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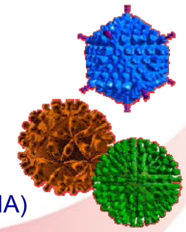
Digital Ring Fence: A novel GIS-based approach to contain Emerging Infectious Diseases (EIDs)

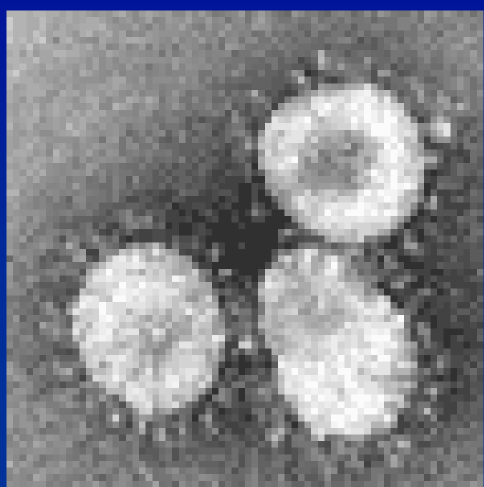
presented by

K C Lun
Immediate Past President,
International Medical Informatics Association (IMIA)
and Professor,
School of Biological Sciences,
Nanyang Technological University, Singapore

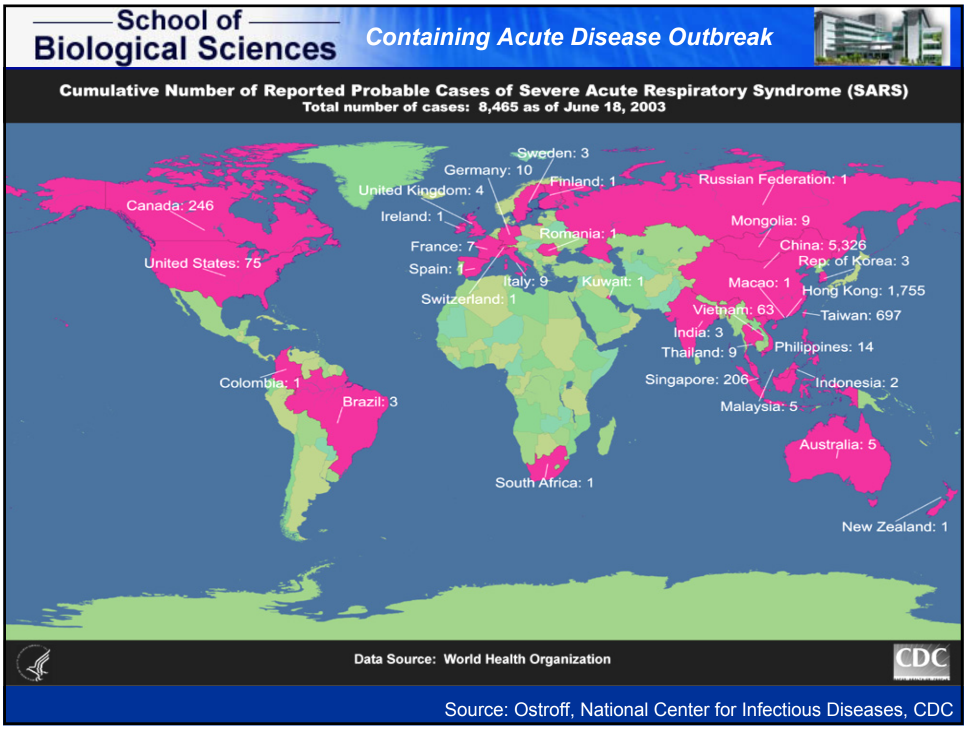


The Lesson from SARS

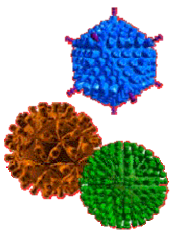
First Quarter, 2003



SARS coronaviruses



"Even if we rapidly eliminate SARS, we remain at risk of future viral mutations and should expect more dangerous new viruses to emerge over the next ten years".



- Patrick Dixon,
  futurist and chairman of
  Global Change Ltd, 7 May 2003

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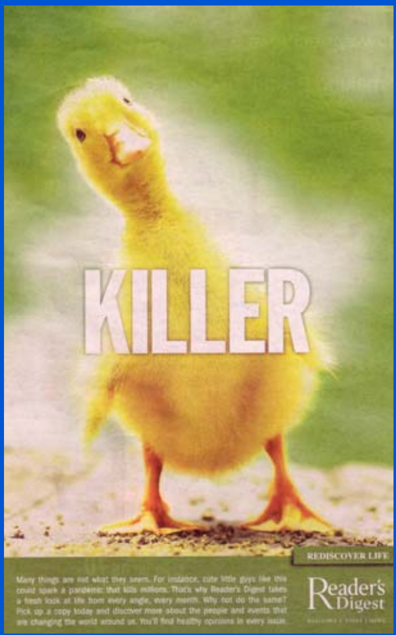
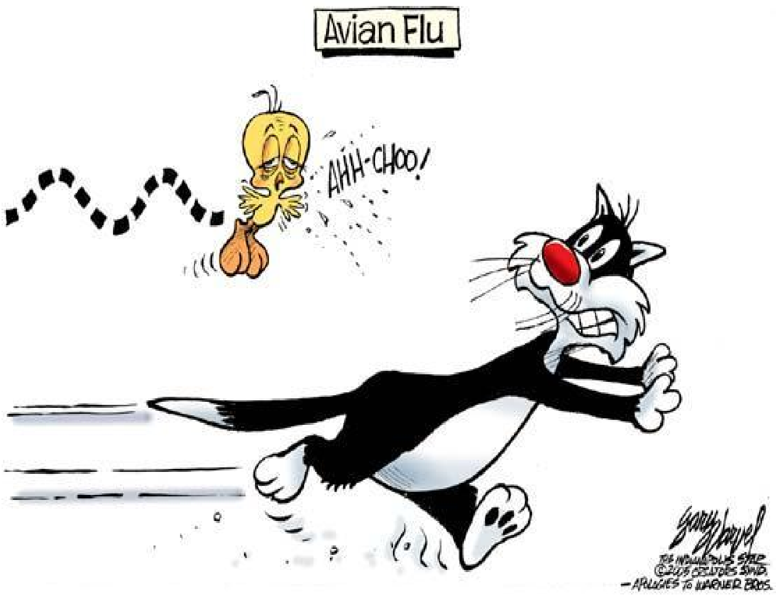
Containing Acute Disease Outbreak



- Will H5N1 be the next scourge after SARS?
- Already spreading beyond Asia to Europe
- Spread possibly by infected migratory birds
- World governments anticipating (and preparing) for a global pandemic



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SARS Containment Strategies : *Detect, Isolate, Quarantine*

Source: Ostroff, National Center for Infectious Diseases, CDC

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SARS Control

- Identify the sick people
- Treat the sick people without infecting others
- Keep contacts of sick people at home for 10-14 days i.e. *Ring-fence (corral) the spreader and potential spreaders*

Nurses under quarantine at Hoping Hospital, Taipei

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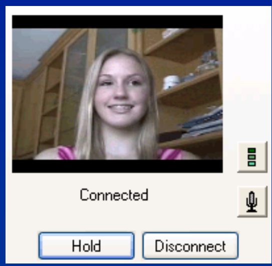
Ring-fence strategy in disease epidemiology

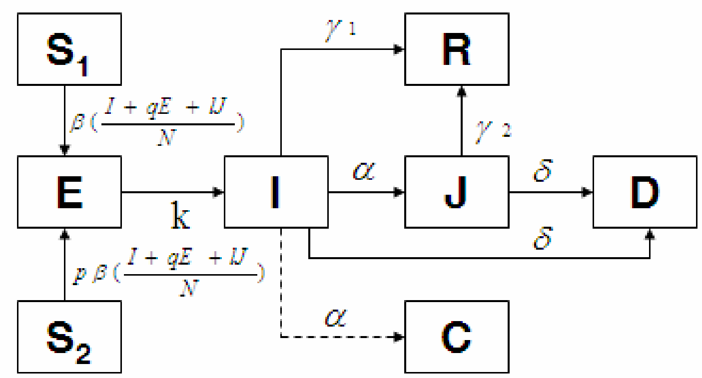
- Denotes an activity to contain the spread of infection by
  - isolating contacts (exposure)
  - monitoring them for the disease (infection)
- For SARS, Singapore Ministry of Health enforced strict quarantine of exposed through rigorous contact-tracing



Physical ring-fencing gave rise to idea of Digital (electronic) Ring-Fencing Technology (DRiFT)

Classical Epidemiological Modeling

Compartmental model



Source: Carlos Castillo-Chavez, Center for Nonlinear Studies, Los Alamos National Laboratory, Cornell University

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Modeling SARS transmission

- Traditional "compartmental" modeling (SEIR) in epidemiology assumes population groups are fully-mixed i.e. every individual has equal chance of getting the disease and spreading it to one another
- For a disease like SARS, the basic reproductive number (R_o) has not produced large-scale epidemics as predicted
- Compartmental modeling breaks down for diseases transmitted through close contact e.g. SARS

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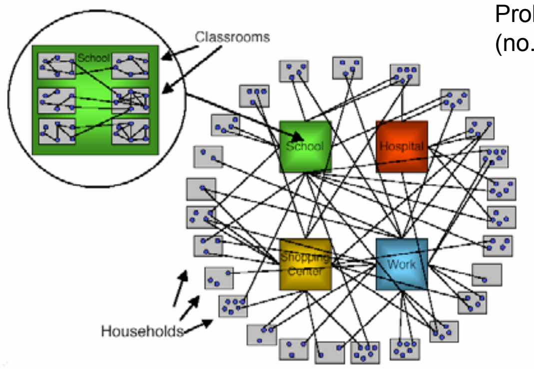
Contact Network Modeling

- Discrepancy between estimates of R_o and observed epidemiology possibly due to early and effective intervention
- Need to focus on *"individual-based modeling"* instead of *"compartmental modeling"*
- Recent work focuses on "contact network modeling" to characterize every interpersonal contact that can potentially lead to disease transmission in the community

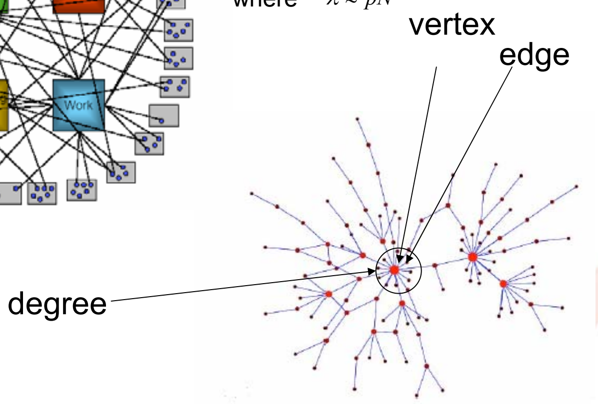
Contact Networks to model spread



Probability of 1 point having k degrees (no. of lines connected to it) =

$$p_k = \binom{N}{k} p^k (1-p)^{N-k} \approx \frac{e^{-\lambda}\lambda^k}{k!}.$$

where $\lambda \approx pN$



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DRiFT: Digital Ring Fence Technology for EID containment using GIS platform

- ✓ Map occurrences of cases (vertices of contact network)
- ✓ Encircle each vertex with digital ring fence
- ✓ Radius of digital ring fence proportionate to estimated risk of infection of individuals within the ring fence
- ✓ GIS platform allows containment efforts to be directed at places of population concentrations (markets, shopping malls, entertainment centres) within geographical area marked out by digital ring fence

Strategy: Make disease containment one-step ahead of its spread

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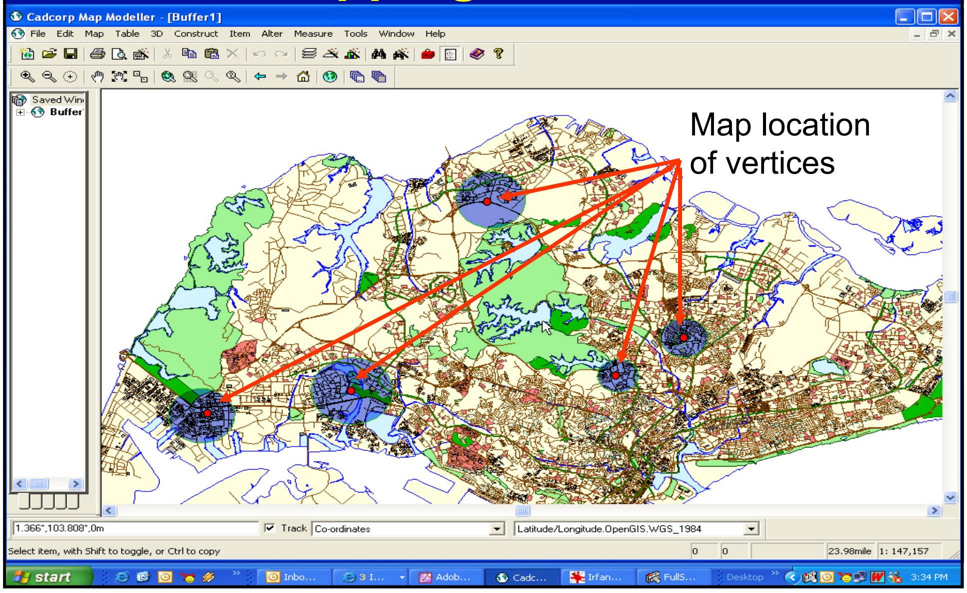
GIS mapping of outbreaks



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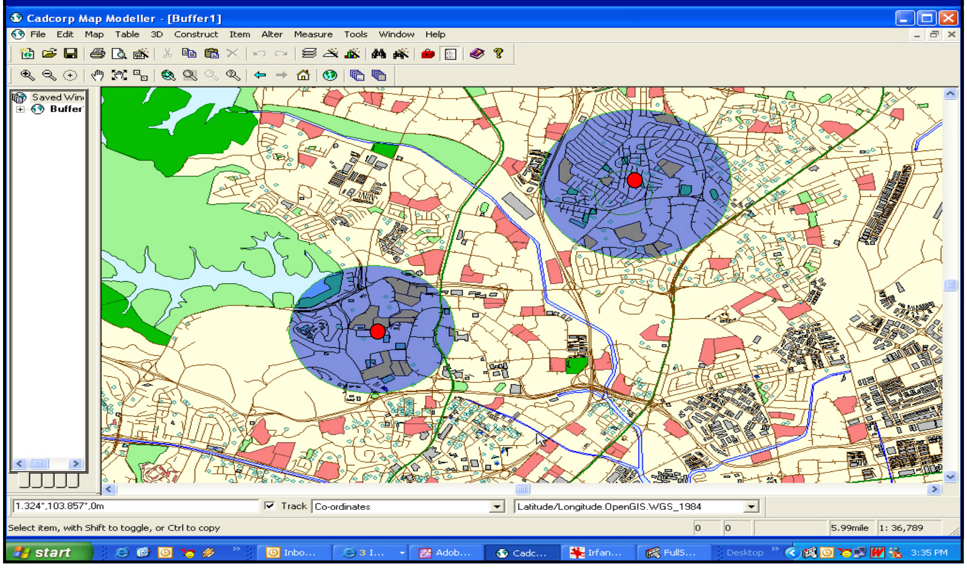
Multi-layering of GIS maps



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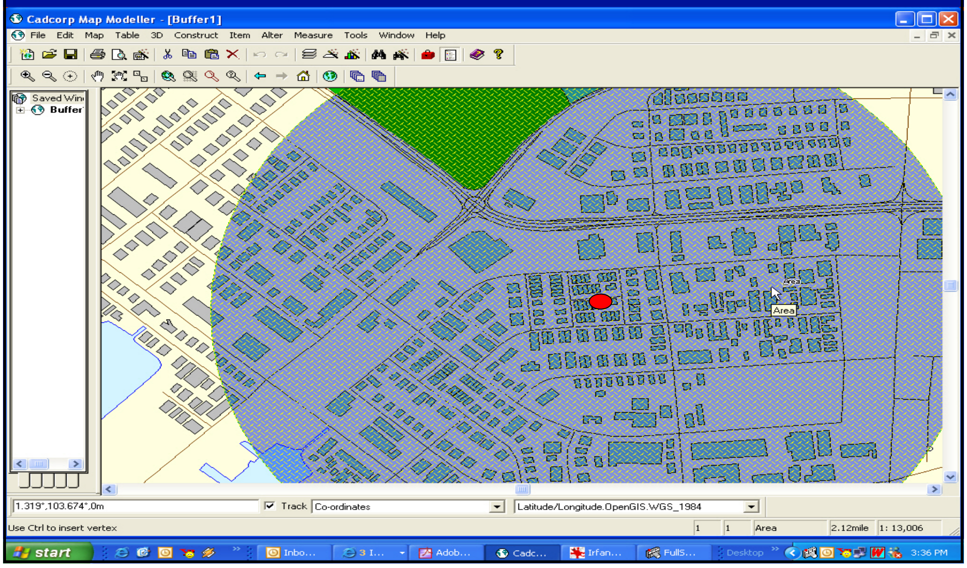
Multi-layering of GIS maps



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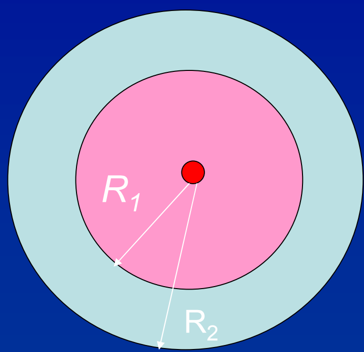
DRiFT Focus: Contact network to model disease containment

- Given the vertex, what is the risk of someone in the contact network getting the disease within x distance from the vertex?
- Distance from vertex and its concomitant risk provide basis for the digital ring fence construction



Risk 2 (R_2) < Risk1 (R_1)

Model focuses on containment, not spread of the disease

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Digital Ring Fence: Model

If the probability

$$P\{[N(y)-N(x)]=n\}=e^{-(\lambda(y)-\lambda(x))}\frac{[\lambda(y)-\lambda(x)]^n}{n!}$$

where $\lambda(x)=\int_0^x g(z)dz$

then N(y)-N(x) has a Non-Homogeneous Poisson distribution with parameter $\lambda(y)-\lambda(x)$

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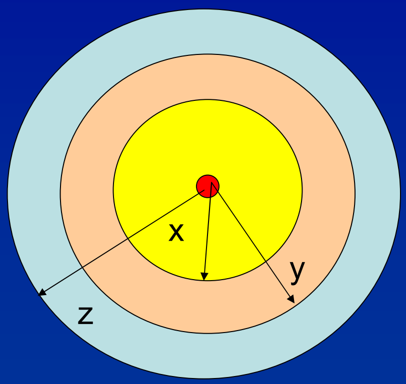
Digital Ring Fence: Model

The overall risk of infection within the defined area is given by:

$$r(x,y)=\frac{E(N(y)-N(x))*T}{PS(y-x)}.$$

where PS(y-x) = the population size within the defined area and T = infectivity of the infected person

Digital Ring Fence: Model



Depending on the risk of infection calculated, will adjust the radius of the e-ring fence to cope with the containment of the disease spread

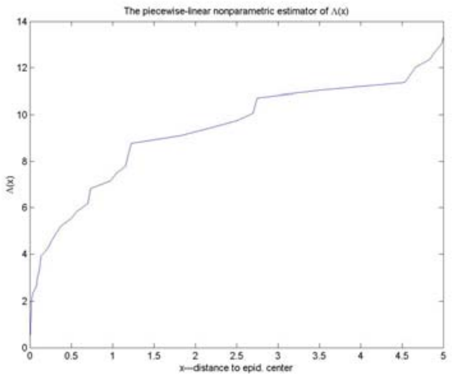
Simulation Studies

- Hypothetical data of individuals coming into contact with a probable case *over last 3 days* are electronically captured
- Stored in secured database

Data 1 records the information regarding the distance between the probable case and his contacts on day 1

Data1 = {0.00126018392283 0.00893845993502
0.01293193288195 0.01721042081285 0.11229577204808
0.21482253481043 0.31507974052212 0.37614151271792
0.49735498028620 0.70294088286048 0.97109194057815
2.16890715160328 2.72096888046909 3.52297913844732
4.66629786044356 4.83623313936767}(kilometers)

Simulation Studies



From data, piecewise-linear nonparametric estimator of the cumulative intensity function is derived with confidence intervals given by:

$$\left[\hat{\Lambda}(x) - z_{\alpha/2}\sqrt{\frac{\hat{\Lambda}(x)}{k}}, \hat{\Lambda}(x) + z_{\alpha/2}\sqrt{\frac{\hat{\Lambda}(x)}{k}}\right]$$

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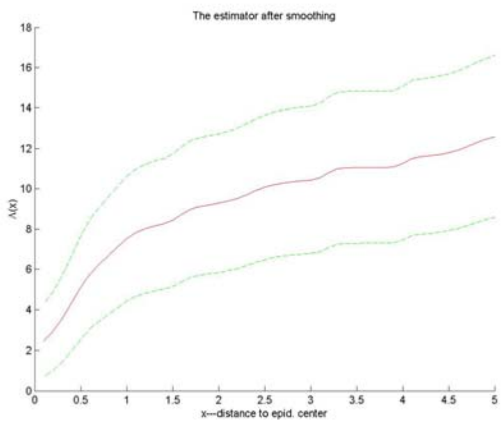
Estimator with 95% CI after smoothing



Estimator allows us to estimate average number of individuals coming into contact with probable case per day within the area of the digital ring fence

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Computing Risk of Infection for DRiFT

$$r(x,y) = \frac{E(N(y)-N(x))*T}{PS(y-x)}.$$

- E(N(y)-N(x)) = estimated number of contacts with probable case within area of concentric rings with radii y and x
- T = transmissibility of infectious disease
- PS(y-x) = population size within area of concentric rings with radii y and x

Advantage of the GIS – allows estimation of population size within the defined area

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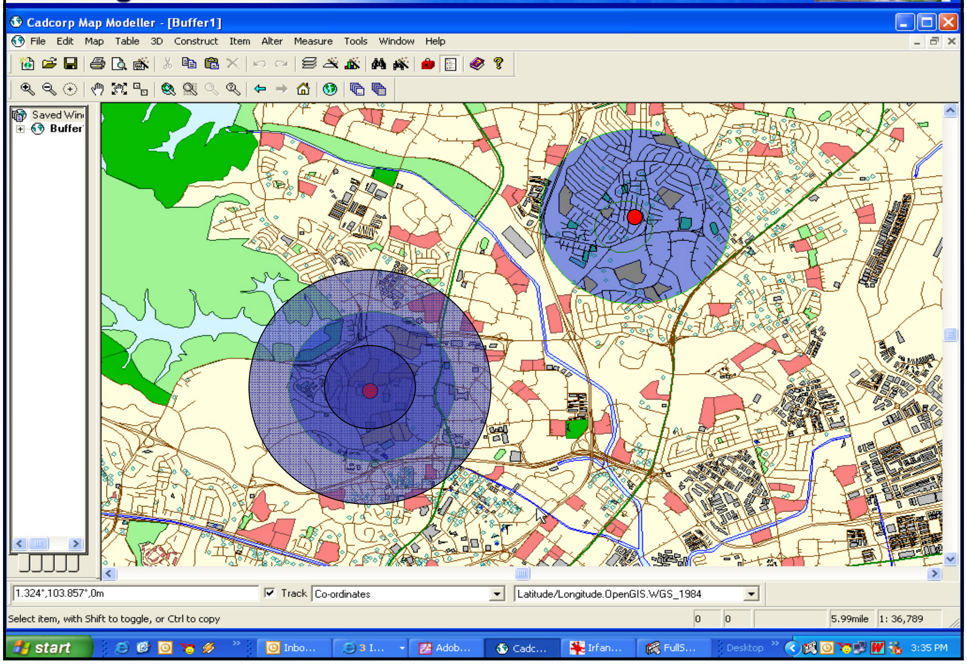

The Real Test

- The digital ring fence concept is to guard against the spread of infection
- When an outbreak occurs, places within the buffer zone on the GIS with high population concentrations can be put on high alert to keep the outbreak in check
- Real test comes when an outbreak does occur, especially if the mechanism of transmission goes beyond person-to-person contact

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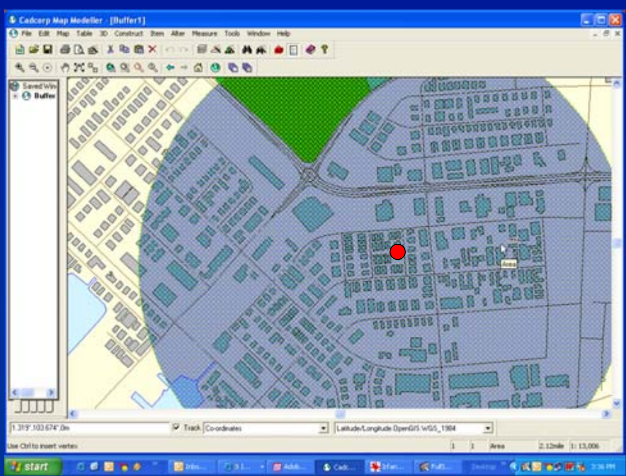
Containing Acute Disease Outbreak

Summary: Handling EID outbreaks



Strategy:
Containment *not* prediction of the course of outbreak

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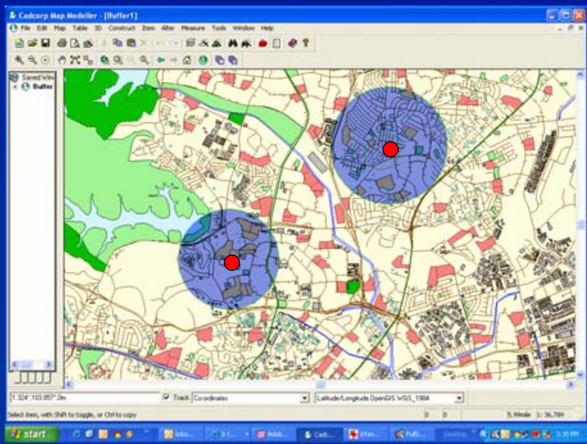
Containing Acute Disease Outbreak

Summary: Handling EID outbreaks

Containment Strategy:

Construct digital ring fence and focus contain-ment efforts on places with high infection risks within the digital ring fence



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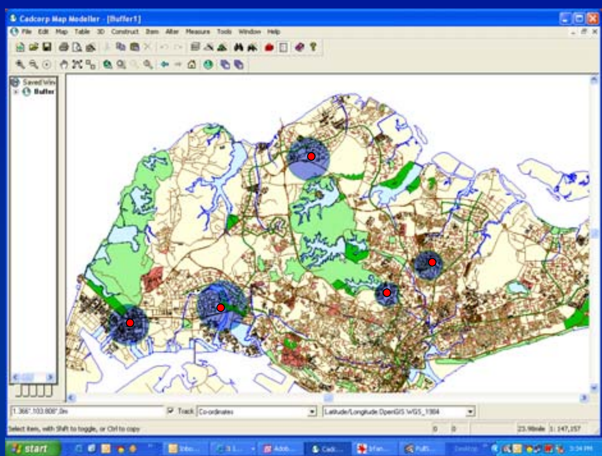
Containing Acute Disease Outbreak

Summary: Handling EID outbreaks

Goal:

Make disease containment *one step ahead* of its spread



Summary: Handling EID outbreaks

H5N1 Outbreaks

Digital ring fence concept can also be applied to delineate culling zone for poultry

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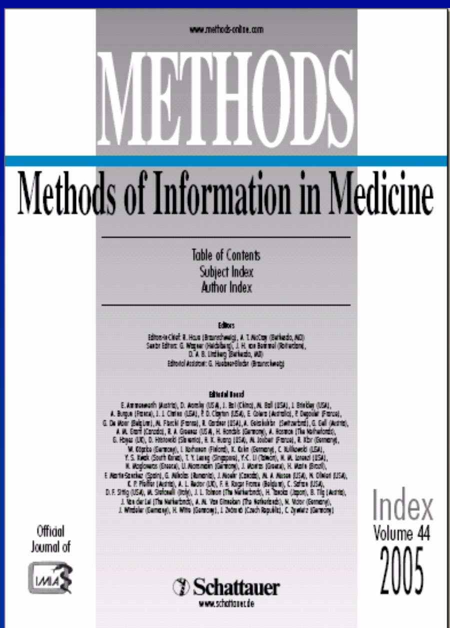
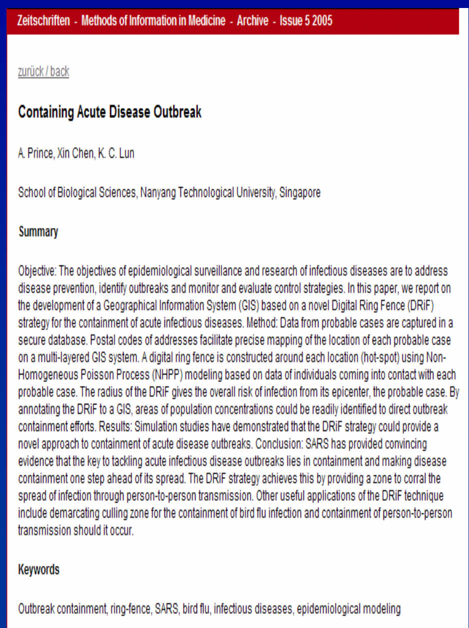
Containing Acute Disease Outbreak





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Containing Acute Disease Outbreak

A. Prince, Xin Chen, K. C. Lun

School of Biological Sciences, Nanyang Technological University, Singapore

Summary

Objective: The objectives of epidemiological surveillance and research of infectious diseases are to address disease prevention, identify outbreaks and monitor and evaluate control strategies. In this paper, we report on the development of a Geographical Information System (GIS) based on a novel Digital Ring Fence (DRiF) strategy for the containment of acute infectious diseases. Method: Data from probable cases are captured in a secure database. Postal codes of addresses facilitate precise mapping of the location of each probable case on a multi-layered GIS system. A digital ring fence is constructed around each location (hot-spot) using Non-Homogeneous Poisson Process (NHPP) modeling based on data of individuals coming into contact with each probable case. The radius of the DRiF gives the overall risk of infection from its epicenter, the probable case. By annotating the DRiF to a GIS, areas of population concentrations could be readily identified to direct outbreak containment efforts. Results: Simulation studies have demonstrated that the DRiF strategy could provide a novel approach to containment of acute disease outbreaks. Conclusion: SARS has provided convincing evidence that the key to tackling acute infectious disease outbreaks lies in containment and making disease containment one step ahead of its spread. The DRiF strategy achieves this by providing a zone to corral the spread of infection through person-to-person transmission. Other useful applications of the DRiF technique include demarcating culling zone for the containment of bird flu infection and containment of person-to-person transmission should it occur.

Keywords

Outbreak containment, ring-fence, SARS, bird flu, infectious diseases, epidemiological modeling

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Research team members:
K C Lun (Principal Investigator)
Antony Prince (Research Associate)
Chen Xin (Research Associate)

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