Australian Government
Department of Defence
Defence Science and Technology Organisation

Epidemic Spread Modelling: Alignment of Agent-based Simulation with a SIR Mathematical Model

Presenter: Peter Dawson

Collaborators: Alex Skvortsov, Russell Connell+, Ralph Gailis
HPPD, +AOD
Defence Science and Technology Organisation

5th July 2007

References:

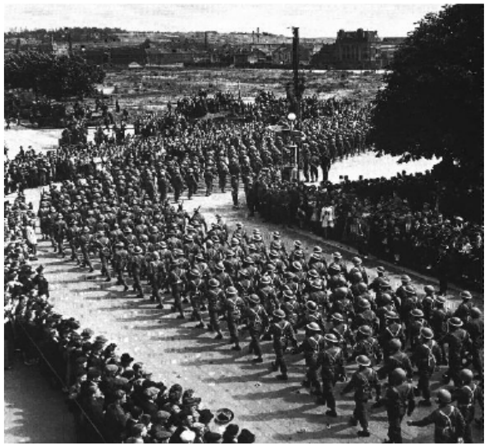
A. Skvortsov, R. Connell, P. Dawson and R. Gailis, BioComp07
B. H. Rahmandad, J. Sterman, MIT ESD-WP-2004-05
C. M. Bootsma, N. Ferguson, Proc. Natl. Acad. Sci. USA, 10.1073/pnas0611071104, 2007

Why is the DSTO interested in Epidemic Modelling?

Australian Government
Department of Defence
Defence Science and Technology Organisation

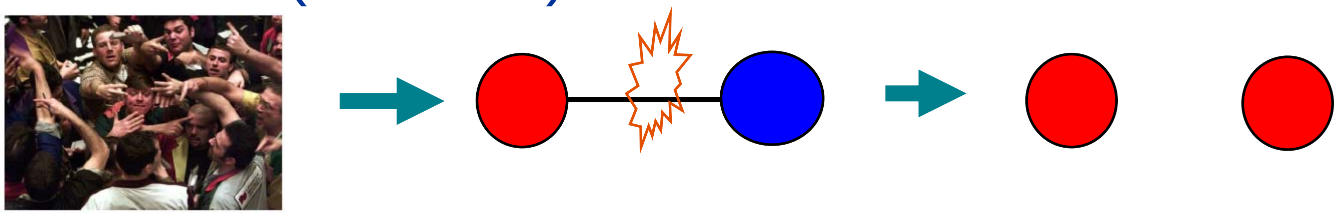
- DSTO tasked with research into defence against biological attacks
- Would like a model that is adaptable to different Australian civilian and military populations
- For the estimation of the availability of resources (*Capacity Planning*)
- We had an advanced in-house agent based model to simulate Australian townships, ready for adaptation to epidemiology
- Have in-house experts on epidemiology

Epidemics have a direct impact on Defence capabilities!



How can we model the disease spread?

- State Machine approach: assign an ‘infectious’ state to each individual and allow state to change as a result of social interactions (contacts)



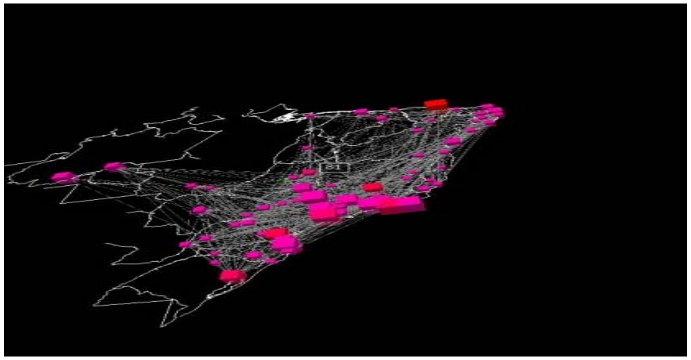
- For realistic scenarios we need at least three states (**S** - susceptible, **I** - infected, **R** - recovered/removed).

- Main goal: predict the evolution of populations in S, I and R

What factors can influence disease spread?

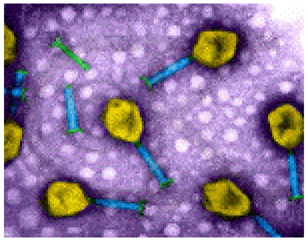
Australian Government
Department of Defence
Defence Science and
Technology Organisation

1 . Population Demographics (Social networks)



- Mobility
- Contact hubs
- Connective network
- Effect of social distancing/quarantine

2. Disease (Biology)

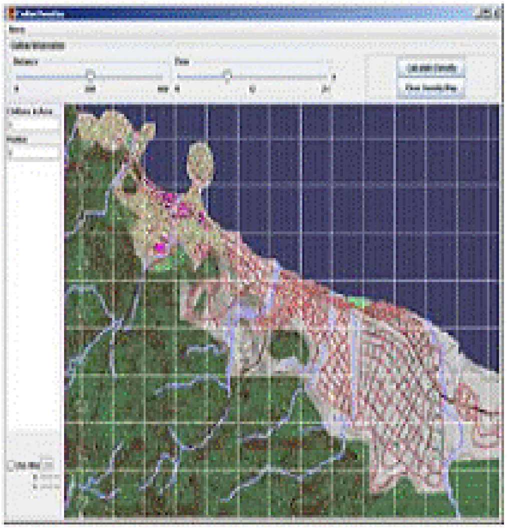


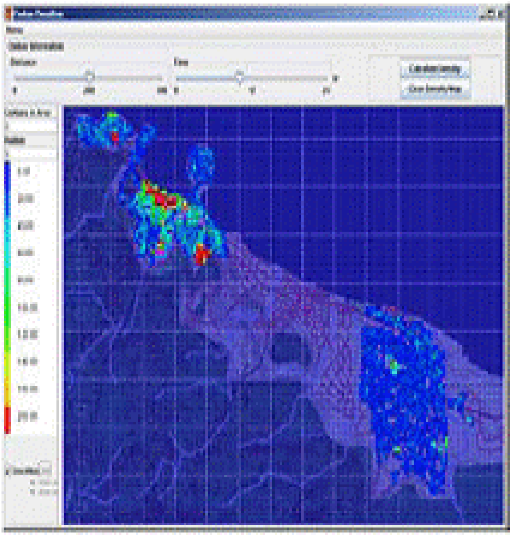
- Infection probability *(hard to estimate)*
- Infectious period
- Recovery rate
- Immunity
- Effect of vaccination

All of this may need to be modelled!

CROWD–Agent Based Modelling Scenario

Australian Government
Department of Defence
Defence Science and
Technology Organisation





- Small township: 3000 people go about their lives (go to work, come home, meet people, travel…)
- Social Network includes families, workplaces, schools etc
  - Much potential to build in reactions to an epidemic
- Model uses real census data (reconstructs family groups based on age/sex etc)
- Based on JACK Framework + JAVA
- Agents interact, swap information
- *Model for epidemic spread inserted over this behaviour*

Alignment with the SIR Mathematical Model

Australian Government
Department of Defence
Defence Science and
Technology Organisation

1. CROWD model needed validation! Compare to the SIR model (Kermack & McKendrick, 1927)

2. The SIR model long known to model simple epidemics very well.
   - System of *coupled non-linear equations* for the SIR states

$$\frac{ds}{dt} = -\alpha si \qquad \frac{di}{dt} = \alpha si - \beta i \qquad \frac{dr}{dt} = \beta i$$

   - s: susceptible population
   - i: infectious population
   - r: recovered/immune/expired population

   - Only two parameters and the universal condition of epidemic is: $s > \beta/\alpha$

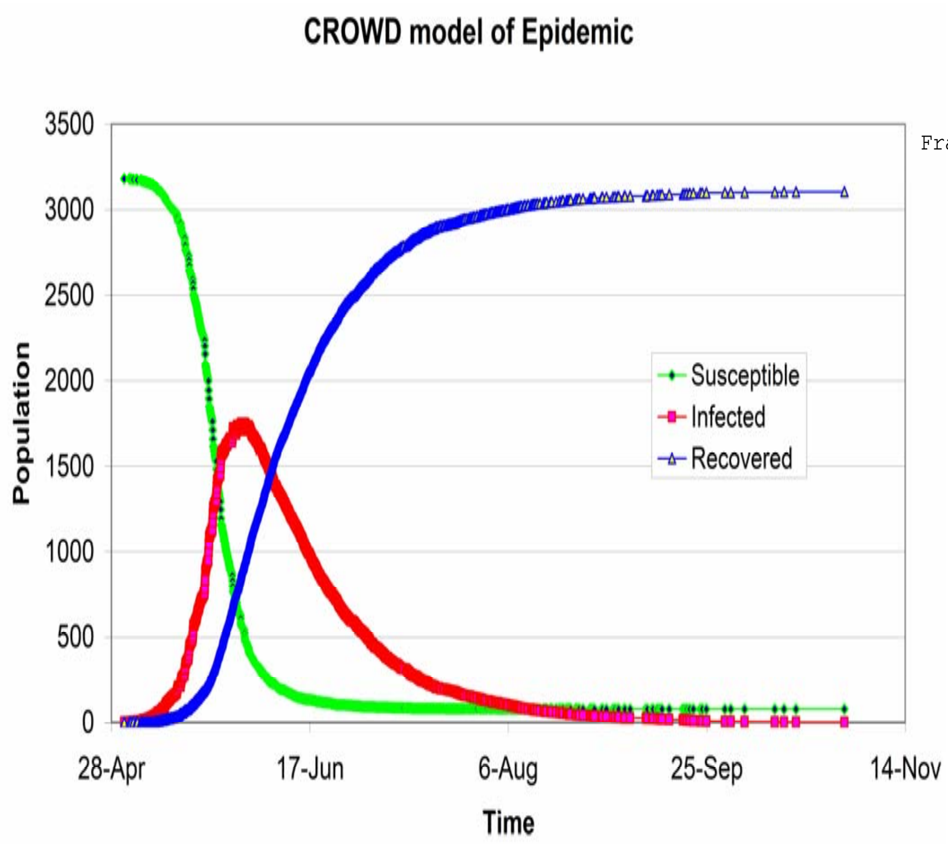
     Disease doesn´t always lead to an epidemic

   - Derivatives in LHS may include space variation and diffusion term

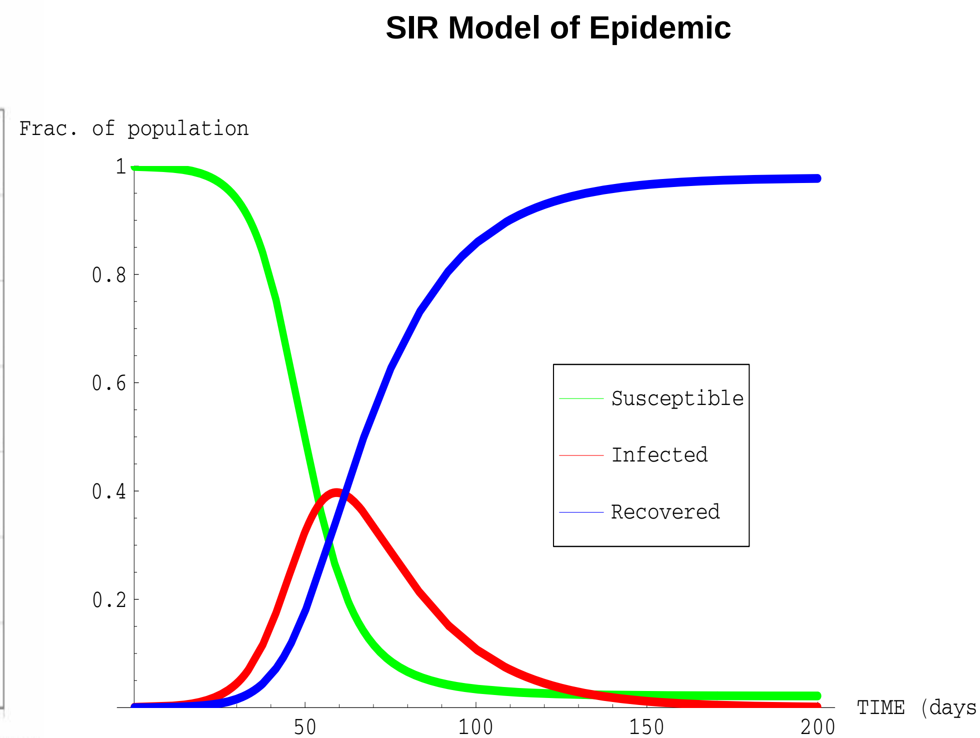
3. *CROWD model deliberated simplified for alignment with the SIR model.*

Model Alignment: CROWD (DSTO) and SIR

Australian Government
Department of Defence
Defence Science and Technology Organisation



AGENT BASED



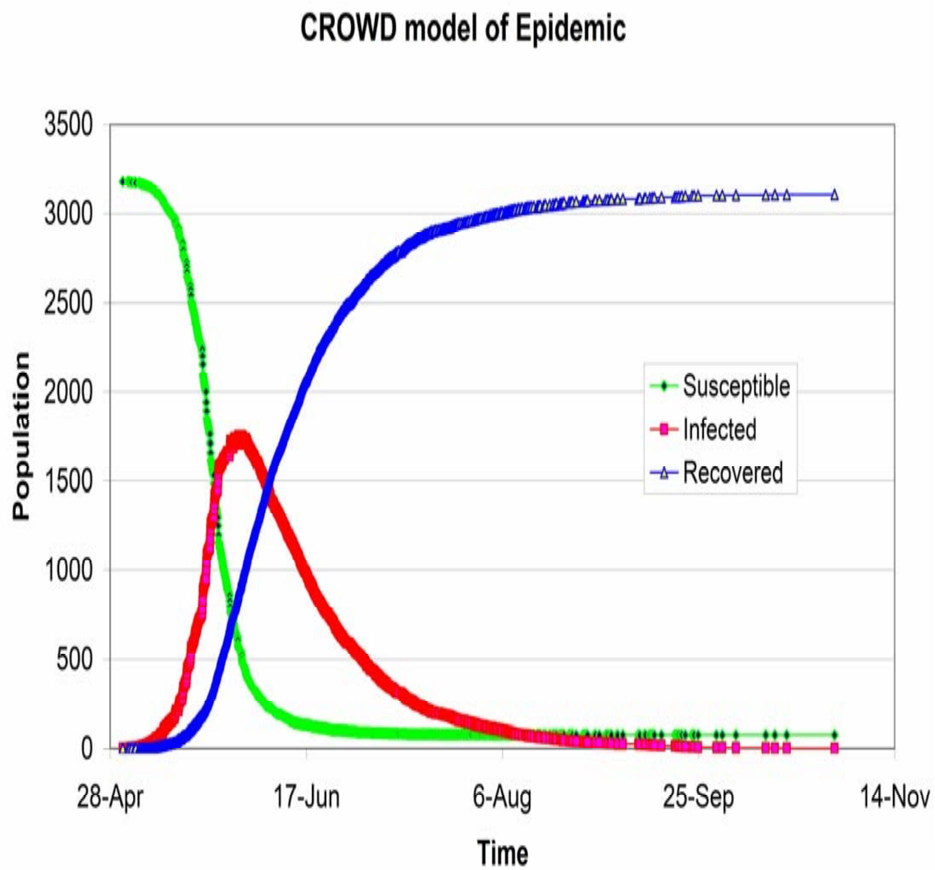
EQUATION BASED

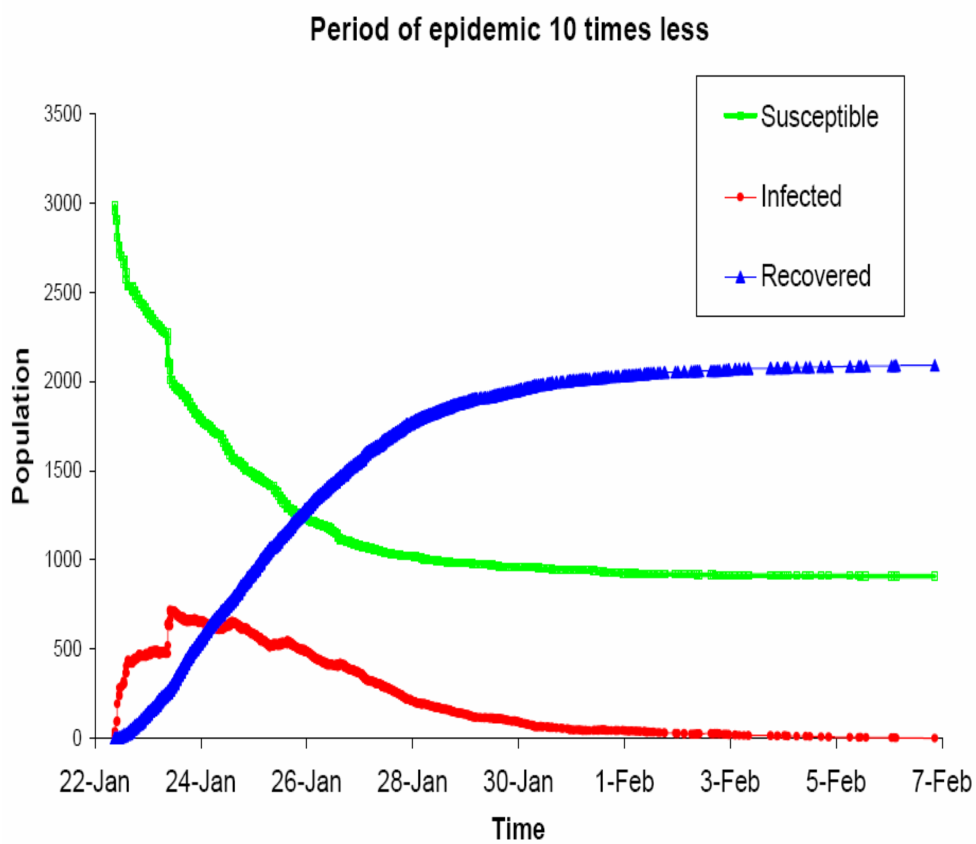
- **Output of the CROWD agent based epidemic simulation and the SIR mathematical model**

SIR model is a good performance check!

Extra time – daily cycle epidemic effects

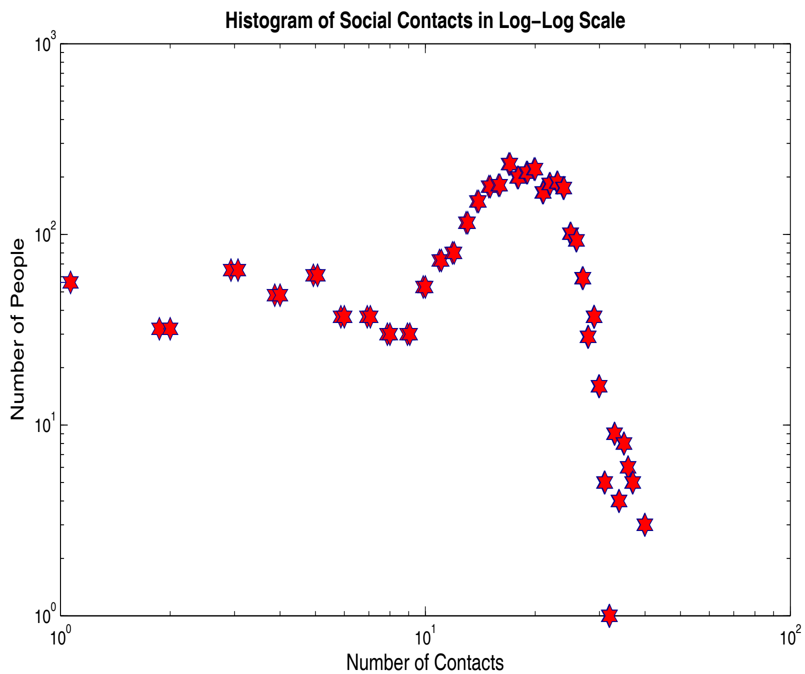
Australian Government
Department of Defence
Defence Science and Technology Organisation

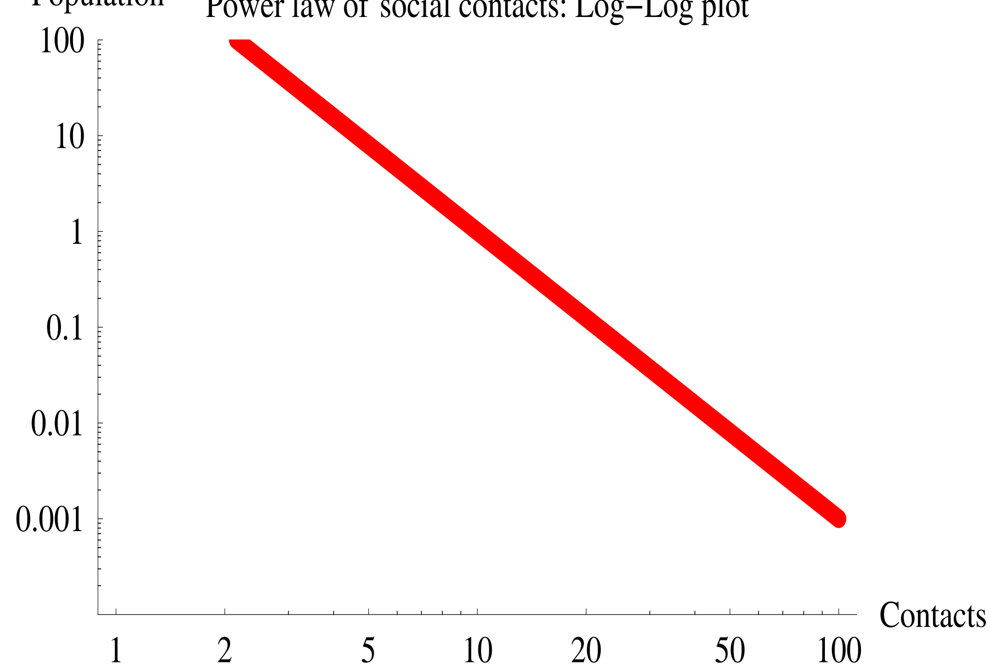




The spike in the infected population (red) in the ‘short period’ case comes on second day as large infected population arrives at work.

Extra time - Contact Network





- Fidelity of epidemic model dependent on accuracy of contact network.
- CROWD contact network in model currently does not resemble a realistic network (it is random, not scale free).
- A simple contact behaviour algorithm used by nature being adapted to produce realistic contacts.

Conclusions and Future Directions

Australian Government
Department of Defence
Defence Science and
Technology Organisation

- Agent model agrees well with the SIR model
- Adjust Social Contact Network and complete validation
- Generalise models for different diseases
- Include reactive social distancing, quarantines, vaccination programs, contact hub closures and other methods
- Adapt to different populations, military and civilian

QUESTIONS?