Practical: Airborne Infection Risk

Session objectives

1. Introduce disease dynamics and transmission modelling
2. Introduce the parameters that affect airborne transmission and Wells-Riley model
3. Demonstrate how it can be coupled with SEIR models
4. Use simple spreadsheet models to explore the effect of parameters and interventions

Disease Transmission

Source

Infectious microorganism

Hazardous substance

Recipient

You

Human behaviour

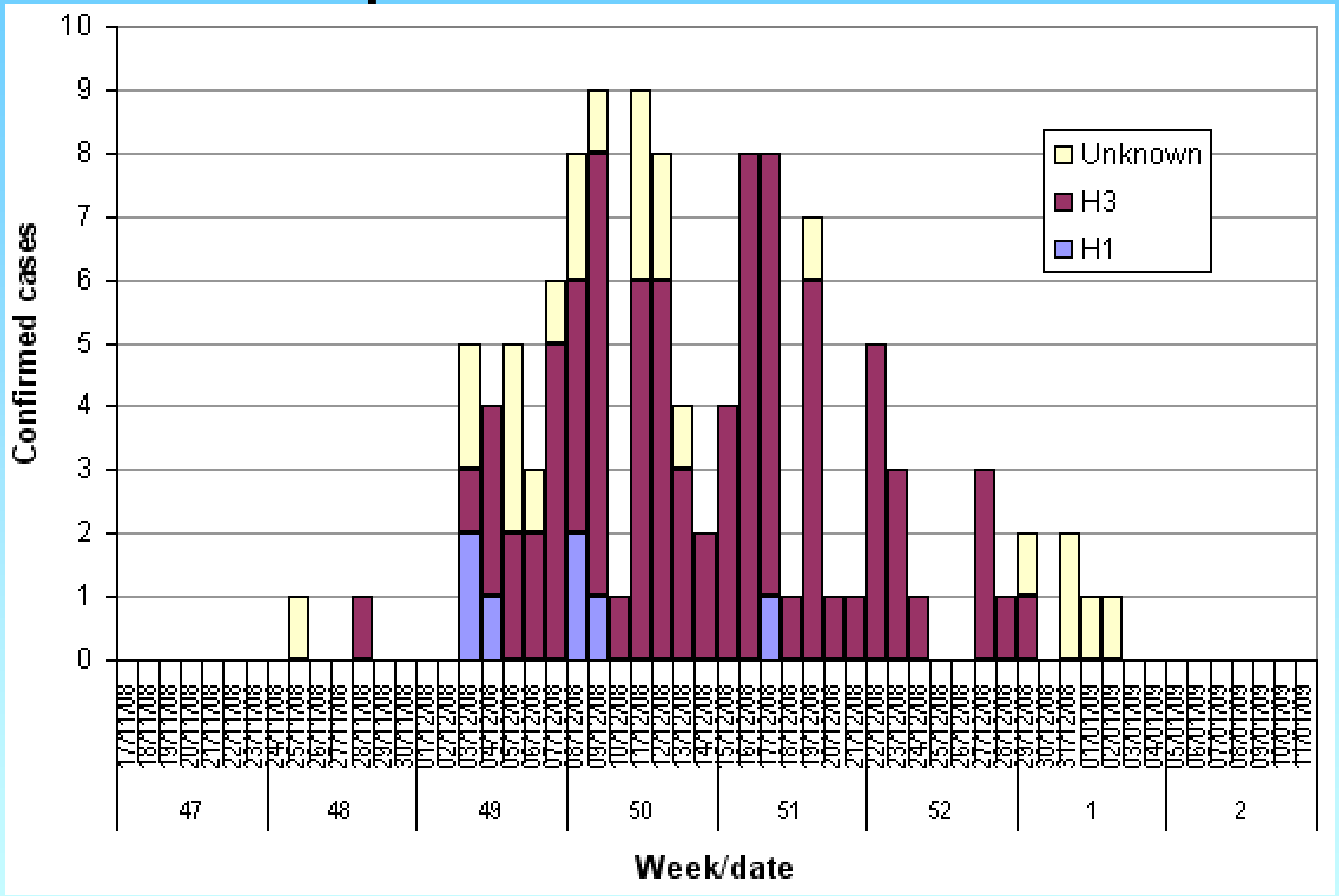
The environment

Disease Dynamics

- Spread of disease depends on many factors:
  - The pathogen concerned - virilence, survival
  - The population of people and their susceptibility to the disease
  - The mode of transmission
  - The time between being exposed to the disease and becoming infectious
  - The symptoms
  - The ability and ease of passing the disease on

  ....

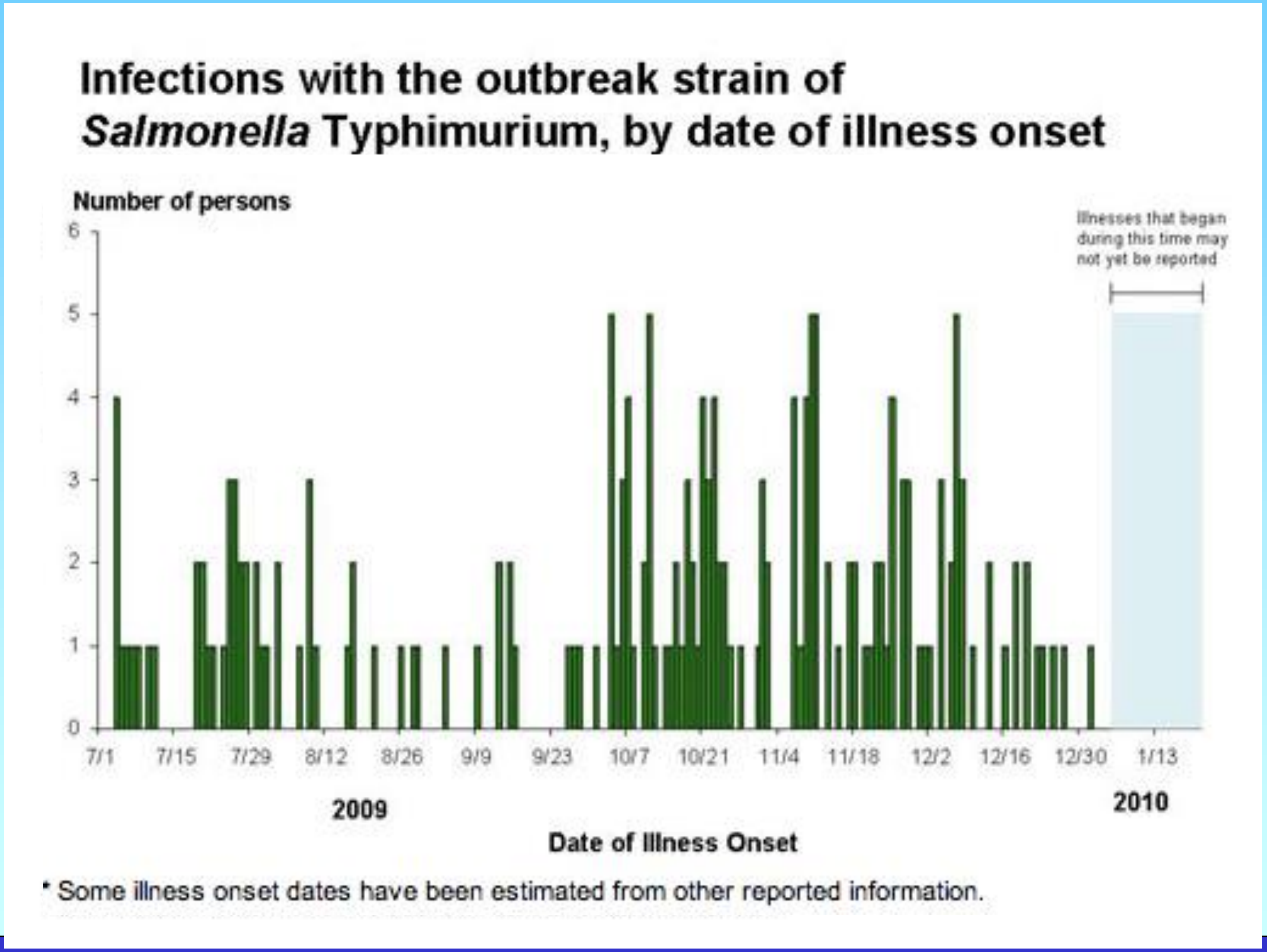
Outbreak patterns



Royal Liverpool University Hospital, and influenza-like illness rates in Liverpool between week 47/2008 and week 2/2009

HPA, www.hpa.org.uk/hpr/archives/2009/news0509.htm

Outbreak patterns



CDC: www.cdc.gov/salmonella/typhimurium/epi_curve.html

Modelling disease transmission

- Models allow assessment of the relative importance of disease parameters
- Describe the progression of disease over time
- Enable intervention or response to disease

- Earliest model – Daniel Bernolli, vaccination against small pox
- Modern approaches based on models of Reed and Frost (1920's) and McKendrick and Kermack (1927)

Model requirements

- Will an infection spread?
- How fast will it spread?
- How many people will be affected?
- How long will the outbreak last?
- What interventions are the most effective?

- In air – how does the building and human breathing ventilation affect risk?

Wells-Riley Model

- Probability of infection (Pr) linked to disease, occupant and ventilation characteristics

$$\Pr = 1 - e^{\left(\frac{Iqpt}{Q}\right)}$$

- Usually used to model new infections (N_C) for S susceptibles

$$N_C = S(1 - e^{\left(\frac{Iqpt}{Q}\right)})$$

Q = ventilation rate (m^3/s)

P = breathing rate (m^3/s)

I = number of infectors

S = number of susceptibles

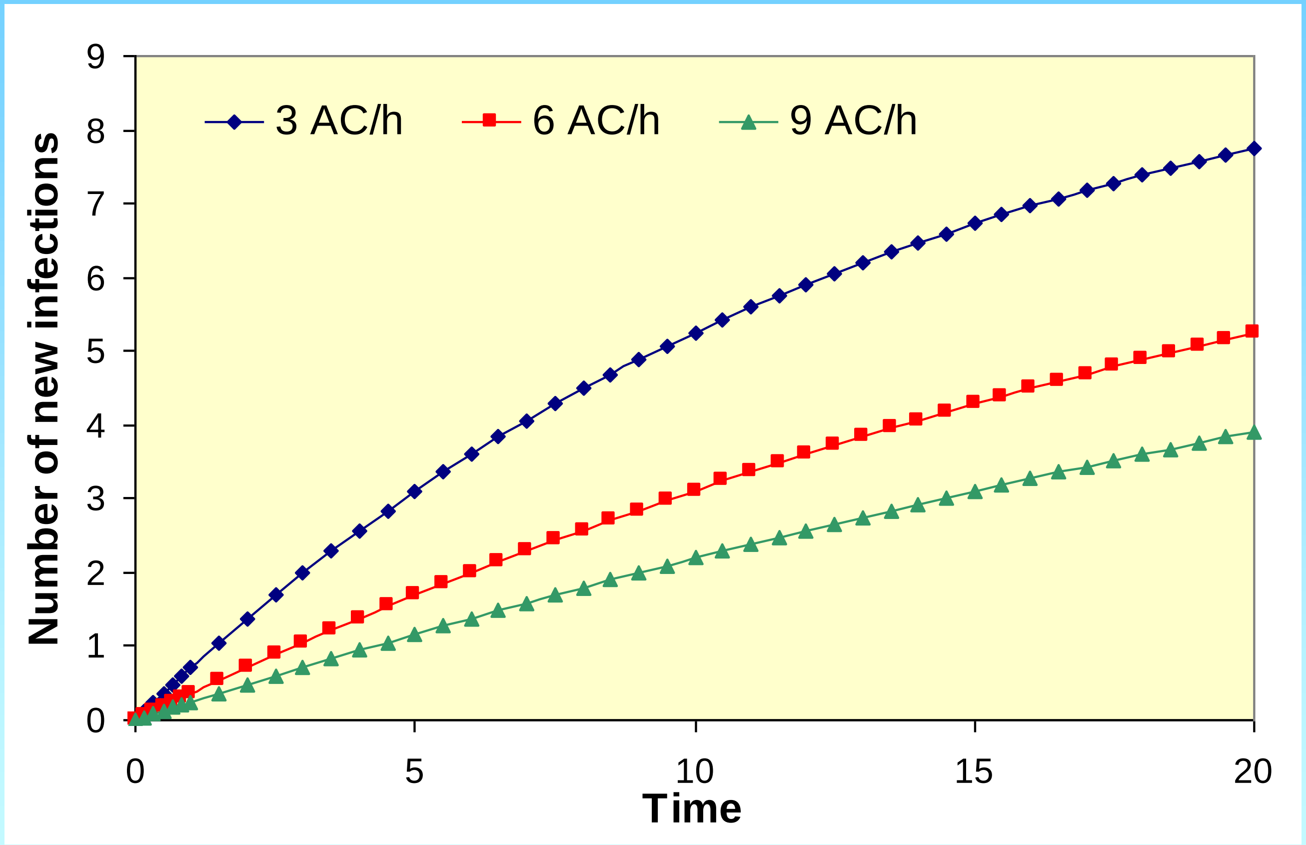
Quanta (q)

- Rate of generation of “infectious doses”
- Encompasses concentration, virilence, host susceptibility
- Used in wide range of risk analysis studies and assessment of disease outbreaks
- Usually estimated from past outbreak data – but not always reliable

Infectious Dose

Disease	Case	Quanta/h	Reported by
TB	Average TB patient	1.25	Nardell *et al* (1991)
TB	Outbreak in office building	12.7	Nardell *et al* (1991)
TB	Human to guinea pig transmission	0.3-44	Escombe et al (2007)
MDR TB	Human to guinea pig transmission (highest infectors)	40,52,226	Escombe et al (2008)
Measles	Outbreak in a school	570	Rudnick &Milton(2003)
Influenza	School cases in Taiwan	66.91 (LN*)	Liao et al (2005)
Influenza	Aircraft outbreak	79-128	Rudnick &Milton(2003)
SARs	Taipei Hospital outbreak	28.77 (LN*)	Liao et al (2005)
Rhinovirus 16	Experimental data of Dick et al 1987	1-10	Rudnick &Milton(2003)

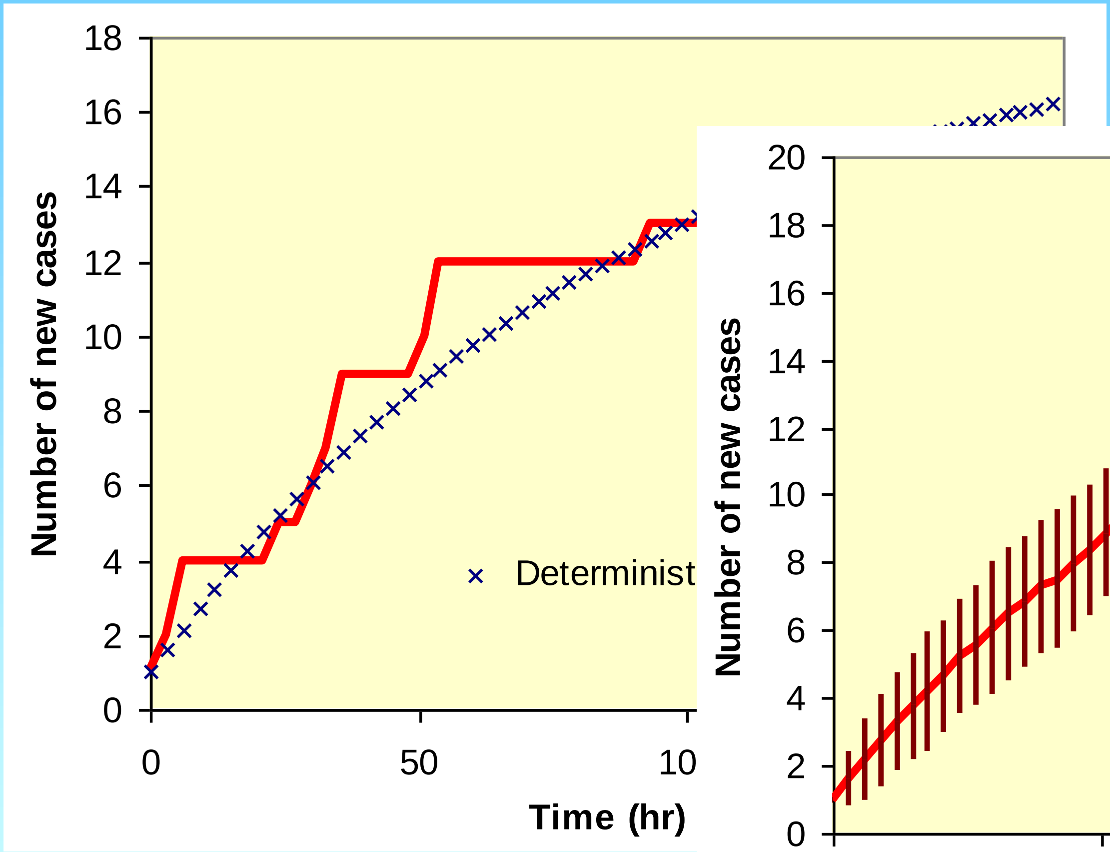
Wells-Riley Results

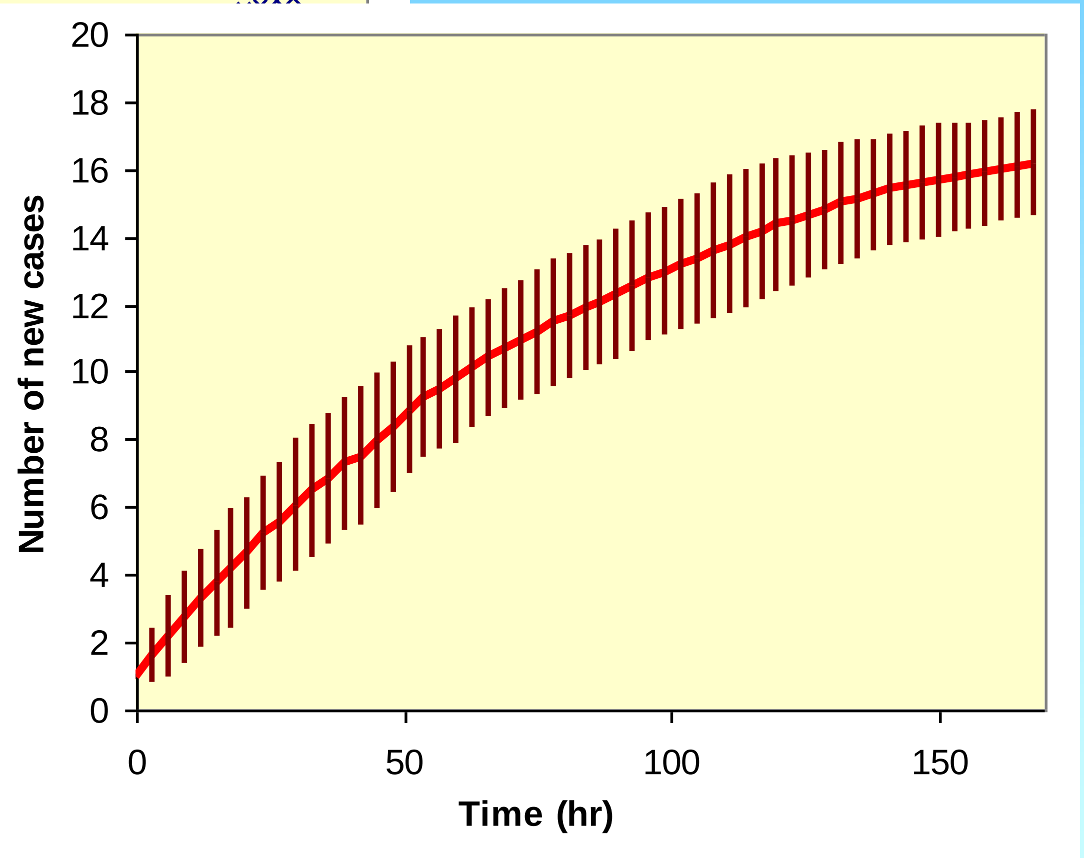


Fully mixed room: 10 susceptibles, 1 infector, 12 quanta/hr,

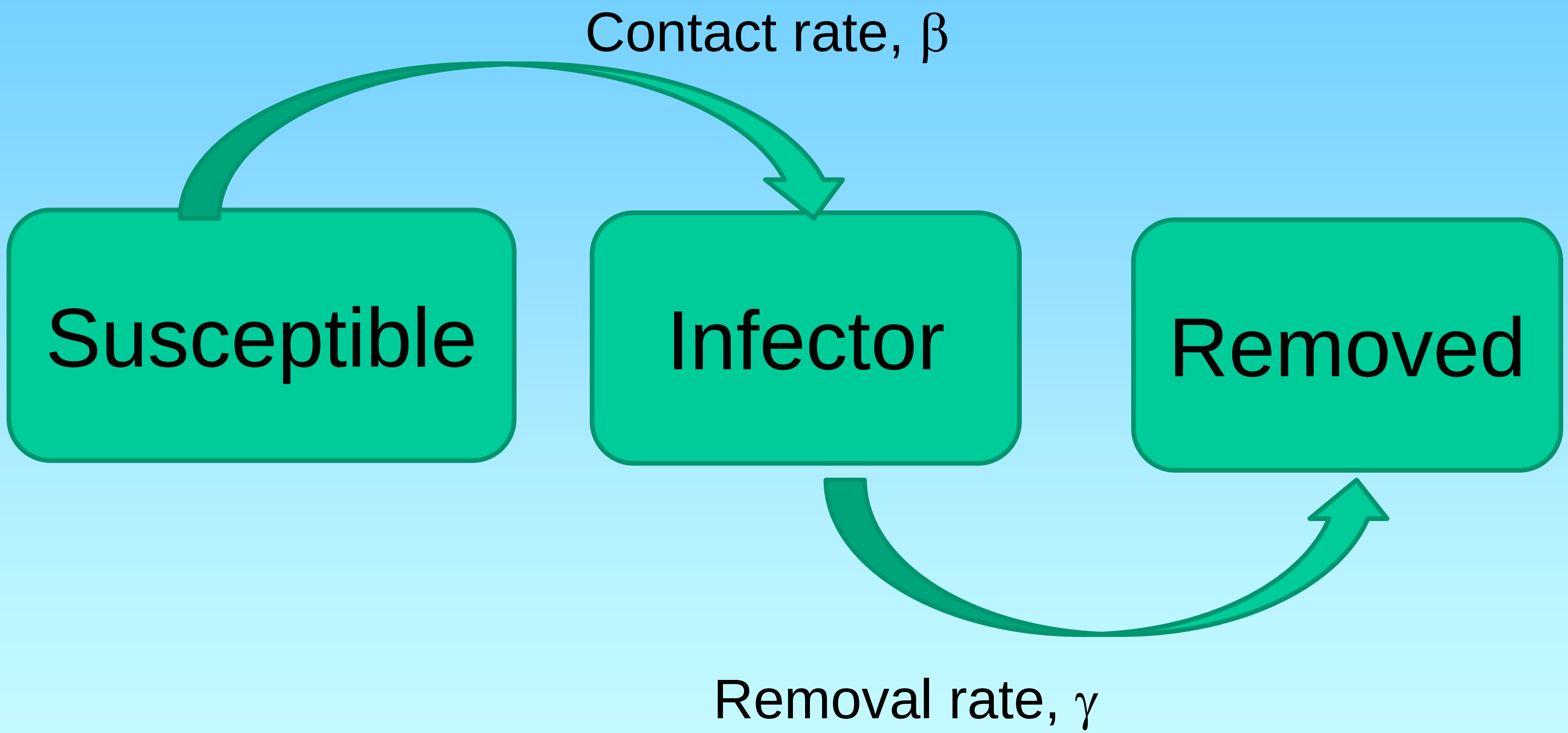
10 l/min pulmonary ventilation, 32.25 m^3 room

Stochastic Effects





Epidemic models



SIR Deterministic Formulation

- For a closed population of N people – no increase or decrease eg. Birth rate

$$N = S + I + R$$

- Assume homogeneity - every person has the same probability of infection, with contact rate β
- People recover at a rate $\gamma = 1$/duration of infection
- Consider rate of transition between states
- Expressed as ordinary differential equations

SIR Deterministic model

$$\frac{dS}{dt} = -\beta SI$$

Rate susceptibles become infectious

$$\frac{dI}{dt} = \beta SI - \gamma I$$

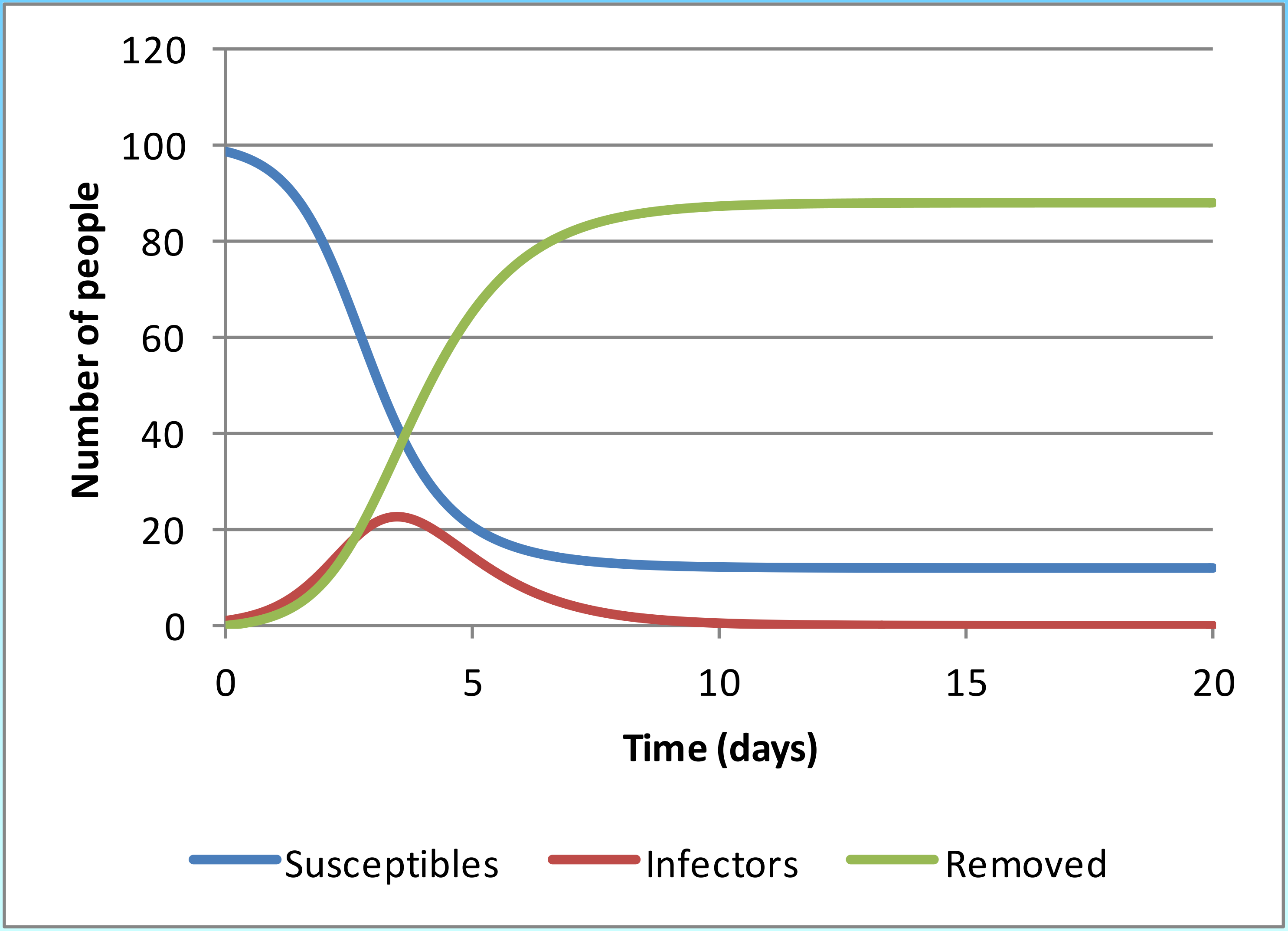
Rate infectors change = new infectors – those who recover/are removed

$$\frac{dR}{dt} = \gamma I$$

Rate infectors recover/are removed

Numerical solution is straightforward

SIR outputs



120
100
80
60
40
20
0
Number of people
0
5
10
15
20
Time (days)
Susceptibles
Infectors
Removed

Reproduction rate

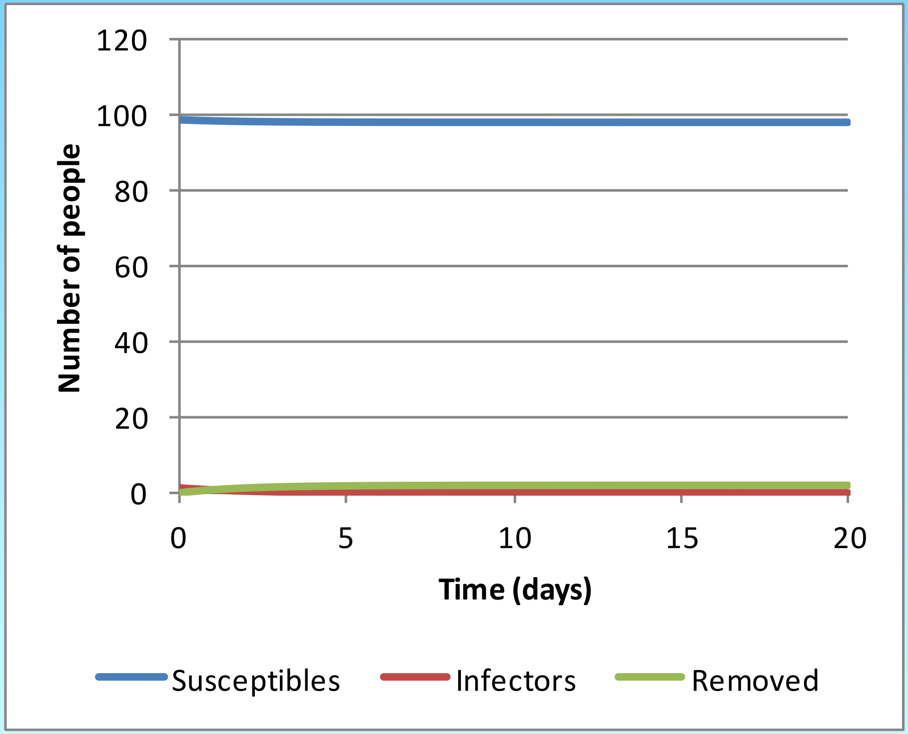
- Measure of rate of spread of an infection

Ro = number of secondary cases produced by an infector

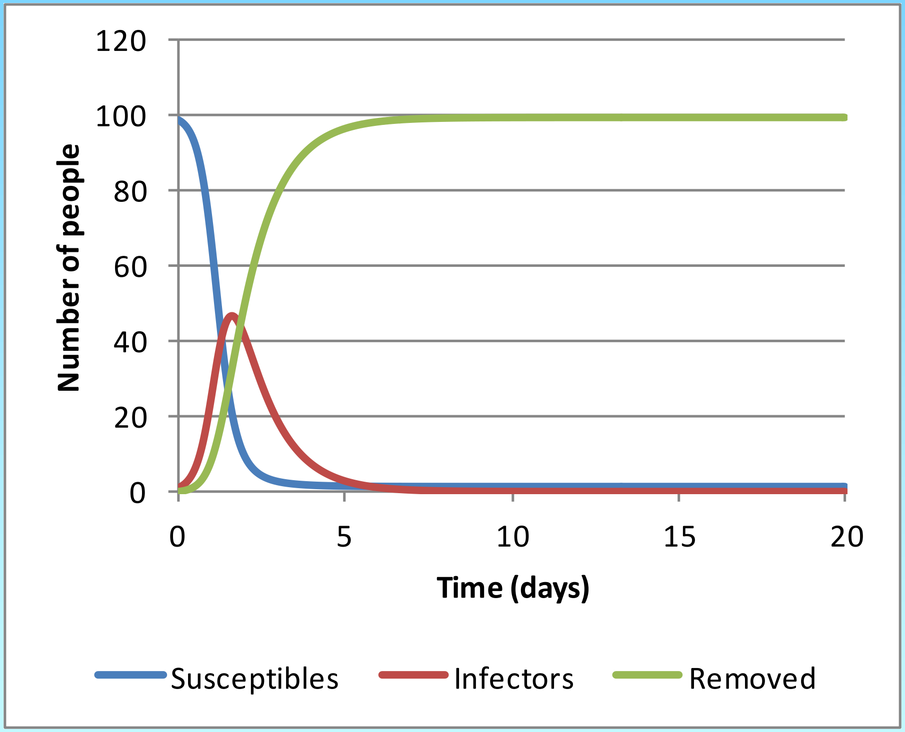
- Ro < 1: infection will die out
- Ro > 1: infection will spread through
- Ro = 1: Epidemic threshold
- Can estimate from

$$Ro = N \frac{\beta}{\gamma}$$

Epidemic threshold



Ro < 1



Ro > 1

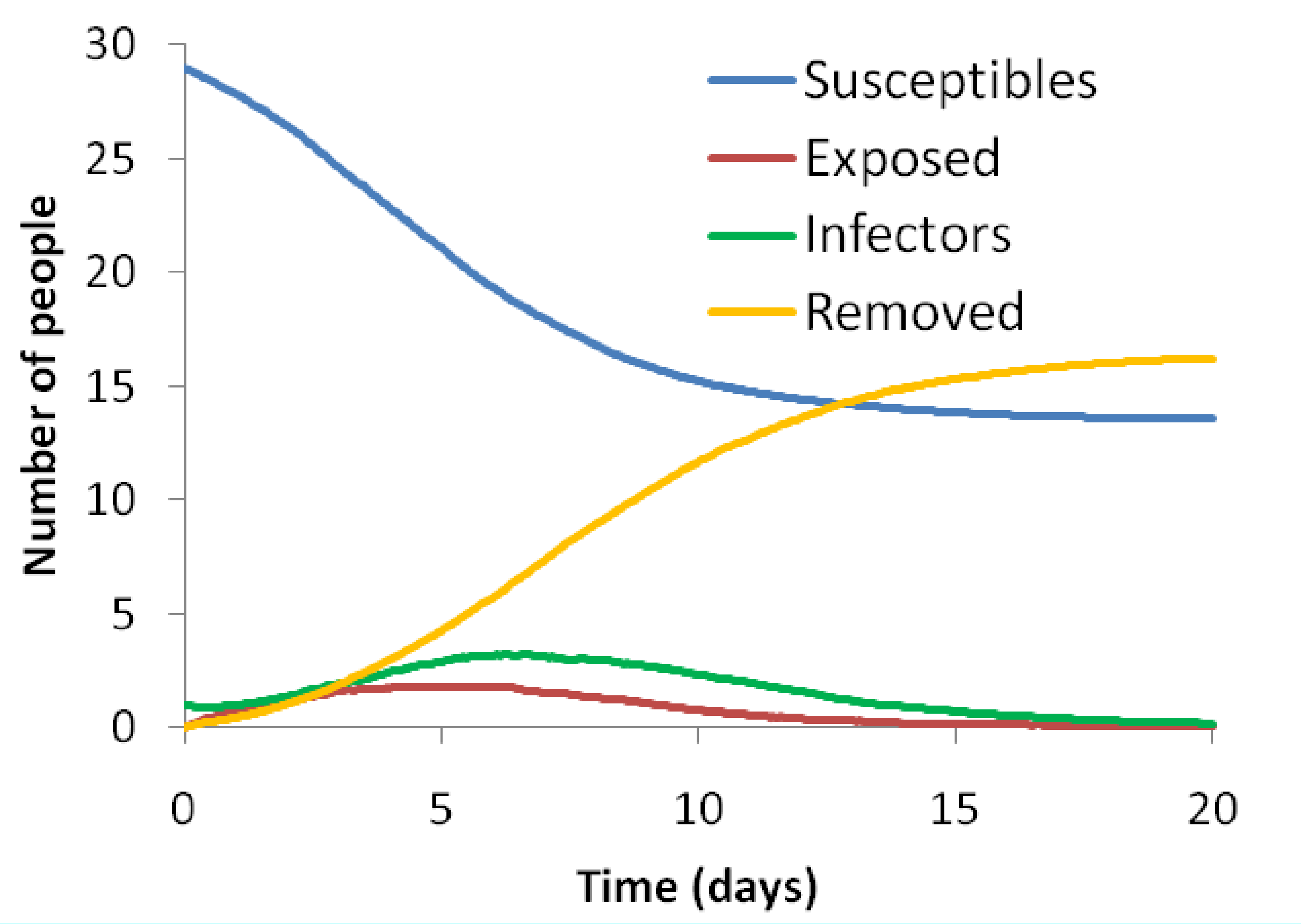
SEIR Models

- Most common variant on SIR model
- Acknowledges that most diseases have an incubation period between exposure and becoming infectious

Incubation period

Susceptible $\xrightarrow{\beta}$ **Exposed** $\xrightarrow{1/\alpha}$ **Infectious** $\xrightarrow{\gamma}$ **Removed**

SEIR Outputs



Linking air and epidemic models

- Wells-Riley developed for TB – generally long incubation period
- Can be applied to short incubation infections such as influenza, SARs etc.
- Contact rate determined by air flows and breathing rate

$$\beta = \frac{pq}{Q}$$

Can use to estimate effectiveness of environmental controls

Activity

In groups or individually:

- Use the spreadsheet models provided to explore how changes to disease parameters and the environment affect outbreaks
- Use the models to evaluate the scenarios described