Networks: stochastic models for populations and epidemics, September 2011

Building behavioural response effects into stochastic models for contingency planning

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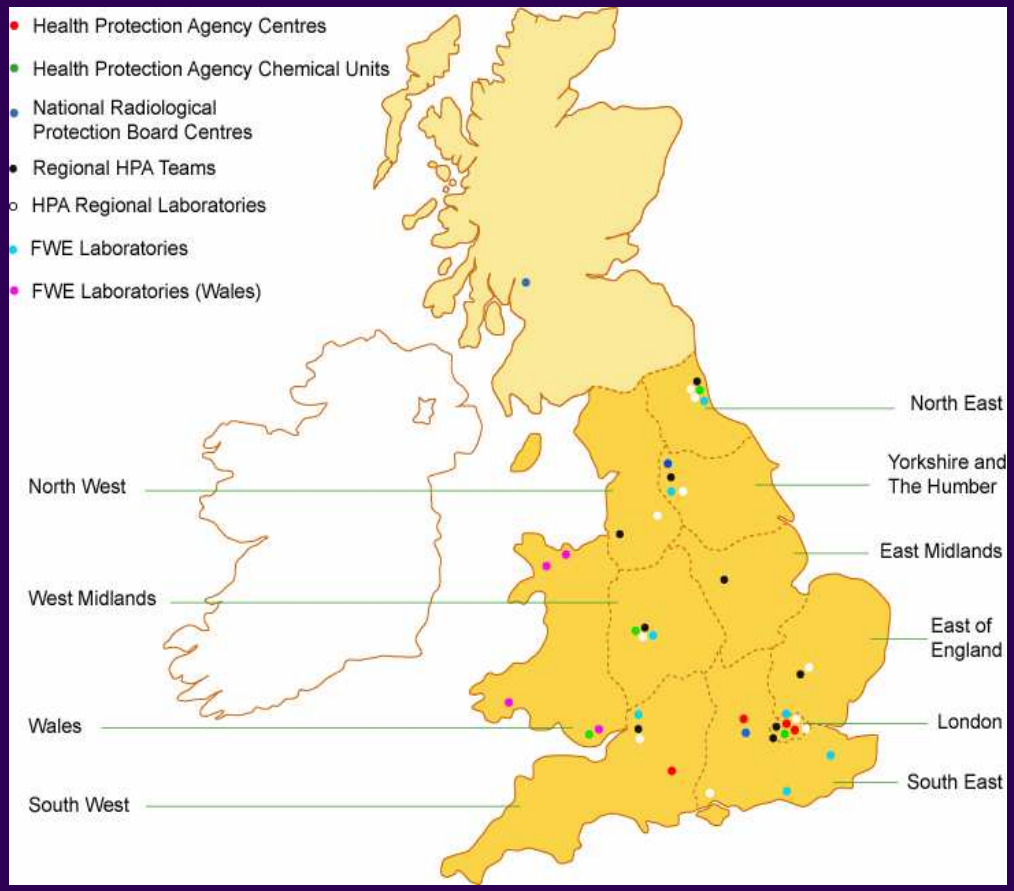
Content

- Introduction to HPA and Microbial Risk Assessment
- Case study of contingency planning
  - Natural History of Plague
  - Initial distribution of cases
  - Subsequent transmission
  - Behavioural responses to interventions
  - Control
- Behavioural responses to Pandemic influenza
- Mass casualty decontamination
- Summary

Health Protection Agency

- *Health Protection Services Division*
- *Microbiology Services Division*
- *Centre for Radiation, Chemical*
- *and Environmental Hazards Division*
- *National Institute for Biological*
- *Standards & Control*

(HPA Colindale)
(HPA Porton Down)
(Local and Regional presences)



A non-departmental public body
An independent government advisory agency
BUT shortly to be incorporated Public Health England

Microbial Risk Assessment and Behavioural Science

A multidisciplinary science and technology group that provides capabilities:

- To identify, model and assess the risks posed to UK public health by newly emerging and high impact infectious disease threats, including bioterrorism.
- To research and better understand the (eco-) epidemiological, political, social, behavioural etc. drivers that exacerbate those risks and impact on public health strategies for their mitigation
- To provide realistic simulated inputs to ERD's table top and field-based exercises;
- To assist with policy and planning ***ahead of time*** for potential infectious disease (and other relevant) emergencies;
- To develop specialist systems to help with real-time outbreak visualisation, analysis and mitigation during an emergency response.

Microbial Risk Assessment

R&D

Scientific/Technical Solutions

Bioterrorism and “Exotics”

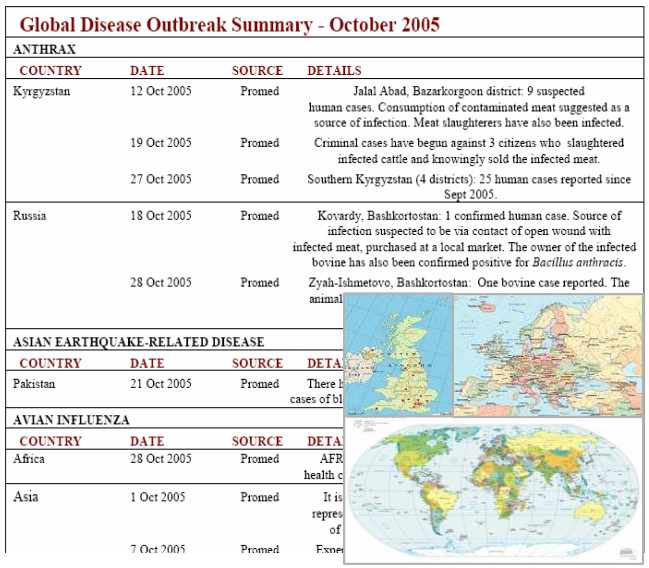
Horizon Scanning

Qualitative and Quantitative RA

Mathematical Models

Geographical Information Sys.

Scientific Computing



Global Disease Outbreak Summary - October 2005

ANTHRAX

COUNTRY	DATE	SOURCE	DETAILS
Kyrgyzstan	12 Oct 2005	Promed	Jalal Abad, Bazarkorgoon district: 9 suspected human cases. Consumption of contaminated meat suggested as a source of infection. Meat slaughterers have also been infected.
	19 Oct 2005	Promed	Criminal cases have begun against 3 citizens who slaughtered infected cattle and knowingly sold the infected meat.
	27 Oct 2005	Promed	Southern Kyrgyzstan (4 districts): 25 human cases reported since Sept 2005.
Russia	18 Oct 2005	Promed	Kovardy, Bashkortostan: 1 confirmed human case. Source of infection suspected to be via contact of open wound with infected meat, purchased at a local market. The owner of the infected bovine has also been confirmed positive for *Bacillus anthracis*.
	28 Oct 2005	Promed	Zyah-Ishmetovo, Bashkortostan: One bovine case reported. The animal

ASIAN EARTHQUAKE-RELATED DISEASE

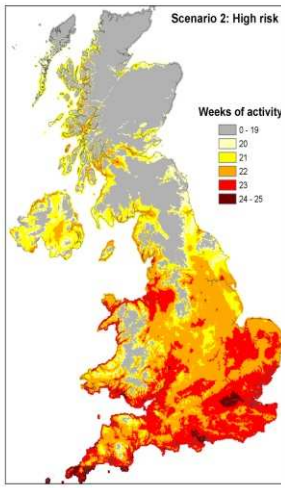
COUNTRY	DATE	SOURCE	DETA
Pakistan	21 Oct 2005	Promed	There h cases of bl

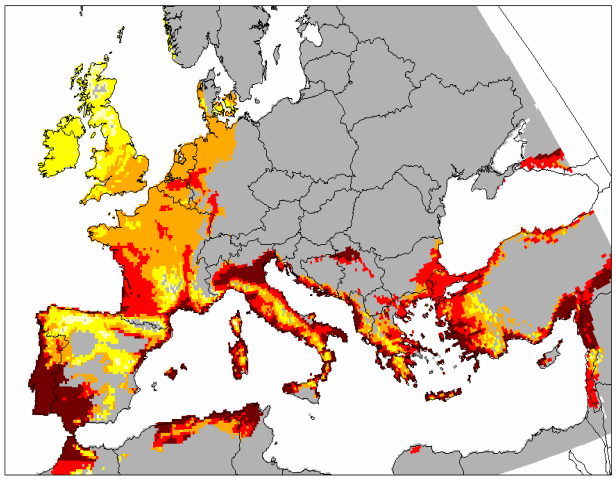
AVIAN INFLUENZA

COUNTRY	DATE	SOURCE	DETA
Africa	28 Oct 2005	Promed	AFR health c
Asia	1 Oct 2005	Promed	It is repres of
	7 Oct 2005	Promed	Expe

Monthly Report – Global Disease Alert

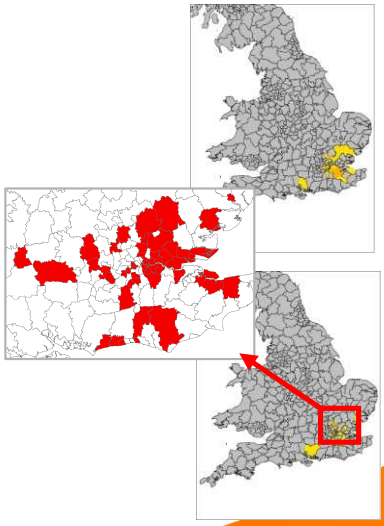
IT infastructure –
Cluster Computing





Vector Borne Disease Risk Assessment

Exotic Mosquitoes & GIS



$$\dot{S} = -(1-(1-\rho)(1-\phi))T + (1-\varepsilon_1)(\tau_O^{-1}C + \tau_V^{-1}S_V)$$

$$\dot{S}_V = -(1-(1-\rho)(1-\phi))T_V - \tau_V^{-1}S_V$$

$$\dot{C} = \rho(1-\phi)(T+T_V) - \tau_O^{-1}C \qquad T_m(t) = \frac{(S_m(t)+S_{Vm}(t))}{\phi\ N_m}C_m(t)$$

$$\dot{E}_U = (1-\rho)\phi(T+T_V) - \tau_L^{-1}E_U \qquad \dot{E}_T = \rho\phi(T+T_V) - \tau_L^{-1}E_T$$

$$\dot{P}_U = \tau_L^{-1}E_U - \tau_P^{-1}P_U \qquad \dot{P}_T = (1-\varepsilon_2)\tau_L^{-1}E_T - \tau_P^{-1}P_T$$

$$\dot{I} = (1-\theta)\tau_P^{-1}P_U - \tau_I^{-1}I \qquad \dot{Q} = \theta\tau_P^{-1}P_U + \tau_P^{-1}P_T - \tau_Q^{-1}Q$$

$$\dot{R} = (\tau_I^{-1}I + \tau_Q^{-1}Q) \qquad D = \delta R + \delta_v(V_p + V_T)$$

$$\dot{V}_T = \varepsilon_1\tau_O^{-1}C + \varepsilon_2\tau_L^{-1}E_T \qquad \dot{V}_P = \varepsilon_1\tau_V^{-1}S_V$$

Bioterrorism

Smallpox Intervention Strategies & Mathematical Models

Some common themes of interest

Health Protection Agency

Mode of dissemination in bioterrorist attacks may lead to atypical presentation of infection (e.g. aerosolised release of anthrax, botulinum toxin) or unusual epidemiology

Diseases not seen for many years or very uncommon (e.g. pandemic influenza, smallpox, inhalation anthrax)

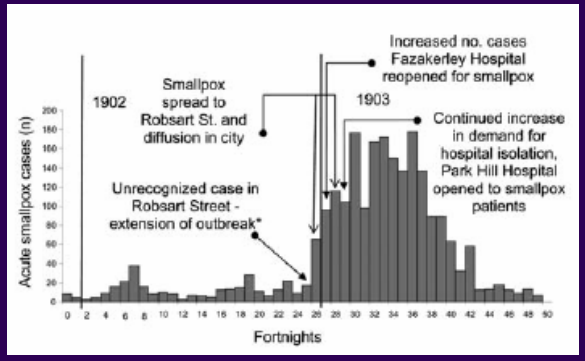
Newly introduced disease, background information from other regions, but unpredictable epidemiology locally (e.g. WNV, CCHF)

Newly emergent disease - completely unknown epidemiology, pathogenicity, etc. (e.g. SARS)

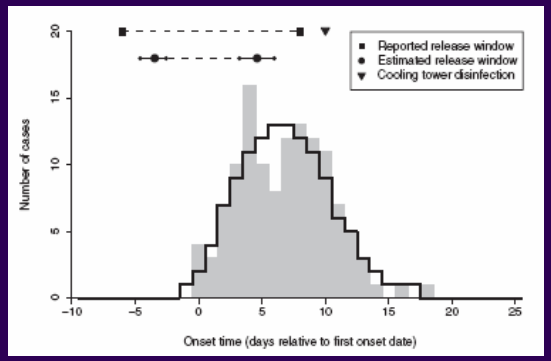
Uncertainty how they will affect the UK

Modelling work

- **Outbreak analysis**
  - Smallpox
  - Influenza
  - Legionnaires Disease
  - MRSA



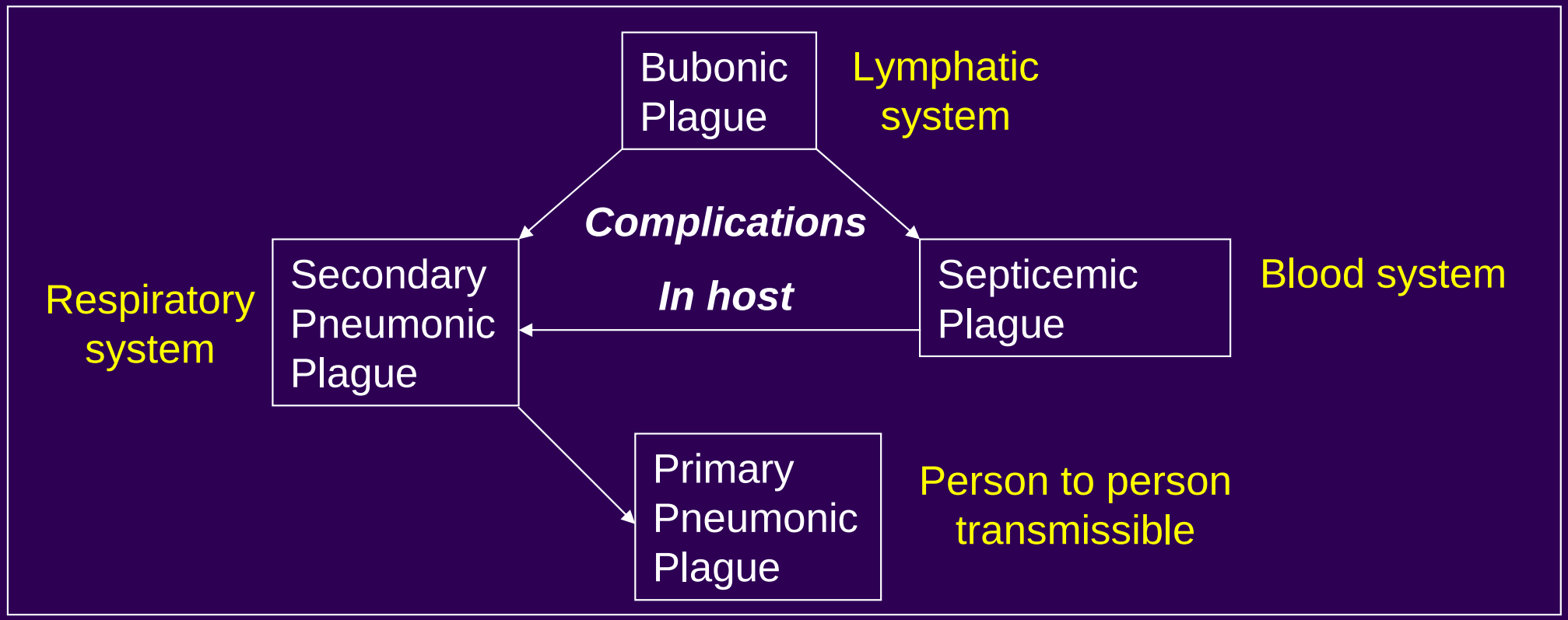
- **Outbreak Response**
  - From dispersion
  - Influenza
  - Legionnaires Disease



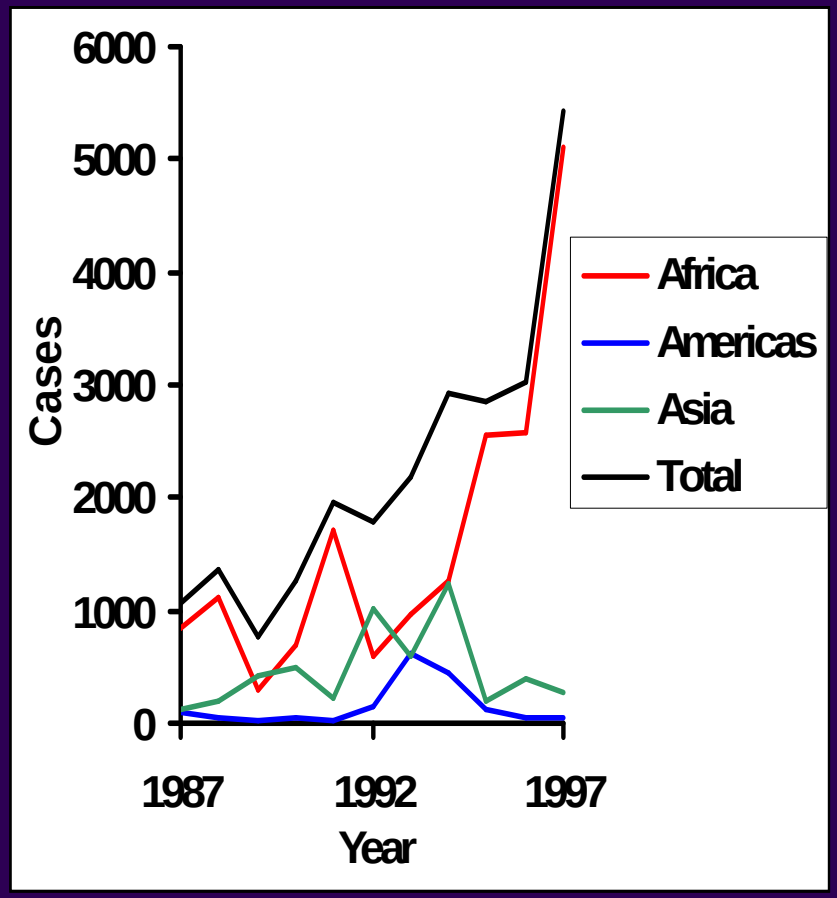
- **Outbreak Preparedness**
  - Pneumonic Plague
  - Tularaemia/Anthrax
  - Lyme Disease

Plague biology

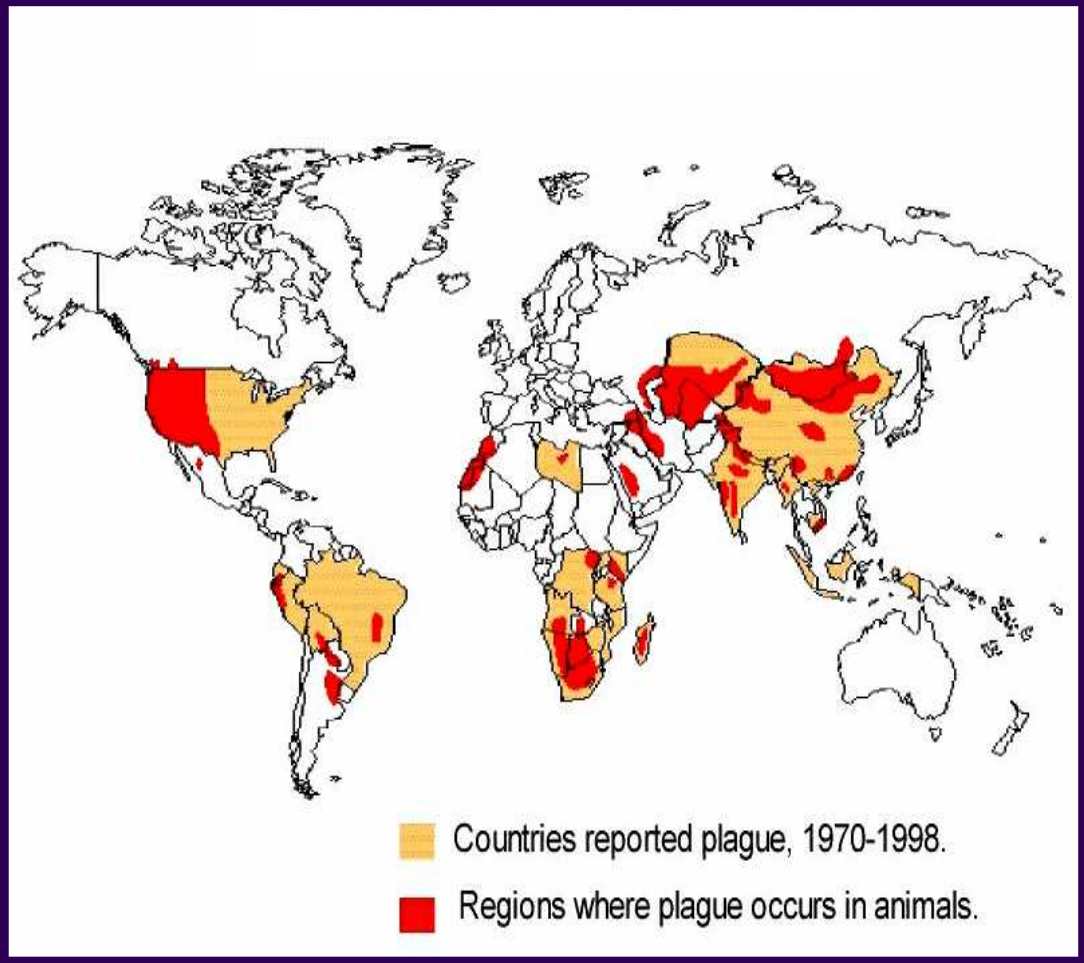
- Bacterium: *Yersinia pestis*
- Enzoonotic vector-borne disease (rodents and fleas)
- Endemic in New Mexico, parts of Russia, Madagascar…
- Human infection by-product of zoonotic cycle



World Distribution & Incidence of Plague



Number of cases of plague reported to the WHO each year from 1987 to 1997 (WHO)



Global Incidence of Plague: Spatial distribution in 1998 (CDC)

Plague as a weapon

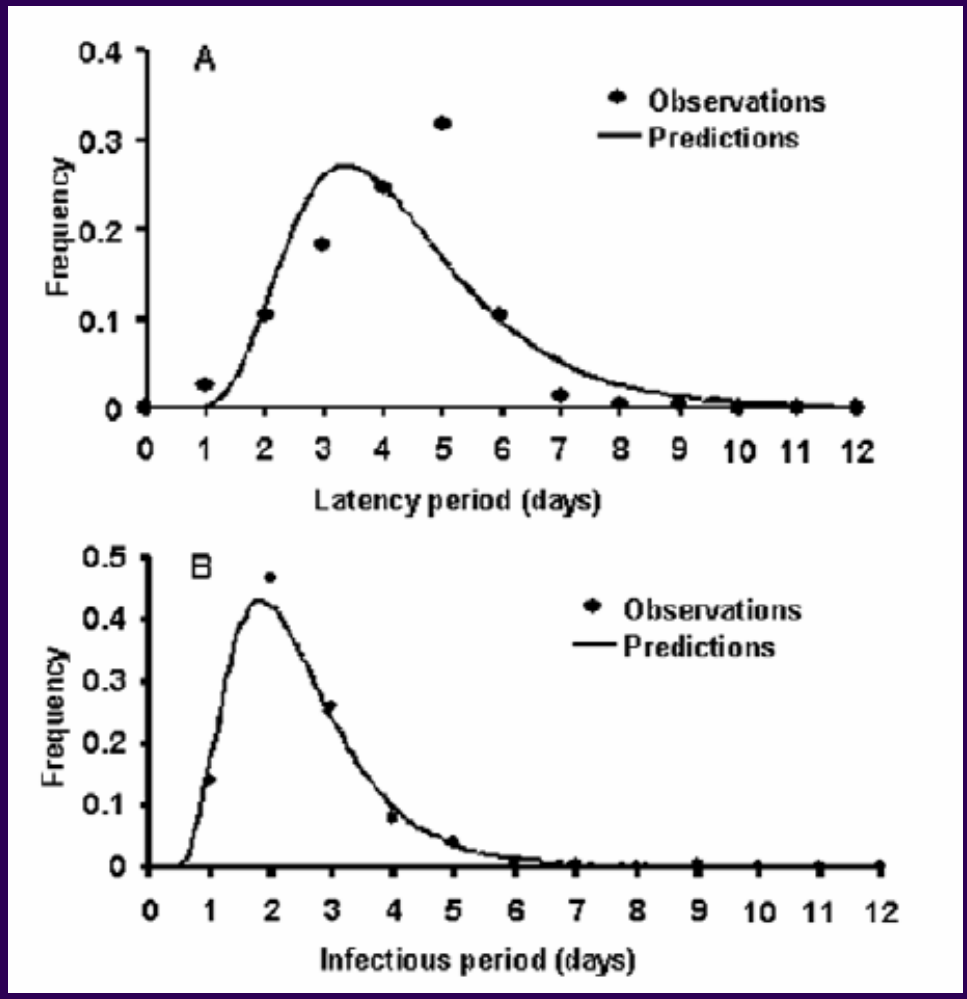
- Untreated all forms of plague have high case fatality rates

- Vector competency in the UK is weak (brown rather than black rat predominant species)
- Last plague case in UK 1918/9
- BUT plague is potential bioterrorist weapon:
  - Catapulting plague victims over besieged walls
  - Dropping fleas over China in 1930's
  - Russian aerosol spray developed up to 1990's

Technology increase

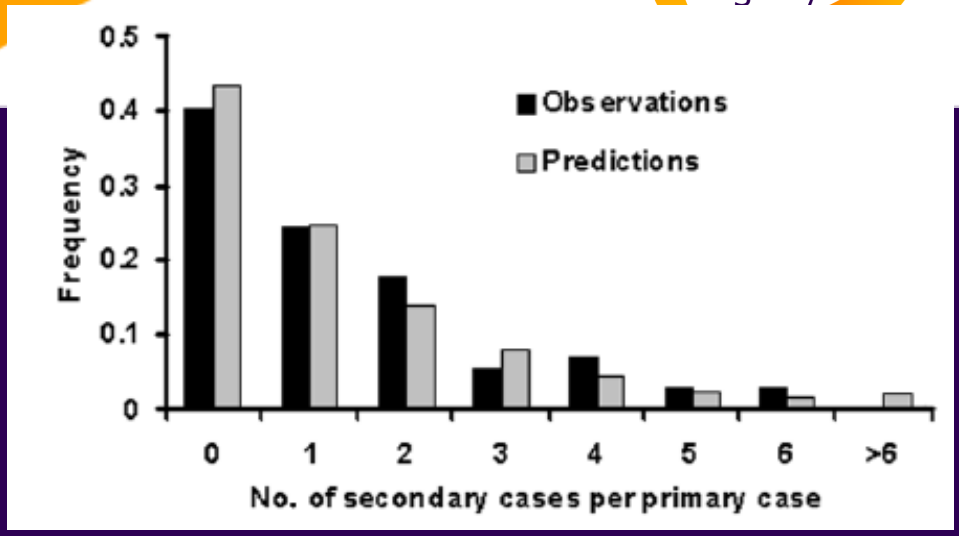
Natural history

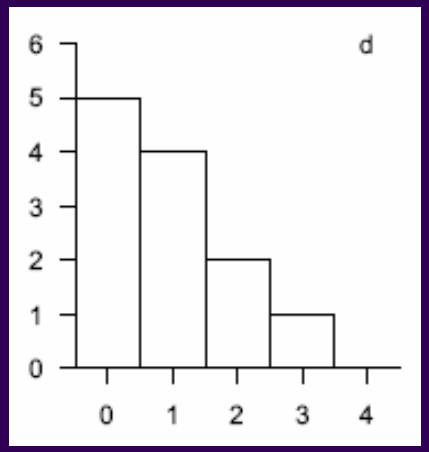
- Only cases receiving no therapy were included in analysis
- Lognormal distributions fitted
- Latent period: mean 4.3 days (sd 1.8, n=224)
- Infectious period: mean 2.5 days (sd 1.2, n=225)
- Infectious period = symptomatic period
- IP divided in two to model treatment efficacy and infectiousness

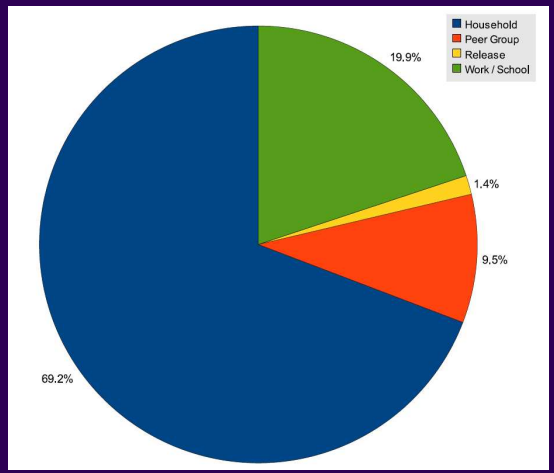


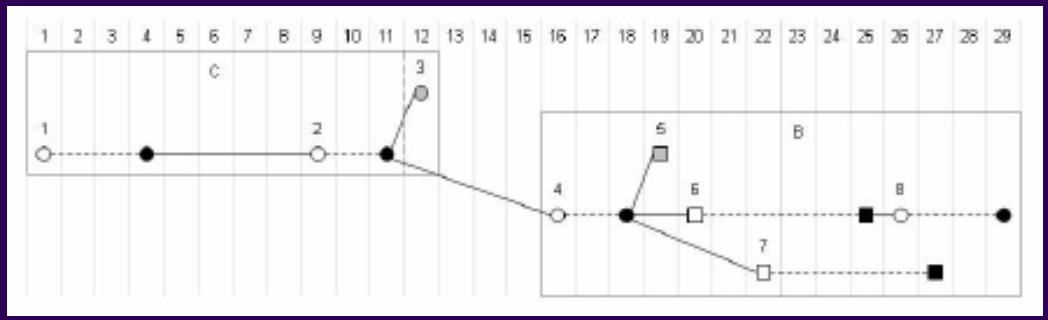
Transmission

- Only cases with unambiguous transmission events included
- Transmission events prior to public health interventions
- Geometric distribution fitted
- Secondary cases: mean 1.3 (var 3.1, n=224)
- Infections occur during later part of symptomatic period









Plague control options

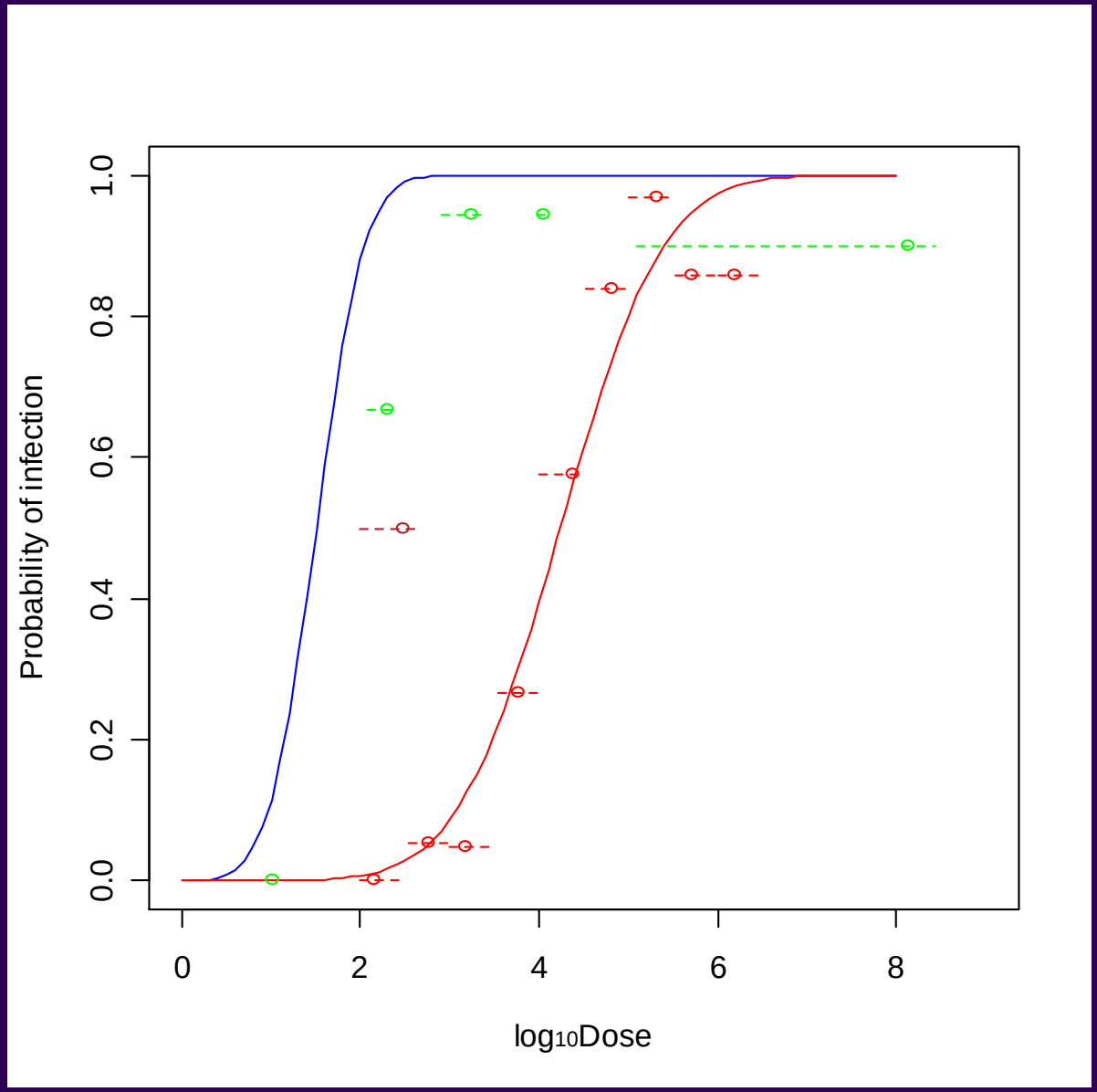
- Isolate cases and treat with antibiotics (resistant strains have been found)
- Initiate nursing precautions
- Contact tracing and prophylaxis
- Mass treatment centres

- Treatment efficacy assumed to be 100% prior to symptomatic onset, 70% during early symptomatic period and 50% in later period
- 10 deaths before outbreak detected, 2 days further before identification of *Y Pestis*

- Unclear as to whether long term immunity is achieved by cases

Dose response

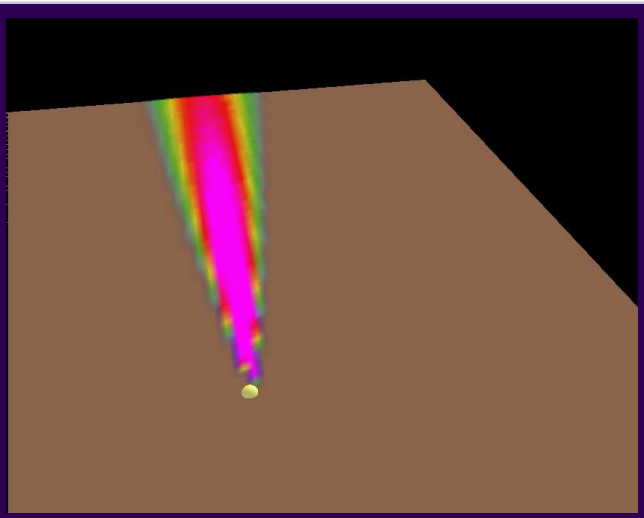
- elicitation exercise (blue curve)
- primate data (red curve and points)
- Dashed lines represent the dose range and points indicate either the average value or mid-point.
- Models were not fitted to the green and brown data due to a lack of information.



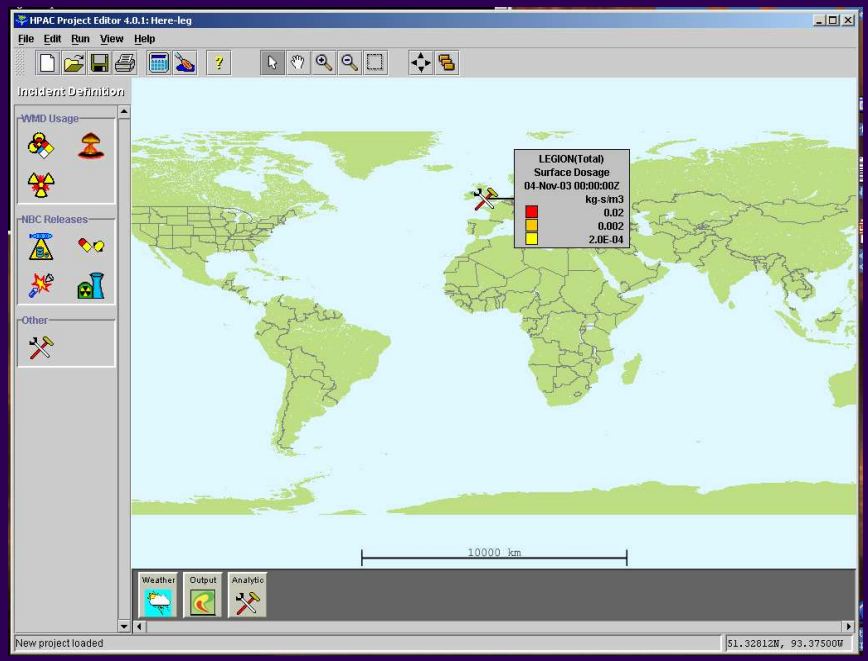
Airborne Dispersion Modelling

Basic airborne dispersion modelling is with puff or plume models

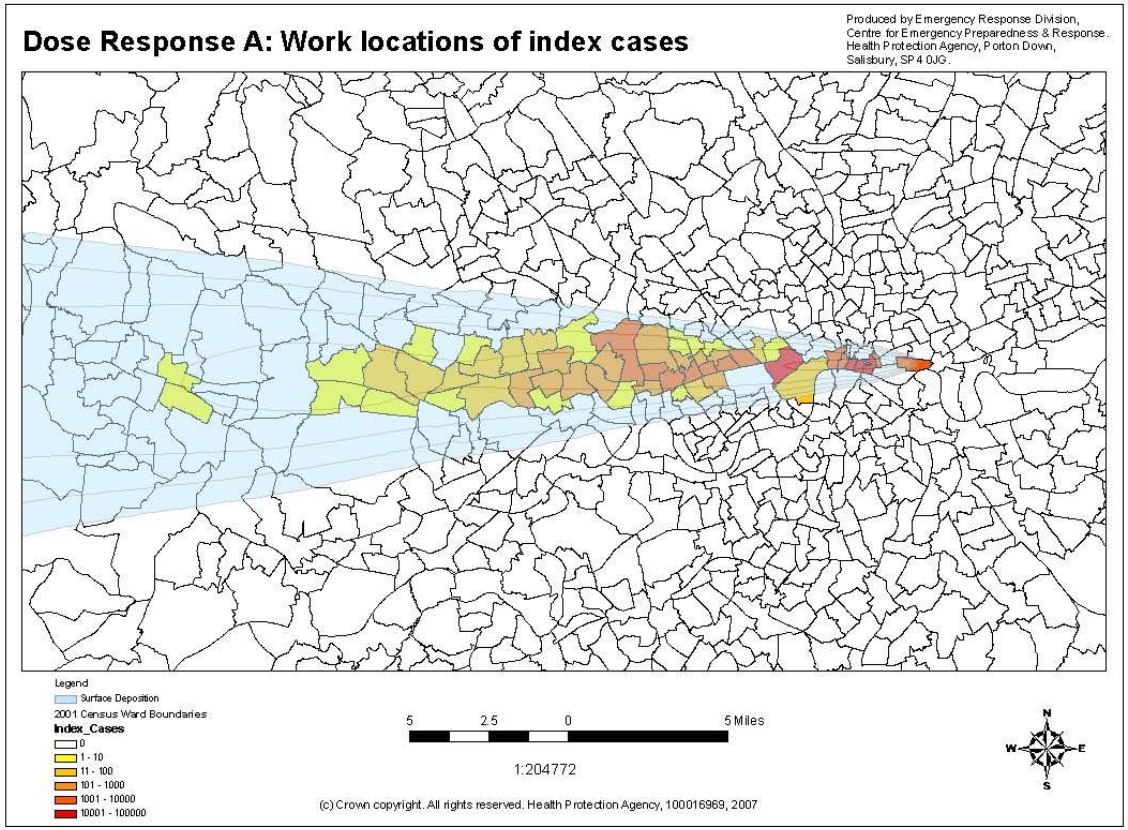
$$\left\langle c(x,y,0,t)\right\rangle = \frac{2S}{(2\pi)^{3/2}\sigma_x\sigma_y\sigma_z} e^{-\frac{\left(x-\bar{u}(t-T)\right)^2}{2\sigma_x^2}-\frac{y^2}{2\sigma_y^2}-\frac{H^2}{2\sigma_z^2}-\gamma(t-T)}$$

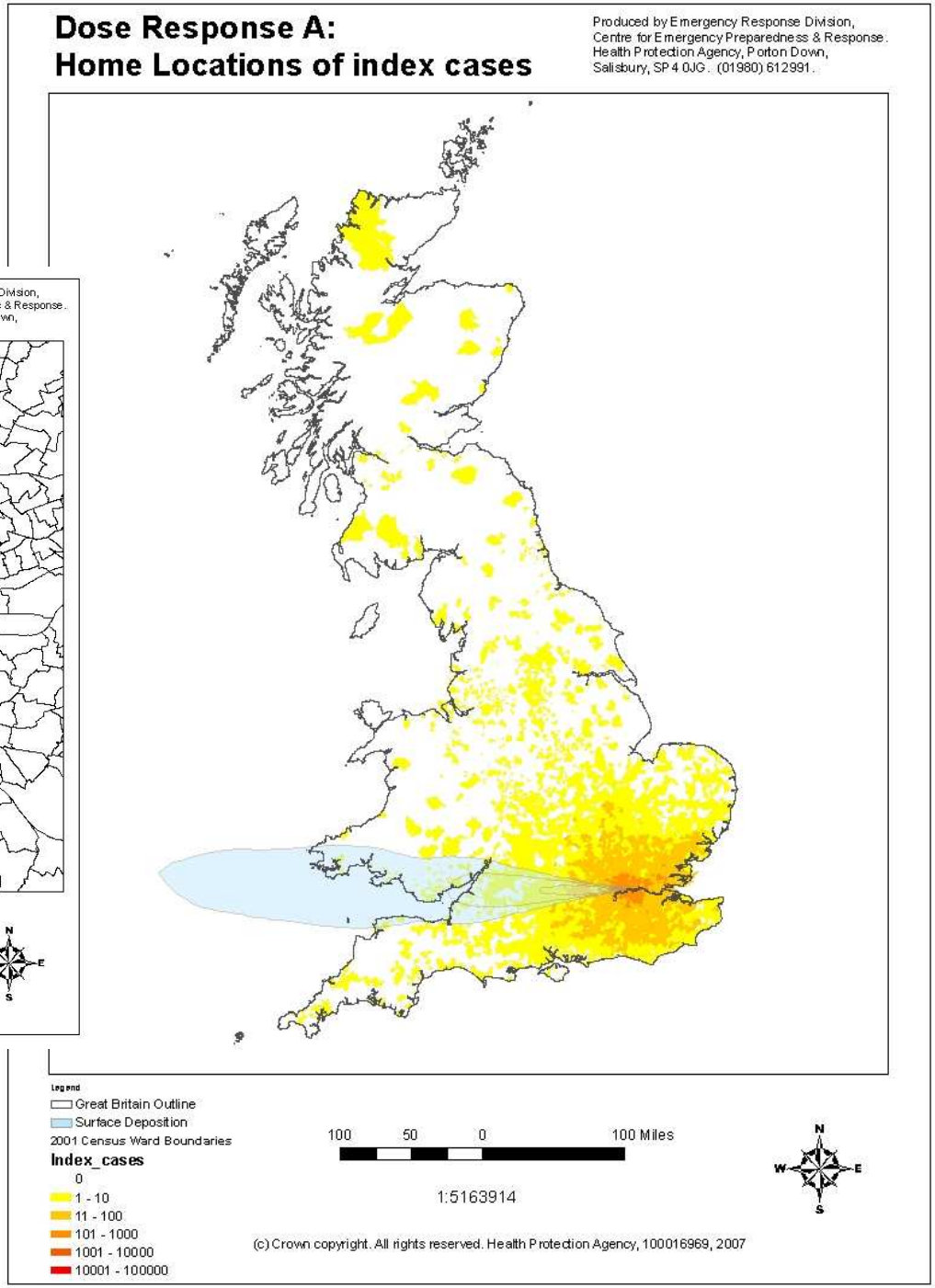


Unfortunately this view can be rather simplistic



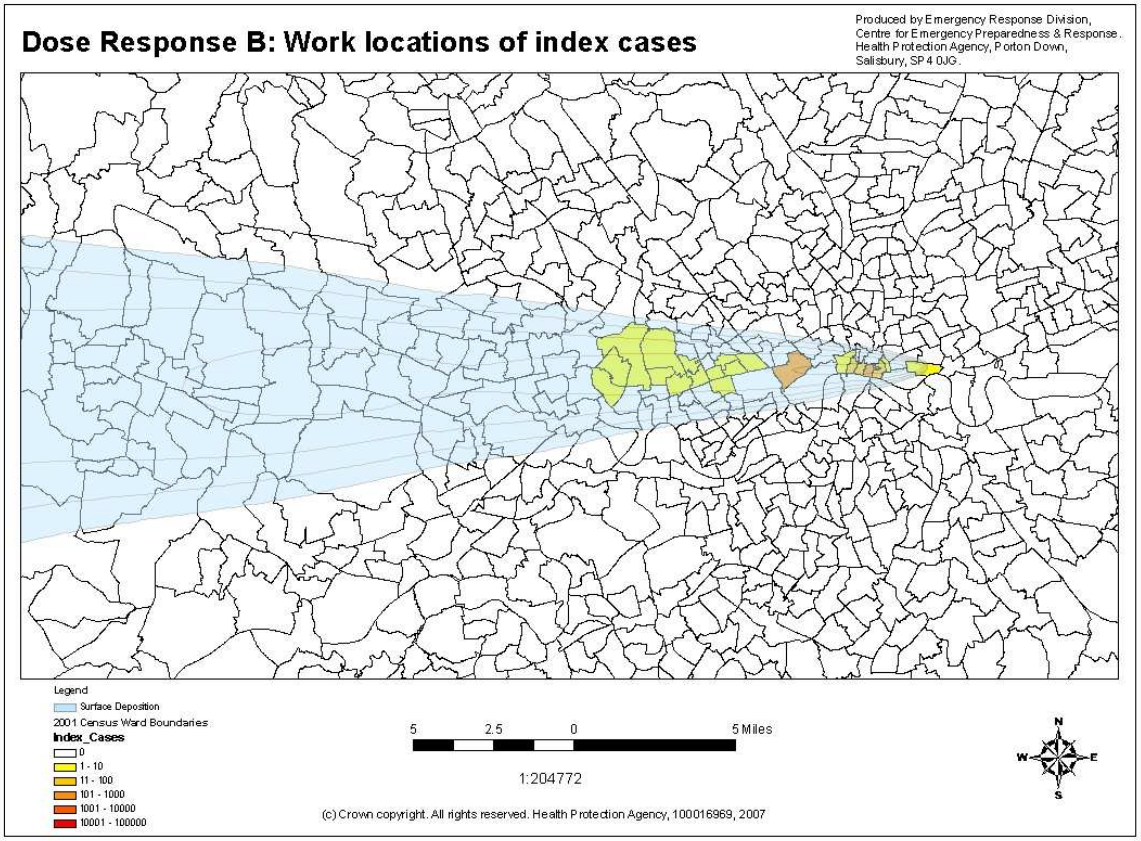
Pneumonic Plague: Distribution of index cases

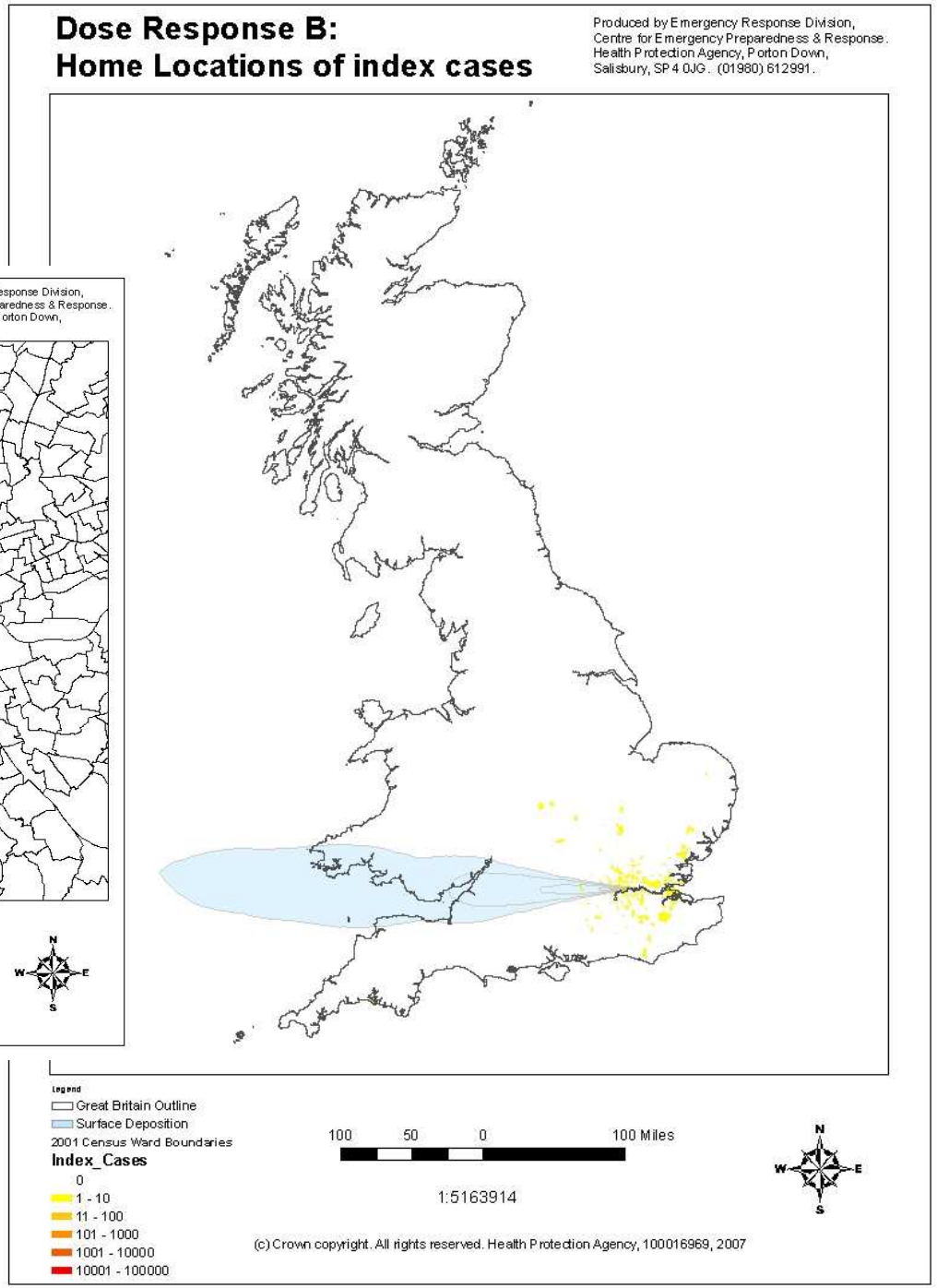




- Plume from HPAC
- Dose response from US elicitation exercise
- ~160,000 cases

Primate data dose response



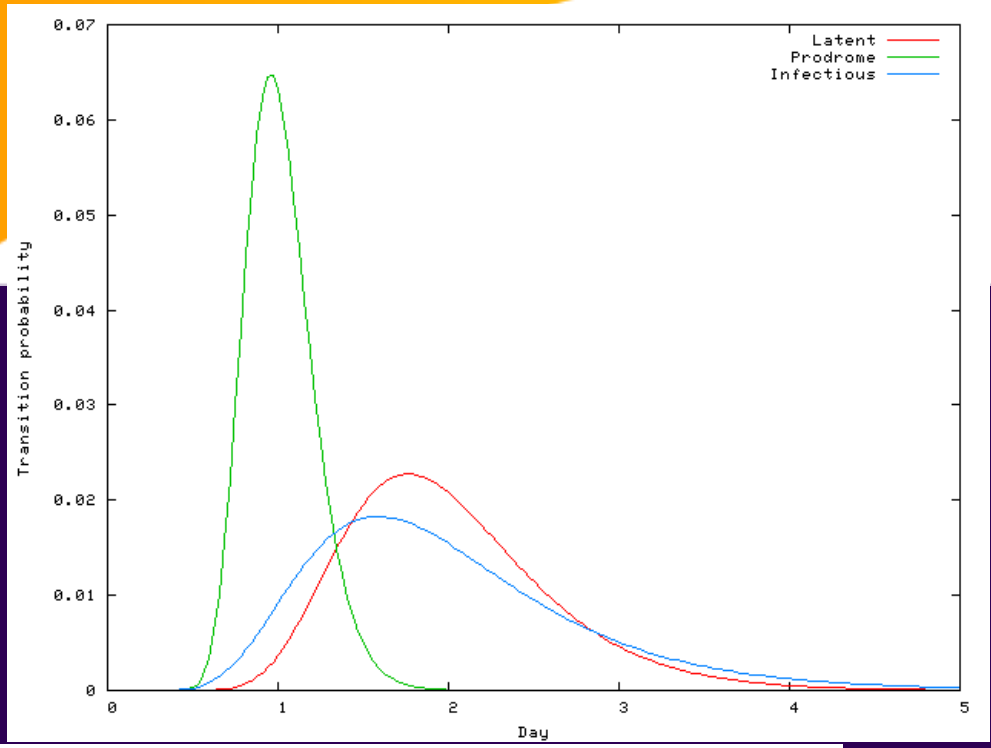


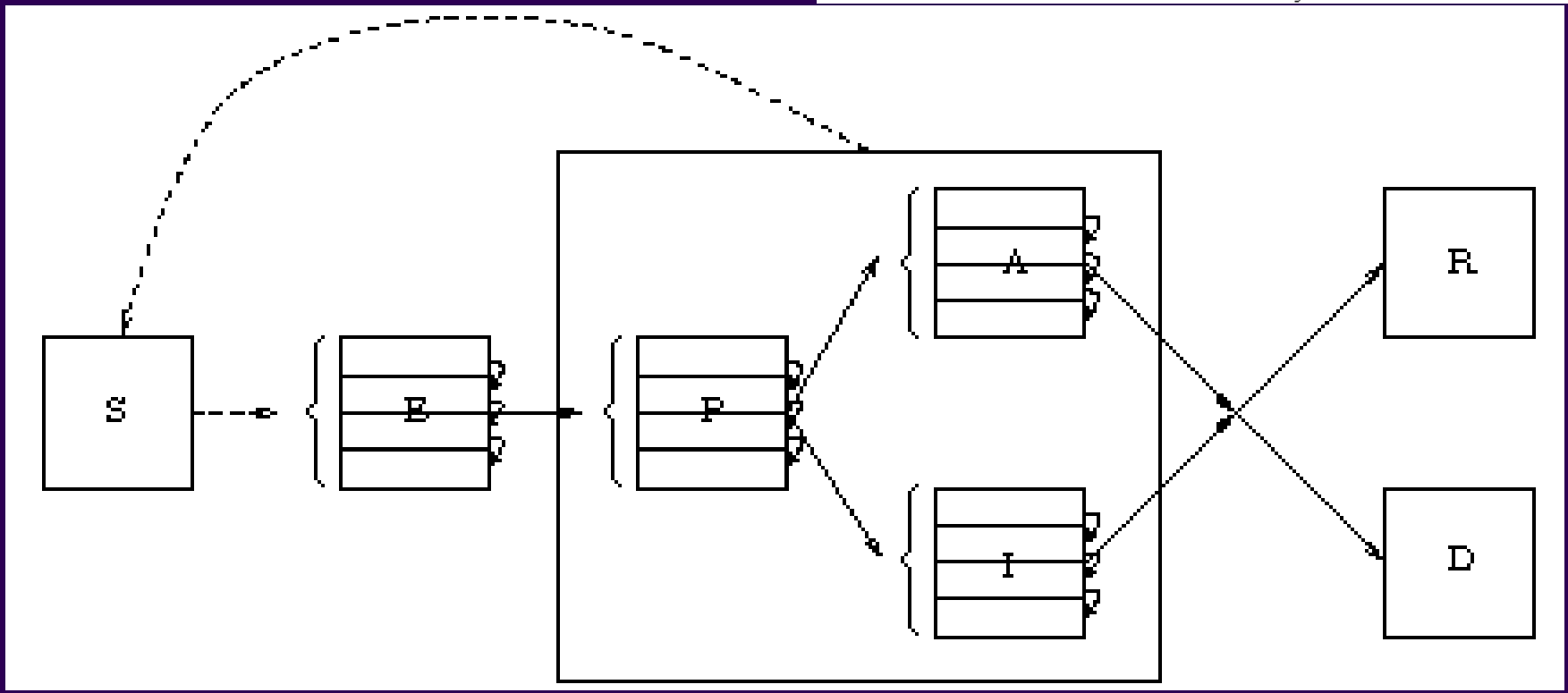
~500 cases

Pseudo-individual models

An extension of basic compartmental models, capturing some aspects of individual infection

Also possible to incorporate variable infectiousness



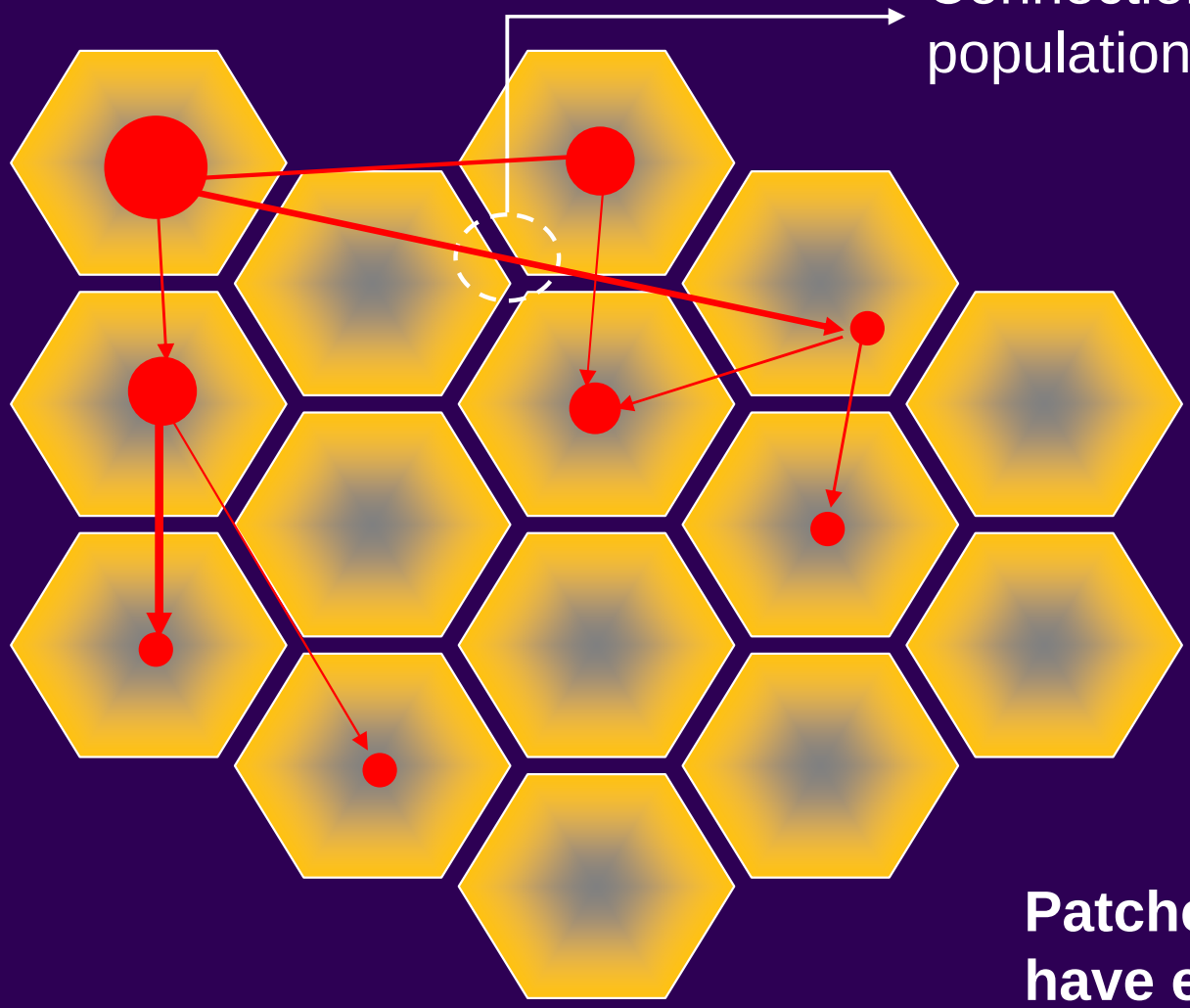


Meta-population patches

Health Protection Agency

SEIR model within patches

Connection given by population movements



Infection is introduced

This may subsequently infect other patches

Patches may have external forcing

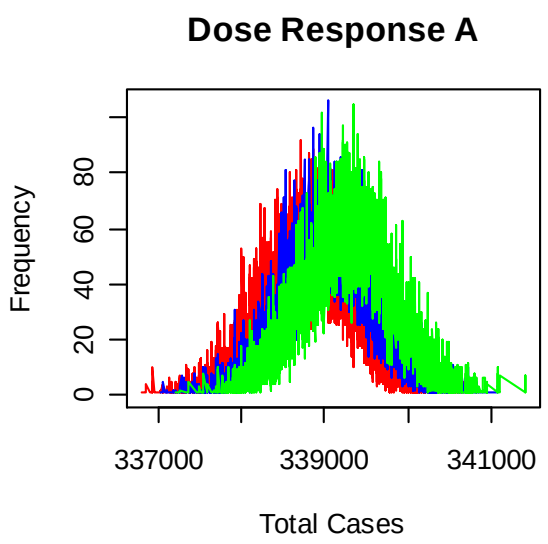
Pneumonic Plague: Subsequent outbreak

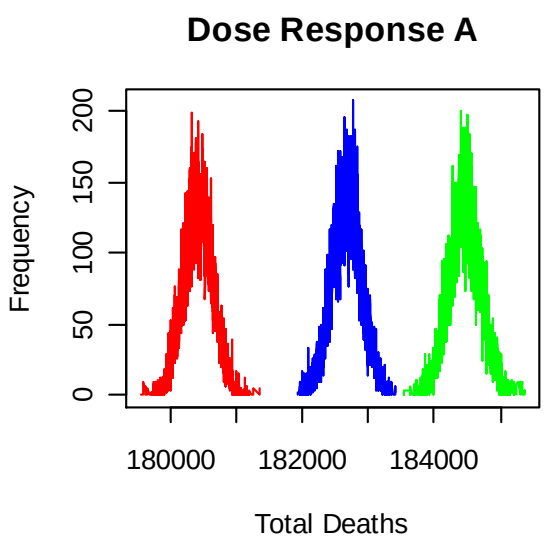
Consistent with earlier studies, onward transmission is likely to approximately double the number of cases caused by the initial release, even with relatively efficient public health responses.

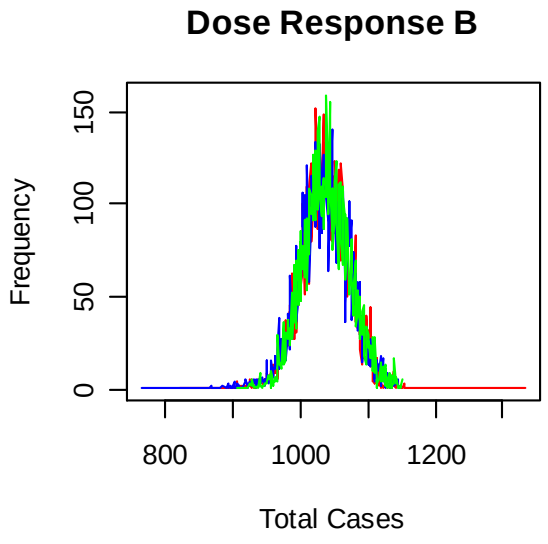
Up to half of the total cases are likely to die due to early misdiagnosis and inappropriate treatment.

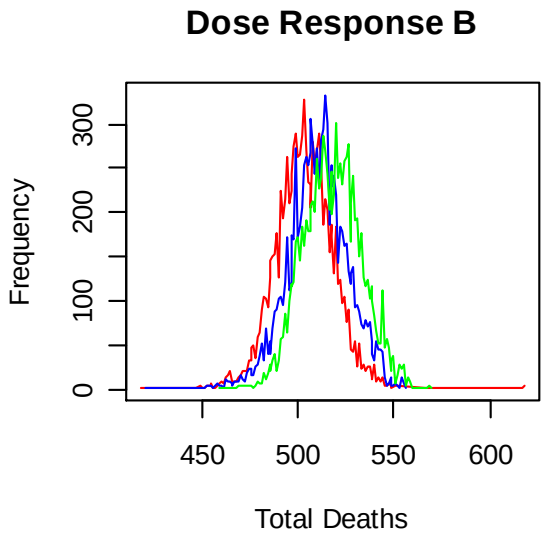
Contact tracing and prophylaxis could help to reduce the number of deaths but only if implemented quickly.

If such resources were delayed then isolating cases and treating them with appropriate antimicrobials is likely to efficiently curtail an epidemic.









Behavioural response

- Surat outbreak – 50 deaths with inhabitants fleeing area and private purchases of antibiotics increasing
- A cross-sectional, random digit dial telephone survey
- Conducted by Ipsos MORI (14 - 24 September 2007)
- 1005 Adult (16ys+) interviewed.
- Quota sampling was used to ensure sample was representative of the British public with regards to age, sex, work status, region and social grade.
- All participants were asked for their verbal consent to take part in this 15 minute survey.
- Ethical approval for the study was given by the King's College London Research Ethics Committee.

Interview construction

Stage one:

Preamble giving a short description of pneumonic plague.

Questions assess current perceptions of pneumonic plague.

Stage two:

Three people from the local area have contracted pneumonic plague. Official advice is to carry on as normal.

Half of the participants are informed that a terrorist link is suspected.

Questions assess likely spontaneous behaviours and willingness to take antibiotics if asked to.

Stage three:

One hundred people from the local area have contracted pneumonic plague. Official advice is to carry on as normal.

Questions assess likely spontaneous behaviours.

Stage four:

Half of the participants are informed that public health advice is to attend a mass treatment centre for assessment and prophylaxis if potentially exposed. The other half are informed that isolation at home is recommended for those potentially exposed.

Questions assess likely compliance with official advice.

Public awareness of plague

How likely or unlikely are the following statements:	Very likely	Fairly likely	Not very likely	Not at all likely	Don't know
If someone catches pneumonic plague they would feel unwell within 24hr of catching it.	353 (35.1%)	337 (33.5%)	127 (12.6%)	22 (2.2%)	166 (16.5%)
There have been cases of pneumonic plague in Britain within the past 10 years.	65 (6.5%)	163 (16.2%)	399 (39.7%)	288 (28.7%)	90 (9.0%)
If you were to come within six feet of somebody who had pneumonic plague and who was clearly ill, you would probably catch the disease from them.	345 (34.3%)	390 (38.8%)	196 (19.5%)	41 (4.1%)	33 (3.3%)
If you were to come within six feet of somebody who had pneumonic plague but who had not yet developed any signs of illness, you would probably catch the disease from them.	218 (21.7%)	405 (40.3%)	275 (27.4%)	58 (5.8%)	49 (4.9%)
Unless they receive immediate treatment, then most people with pneumonic plague will die from it.	429 (42.7%)	338 (33.6%)	152 (15.1%)	17 (1.7%)	69 (6.9%)
If antibiotics were administered immediately after a person had been infected with pneumonic plague, they would probably survive.	413 (41.1%)	467 (46.5%)	61 (6.1%)	8 (0.8%)	56 (5.6%)

Demographic and preconception responses to local outbreak

Scenario	Stocking up On Food	Leaving the area	Avoiding others	Seeking medical advice	Try to obtain antibiotics
Stage 2	673 (67.2%)	132 (13.3%)	746 (74.2%)	667 (66.4%)	591 (59.4%)
Stage 3	798 (79.8%)	223 (22.4%)	850 (84.6%)	792 (79.4%)	724 (72.5%)

- In stage 2, females more likely to stockpile food, OR=1.5
- Young adults (16-34) less likely to stockpile (OR=0.7) and avoid others (OR=0.6), but more likely to leave area (OR=2.1), than over 55's
- People not in work more likely to stockpile, avoid others, seek medical advice and obtain antibiotics than workers (OR= 1.6,1.7,1.5,1.4 respectively)
- People with less years in education are more prone to precautionary behaviour
- Respondents who thought cfr was high and transmission through close contact were more likely to engage in precautionary behaviour
- Preconceptions about plague were not associated with willingness to comply with interventions

- Similar patterns in behavioural response when situation is worse (stage 3)

Leaving the area

No information on “half life” of response

No information on “how” this would be managed by respondent

But some idea of precautionary behaviour

Where would you go?	Stage 2	Stage 3
Elsewhere in the UK but within my region of the country	24 (17%)	27 (12%)
Elsewhere in the UK, outside of my region of the country	62 (45%)	128 (56%)
Elsewhere in Europe but outside the UK	17 (13%)	39 (17%)
Outside of Europe	22 (16%)	27 (12%)
Don’t know	13 (9%)	7 (3%)

People seeking medical advice

Majority of respondents would go to their GP.

Furthermore:

3.2% of respondents said they would go to GP before mass treatment centre if they had been at source

14.7% of respondents would go to GP if they had been at source then developed ILI

39.2% of respondents would go to GP if they had not been at source but had ILI

Source of advice	Stage 2 (n=667)	Stage 3 (n = 792)
GP	487 (73.0%)	630 (79.5%)
NHS Direct	217 (32.5%)	222 (28.0%)
Local Hospital	121 (18.1%)	123 (15.5%)
Internet	122 (18.3%)	132 (16.7%)
Media (e.g. newspaper, television or radio	40 (4.0%)	50 (6.3%)
Medically qualified friend or relative	33 (3.3%)	36 (4.5%)
Pharmacy	17 (2.5%)	42 (5.3%)
Another friend or relative	7 (1.0%)	10 (1.3%)
Emergency services	3 (0.4%)	4 (0.5%)
Other	43 (6.4%)	36 (4.5%)

Response to public health interventions

Half respondents asked to attend mass treatment centres for prophylactic antimicrobials and half asked to consider home isolation for 7 days.

21.3% of respondents would be unlikely to attend mass treatment centre, yet have been near source

17.6% of respondents would be likely to attend treatment centre despite not being at risk

8% would be unlikely to stay indoors for 7 days, though remainder depends on provided assistance scheme (compensation, medical advice “on tap”, entertainment, …)

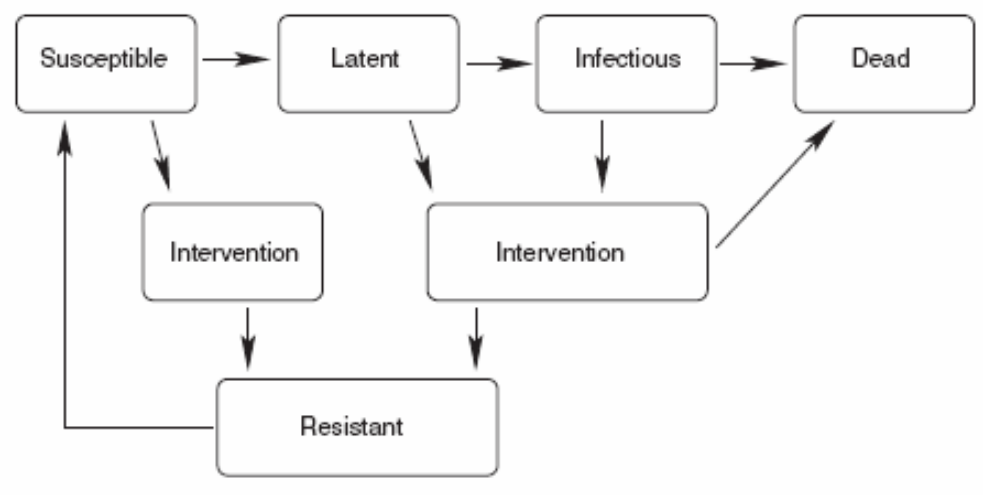
Comments

Very hypothetical scenario - these results as suggestive of the broad level of compliance and precautionary behaviour that may be seen during an outbreak of pneumonic plague, and not as precise predictions.

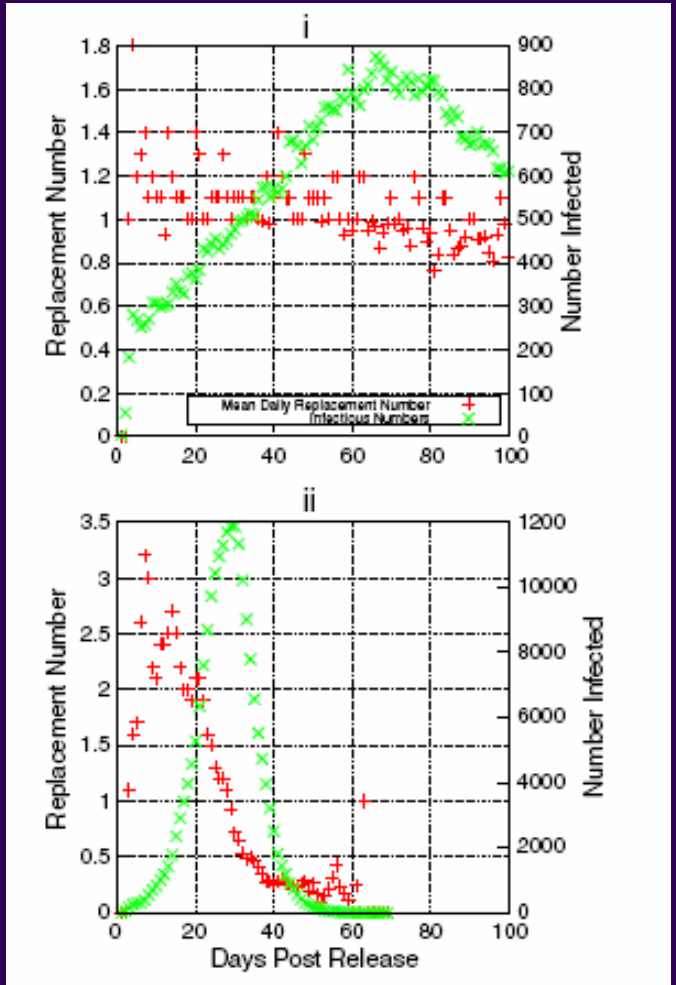
While it is impossible to say with precision how the public will respond, the data presented here go some way towards providing a more concrete base from which to build, test and improve contingency plans.

At the same time, the associations we have identified between perceptions about pneumonic plague and intended behaviours provide an indication of what key communication messages need to be emphasised in the early stages of an outbreak

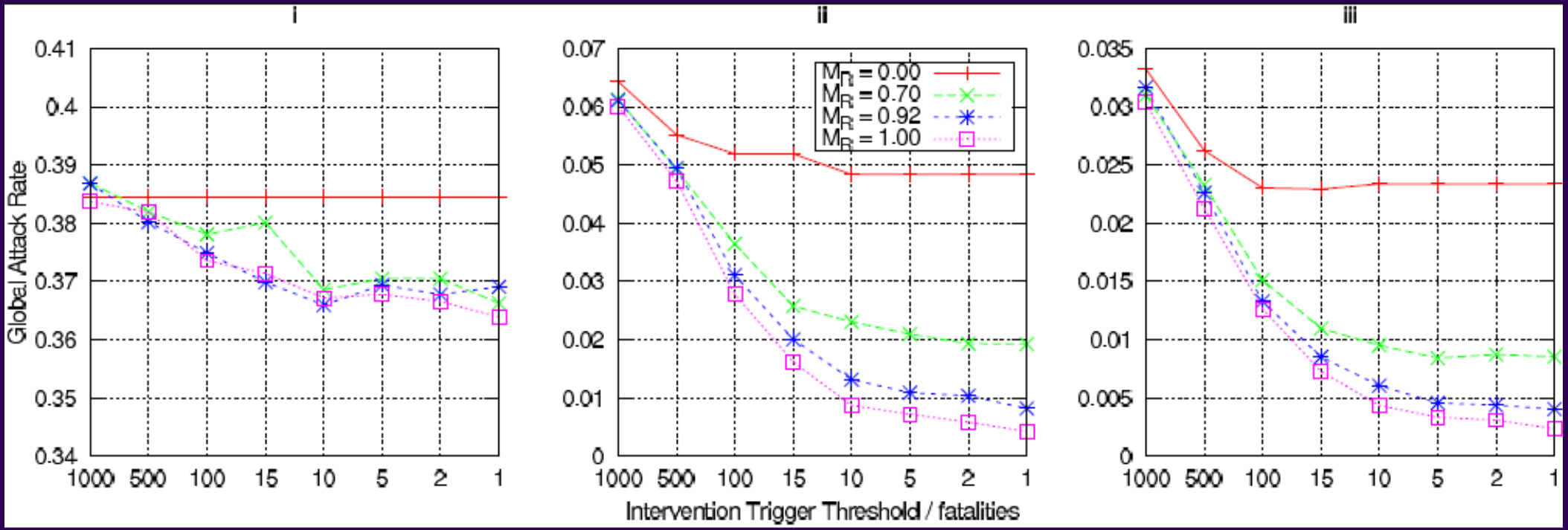
Model design



- Individual based model
- Population contact patterns taken from **POLYMOD** survey
- Cases increasingly infectious as death approaches
- Cases reduce movement as they progress through disease states



Plague control options: Home Isolation



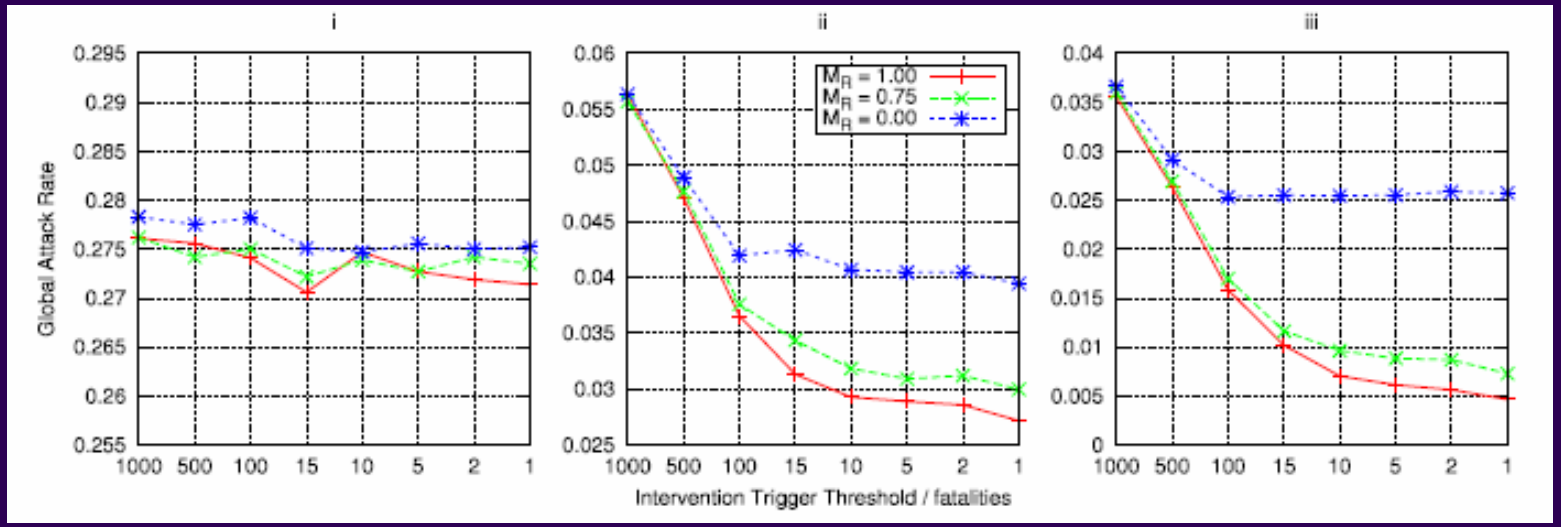
MR – Proportion of those individuals, who having passed through release site would then isolate themselves as soon as possible.

MI - Proportion of those individuals, who were not near release site but would then isolate themselves as soon as possible, if they had ILI. (0,0.29,0.58)

Mass treatment centres

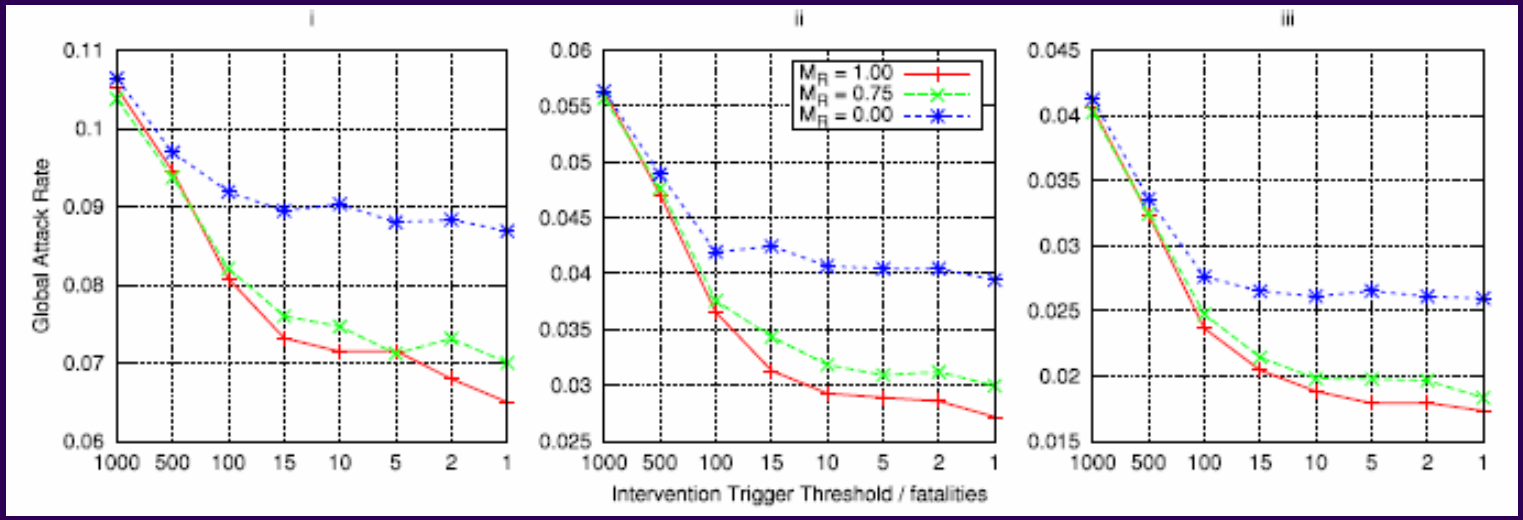
Capacity= 0.1%, 0.5%, 2.5% of population,

MI=0.29

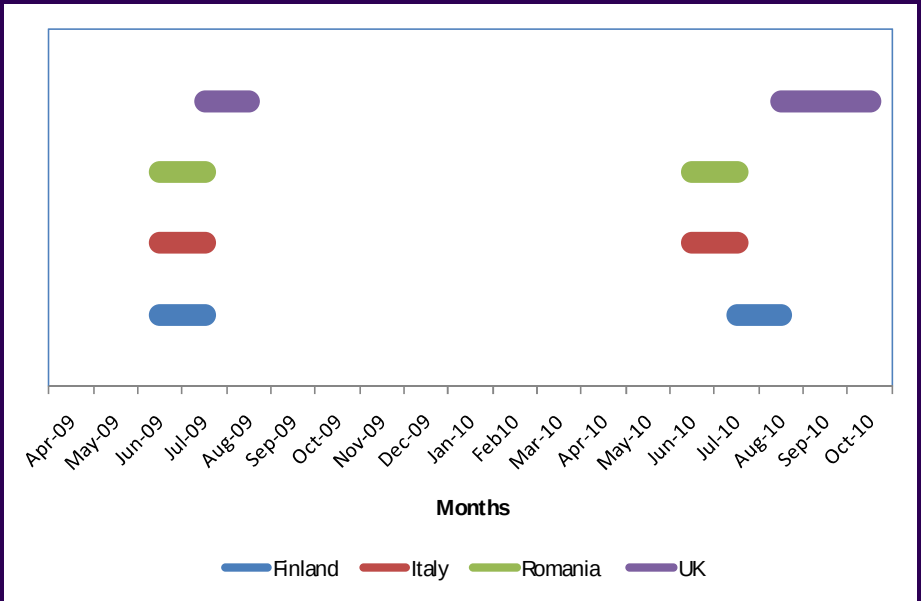


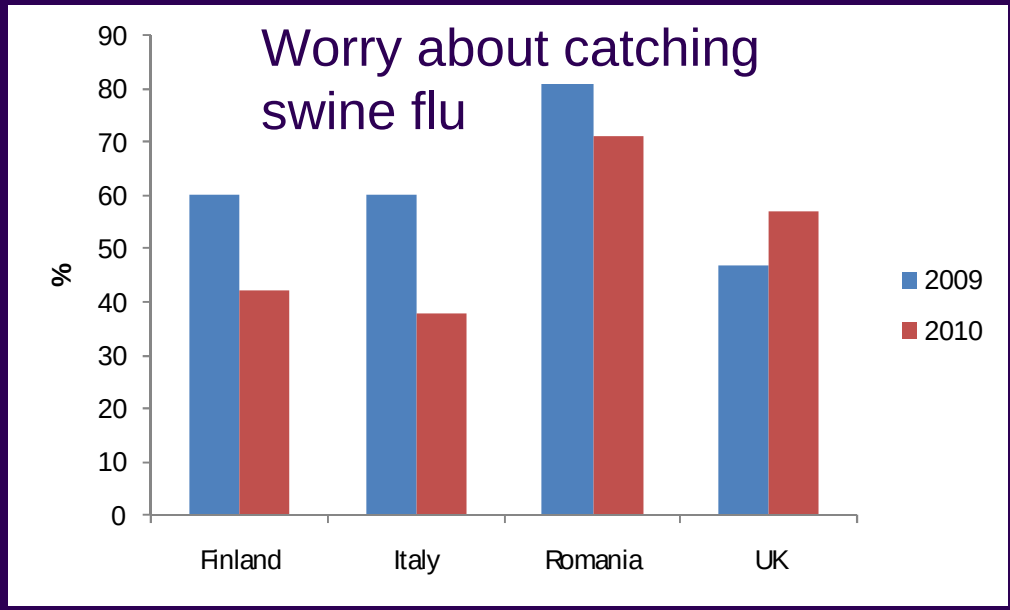
Capacity= 0.5%,

MI=0, 0.29 0.58

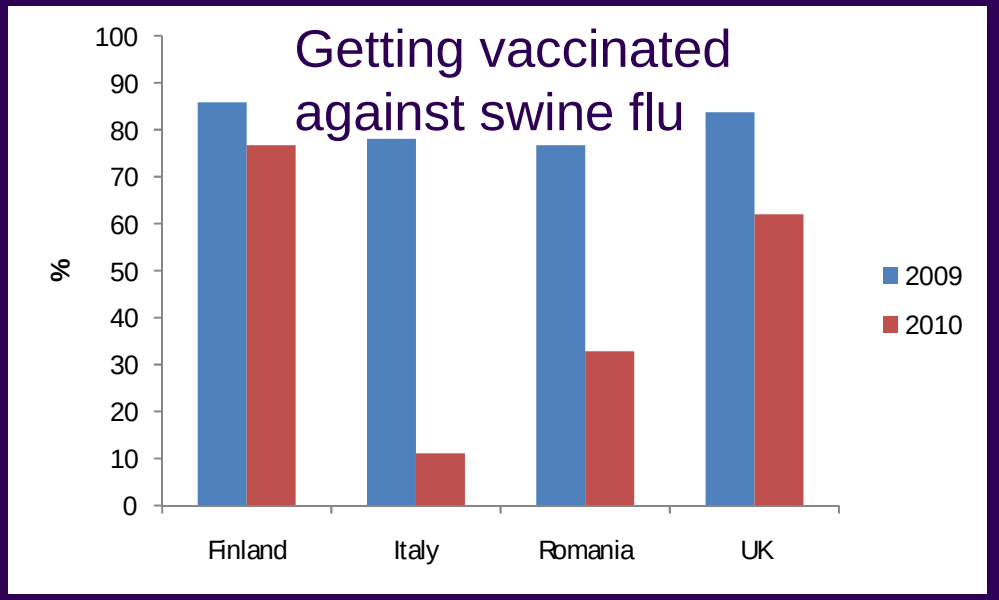


Behavioural response to Pandemic Influenza





Similar survey design but carried out before and after pandemic, enables assessment of behavioural intentions



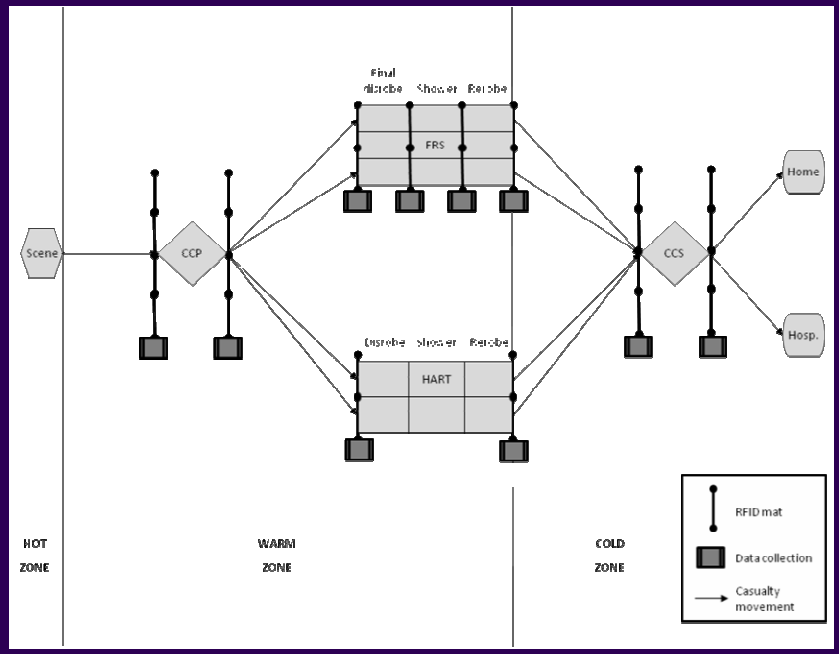
Mass Casualty decontamination process

Use HPA field exercises to capture data via RFID tracking of ‘casualties’.

Use data to parameterise simulation model.

Identify bottleneck in current system

Provide solutions.



Summary

Assumptions in models about behaviour may be limited

Contingency plans need to be in place ahead of time but revisited continually as evidence base improves

Delays in response have negative impact on mortality/morbidity

Public response to planned intervention policy will modify efficacy of the intervention

Mass treatment may be swamped by worried well / quarantine may be compromised.

Public health communication is a control intervention

Acknowledgements

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Any questions?