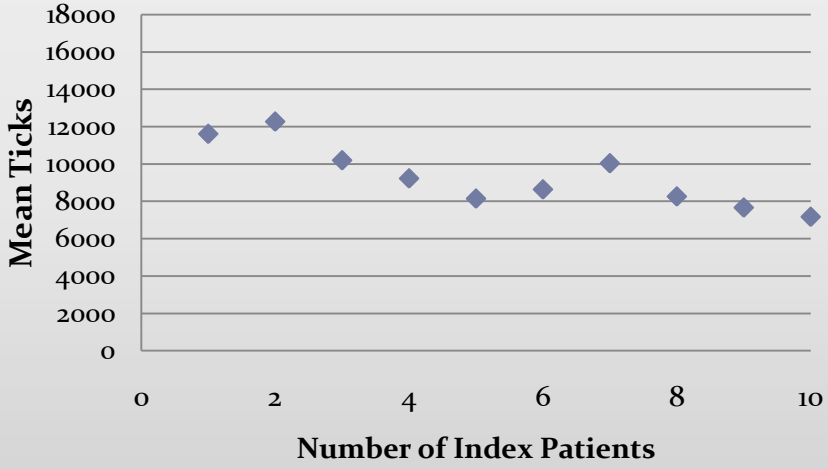
Infection originates index patient(s), who can transiently colonize an HCW

Transiently colonized HCWs can transmit to other patients

The pathogen can only spread along a network path between patients

<u>Key parameters</u>: *virulence, # of index patients*

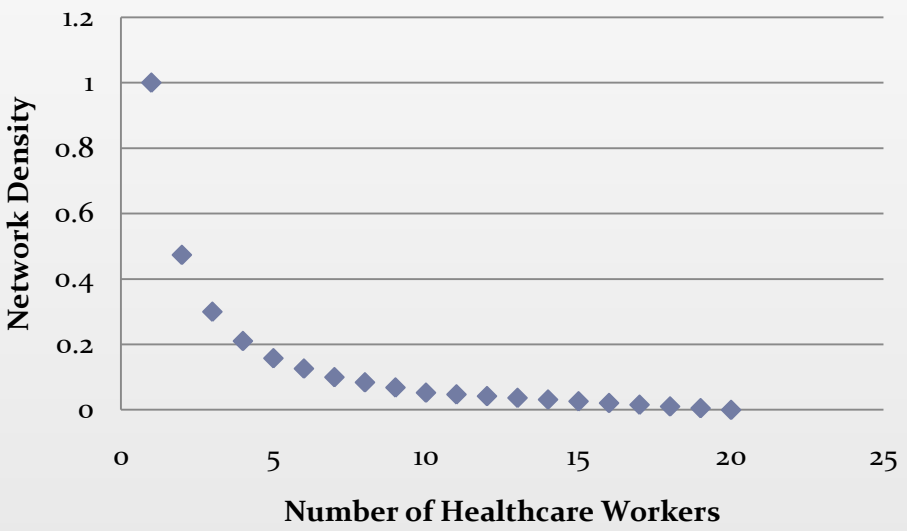




Network Density

Ratio of links in the network to the number of links in the complete network

$$d = \frac{\sum_k \binom{i_k}{2}}{\binom{n}{2}}$$

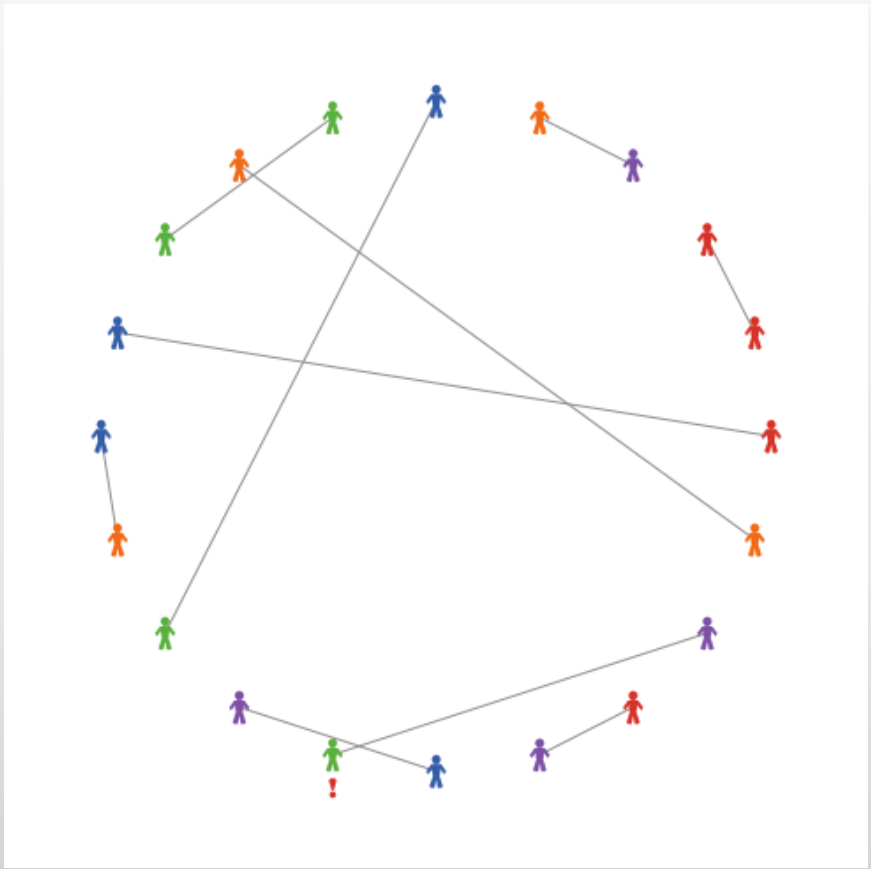


Example:

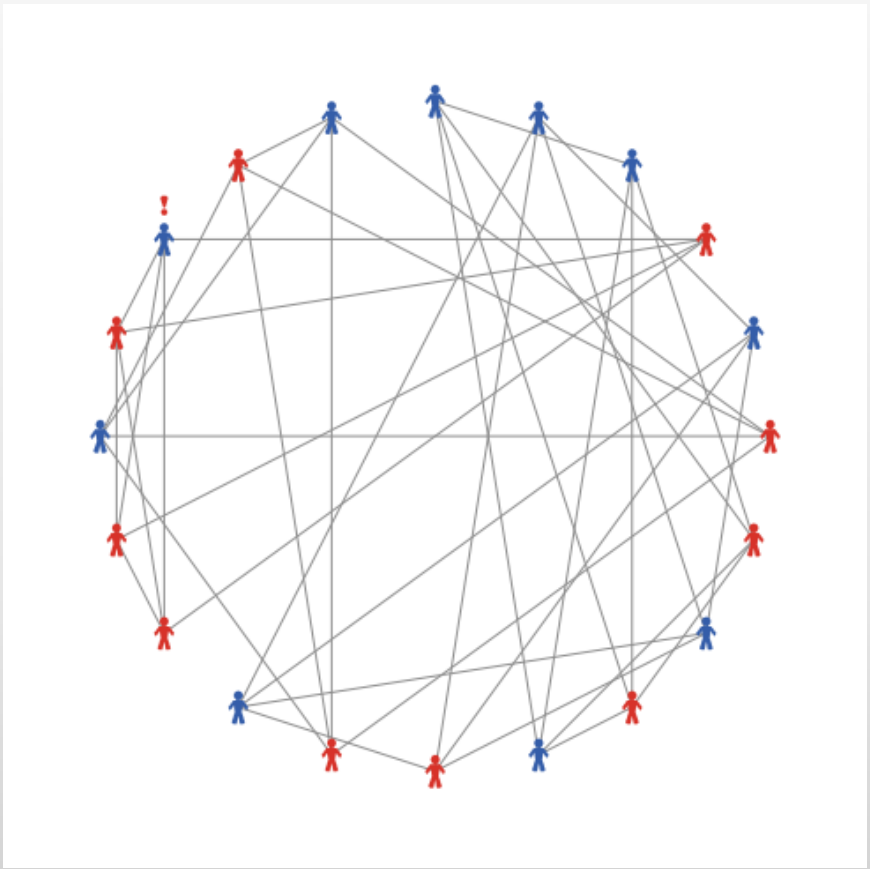
- 20-patient ICU with 10 nurses, 5 physicians
- Nurse density = 10(1)/(20(19)/2) = 0.0526
- Physician density = 5(4(3)/2)/(20(19)/2) = 0.1579

Patient Network Density Comparison

Nurse Density = 0.0526 (10)
Physician Density = 0.1579 (5)



Nurse Density = 0.2105 (4)
Physician Density = 0.4737 (2)



! - Index Patient

Patient Network Density Experiments

Key Parameters

- Number of patients = 20
- Virulence = 0.1
- Nurse visit rate = 0.80 and 0.70
- Vary # of nurses and physicians (network density)

Outputs

- Mean time to transmission: Average number of ticks that elapse between successive transmissions
- # of transmissions due to nurses and physicians

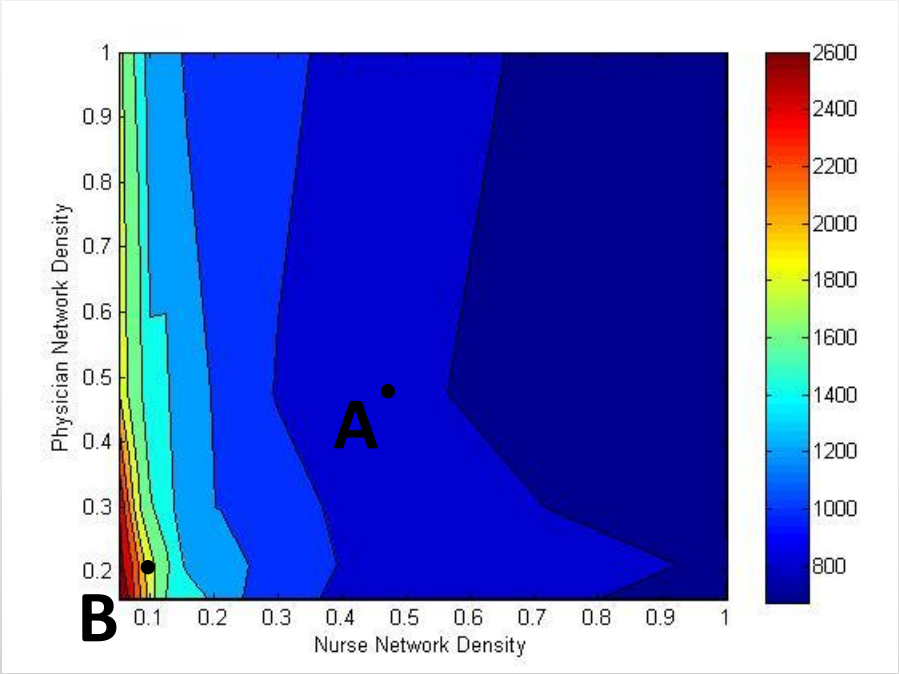
How does density affect the speed of transmission?

High density networks are extremely conducive to transmission

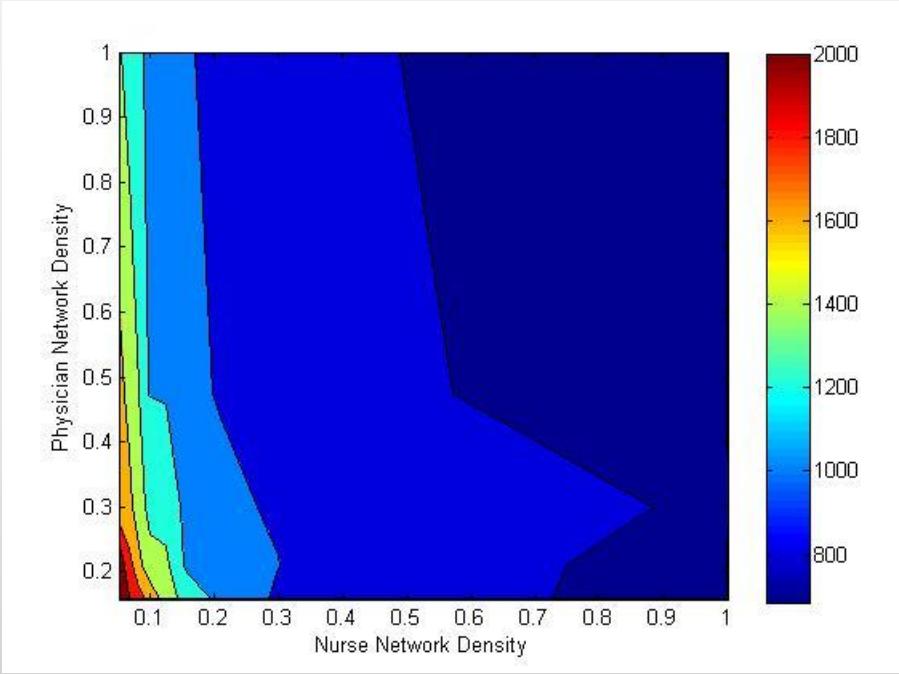
Transmission is strongly tied to the density of the nurse network

- More nurses are needed to minimize transmission, because they typically visit patients more often (1:3 ratio or better)

Nurse visit rate = 0.80



Nurse visit rate = 0.70

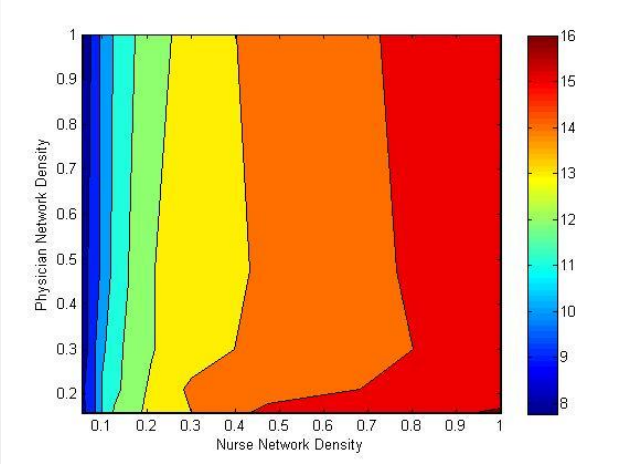


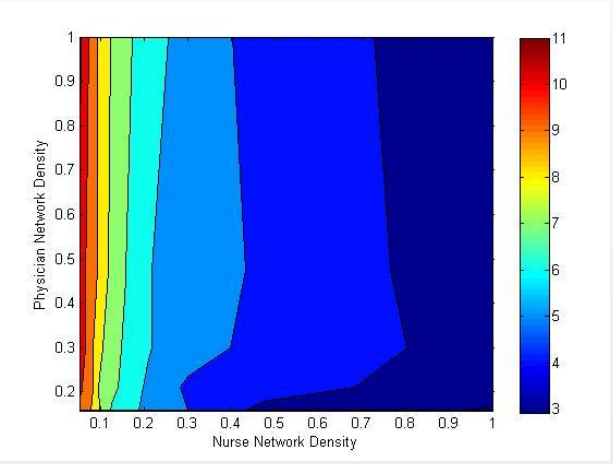
How does density affect the source of transmission?

Nurses account for most transmissions when densities are high, but physicians pose a potentially more serious threat

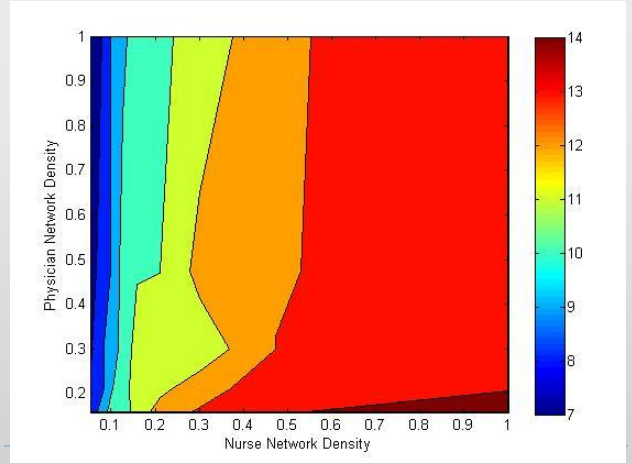
- Physicians become the predominant source when nurse densities are low
- They can also spread to multiple nurse cohorts

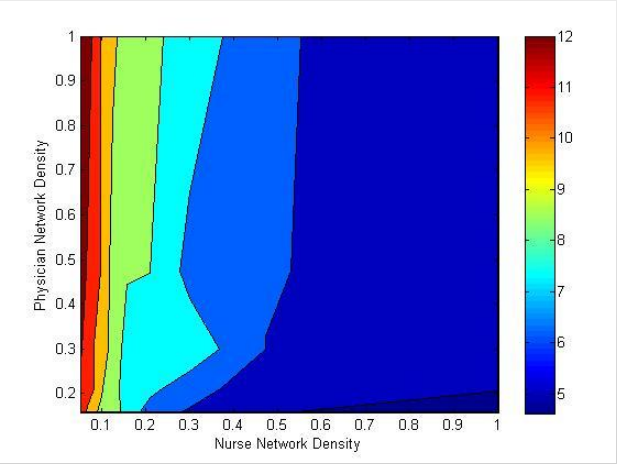
← Nurses | Physicians →





Nurse visit rate = 0.80





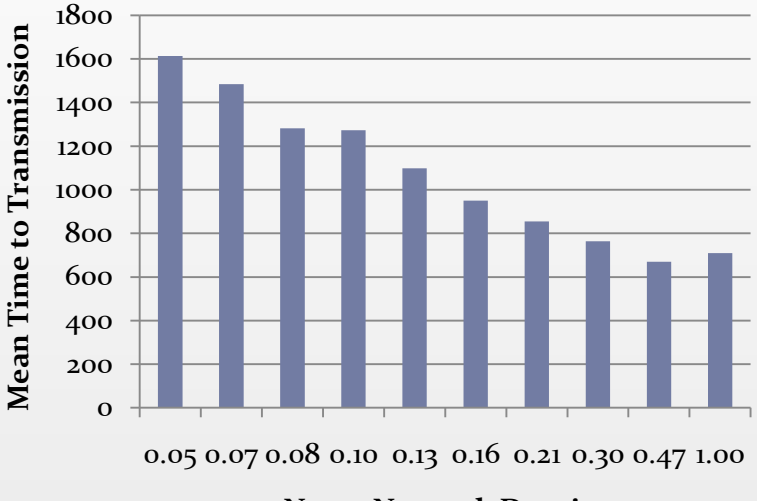
Nurse visit rate = 0.70

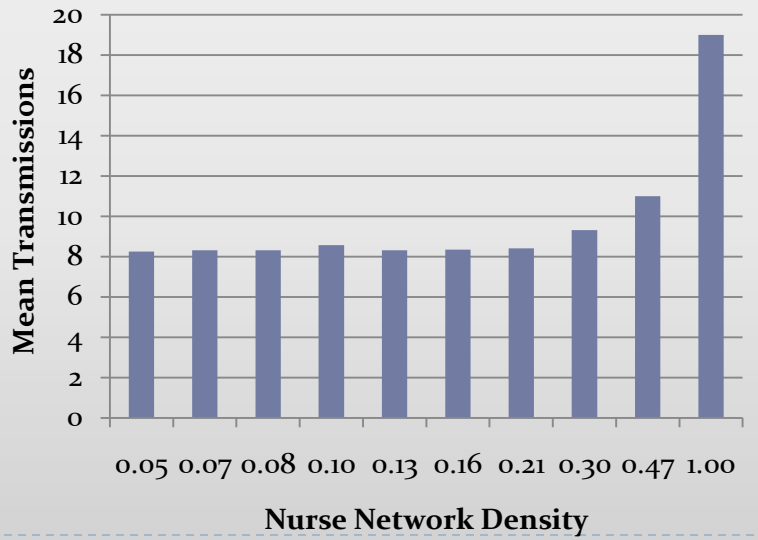
Cohort Alignment

We can assign patients strategically so as to minimize the potential for transmission

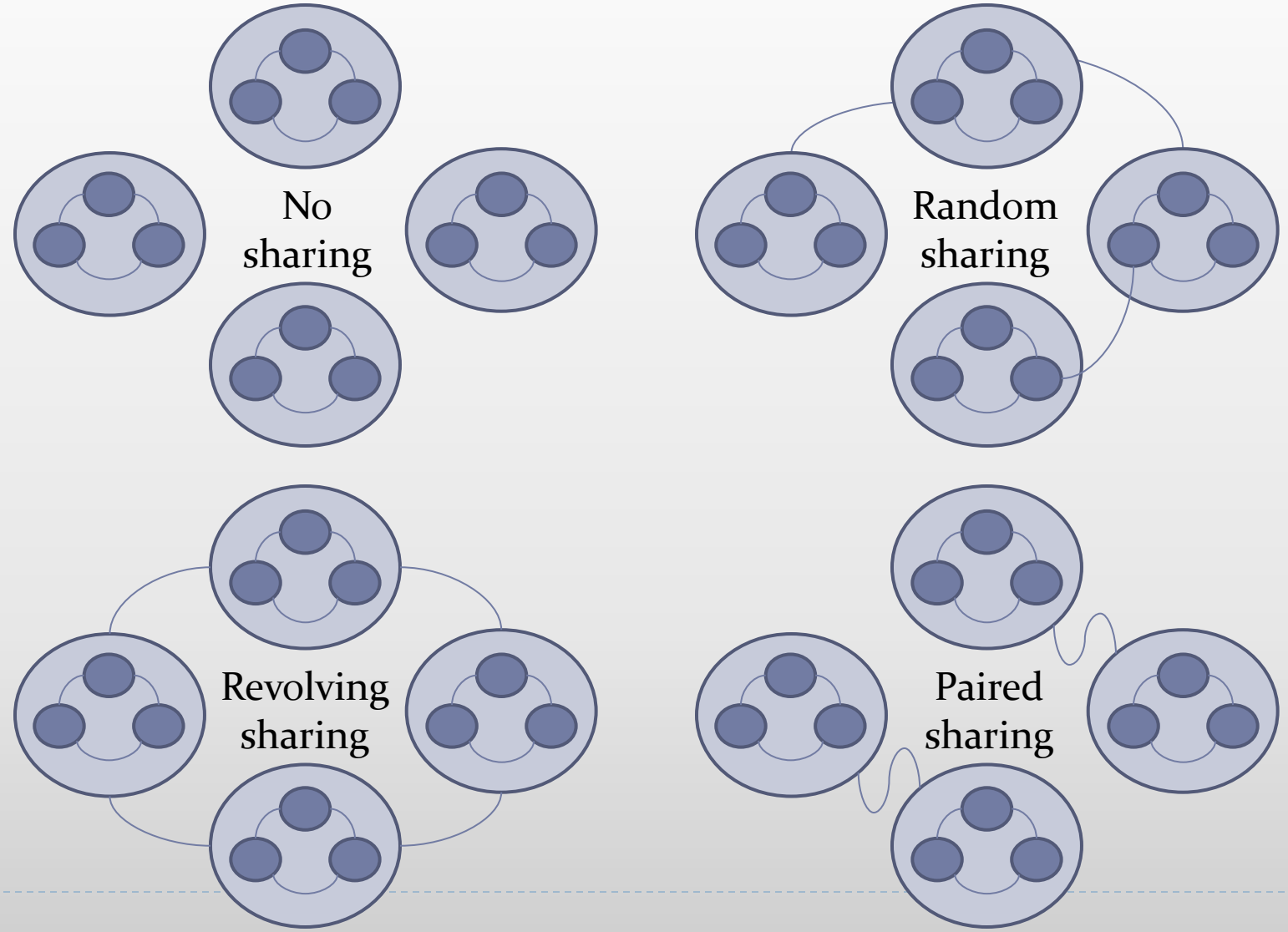
- Assign all patients in a nurse cohort to the same physician

Effect: Slows the rate of transmission and limits its extent



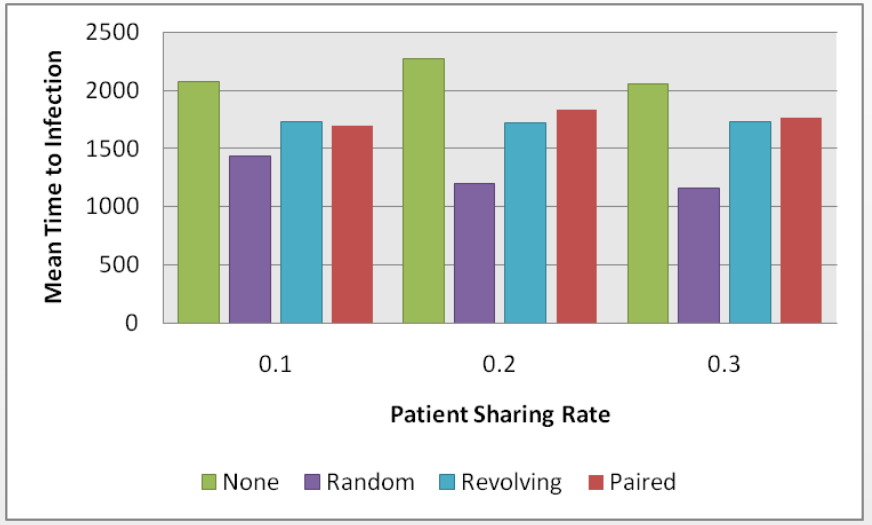


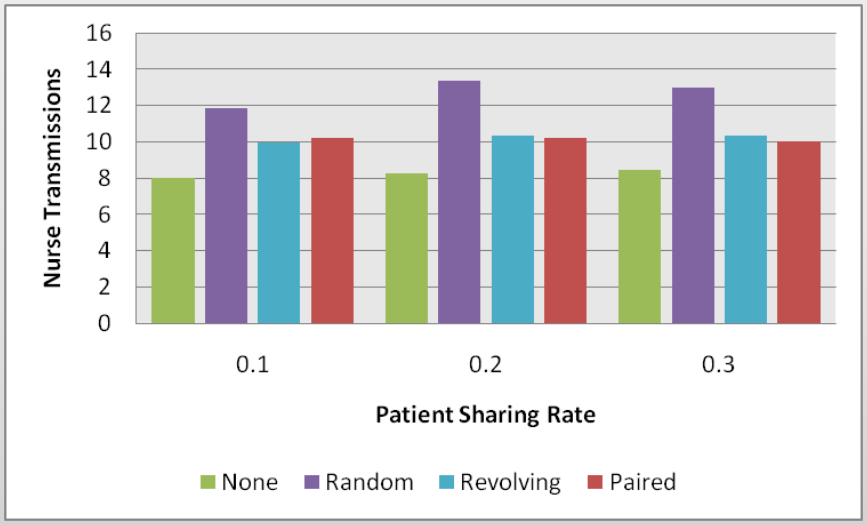
Patient Sharing

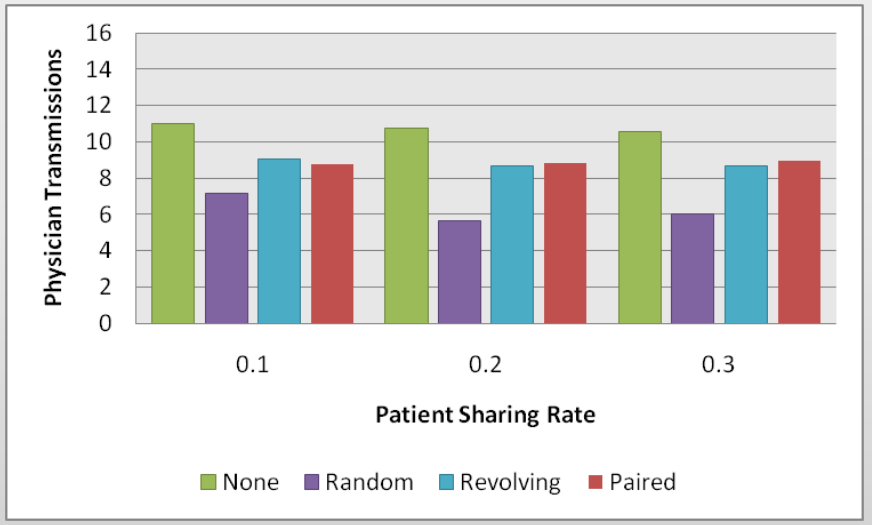


How does patient sharing affect transmission?

- No sharing is ideal but not realistic
- Random sharing is worst
  - 'Small world' effect
- Revolving and paired sharing have similar outcomes
  - Physicians equalize effects







Conclusions

Network structure provides a new perspective on transmission dynamics in a closed population:

- Both nurses and physicians are serious sources of transmission, but in different ways:
  - Nurses typically visit patients more often, and therefore have more opportunities to colonize patients
  - Physicians can spread to multiple nurse cohorts
- Minimizing transmission requires maintaining adequate densities for both networks
- Patient sharing should be kept to a minimum and, when done, should be done in a structured manner

Future Work

- Explore the effect of additional network metrics on transmission
- Incorporate admission dynamics
- Additional sharing configurations
- More complexity
  - Additional healthcare workers (e.g., technicians, residents)
  - Environmental contamination
  - Infection control measures
- Open to suggestions!