

---

# Maximum Utility for Limited Vaccine Stocks -

## A case study using agent-based modelling

Dr Adam Forsyth

Land Operations Division, DSTO

MAJ Ash Fry

Land Warfare Development Centre, Australian Army

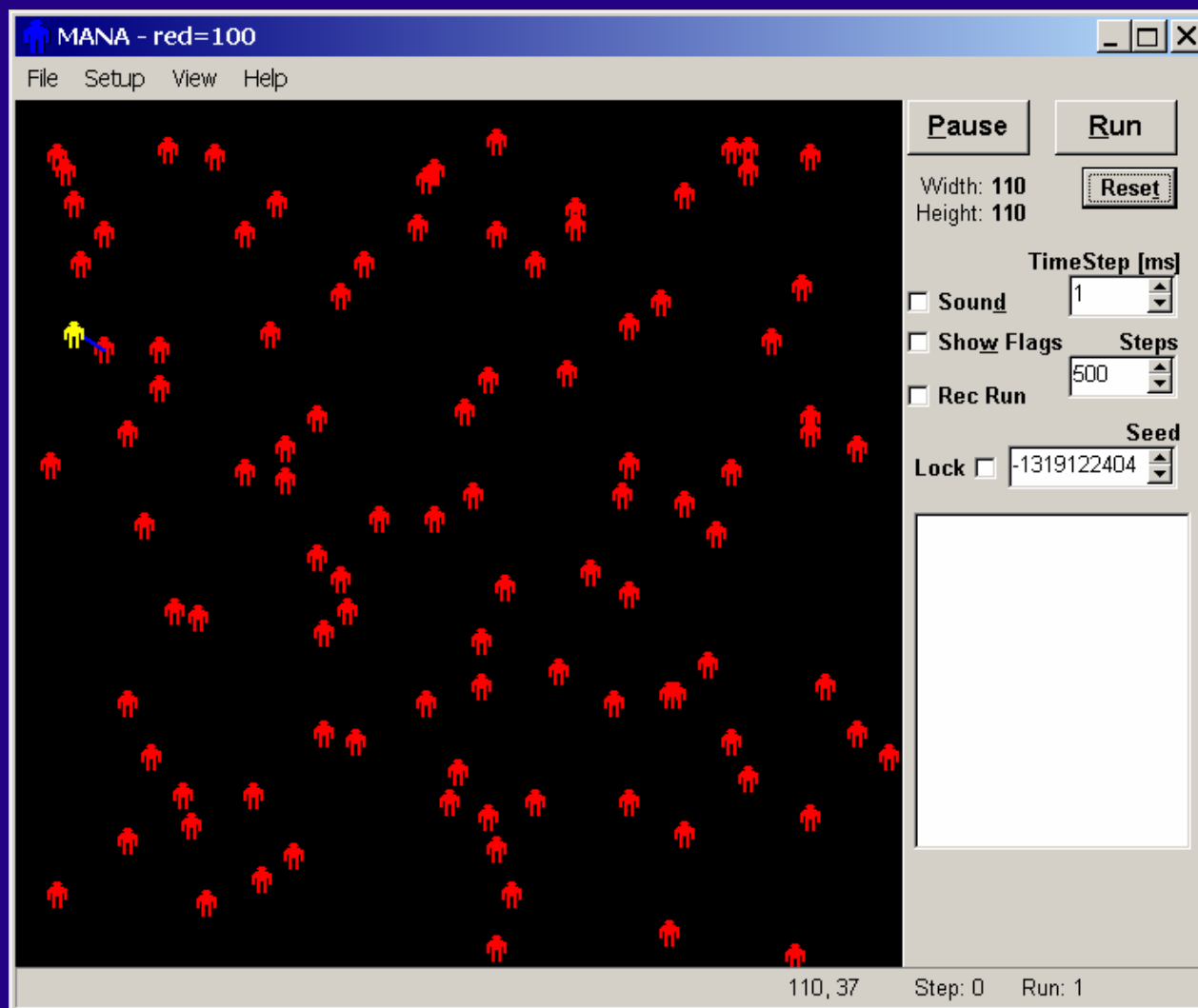
| Report Documentation Page                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              |                                    |                                     |                                            | Form Approved<br>OMB No. 0704-0188          |                                    |
|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------|-------------------------------------|--------------------------------------------|---------------------------------------------|------------------------------------|
| Public reporting burden for the collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington VA 22202-4302. Respondents should be aware that notwithstanding any other provision of law, no person shall be subject to a penalty for failing to comply with a collection of information if it does not display a currently valid OMB control number. |                                    |                                     |                                            |                                             |                                    |
| 1. REPORT DATE<br><b>01 OCT 2003</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   |                                    | 2. REPORT TYPE<br><b>N/A</b>        |                                            | 3. DATES COVERED<br><b>-</b>                |                                    |
| 4. TITLE AND SUBTITLE<br><b>Maximum Utility for Limited Vaccine Stocks - A case study using agent-based modelling</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  |                                    |                                     |                                            | 5a. CONTRACT NUMBER                         |                                    |
|                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        |                                    |                                     |                                            | 5b. GRANT NUMBER                            |                                    |
|                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        |                                    |                                     |                                            | 5c. PROGRAM ELEMENT NUMBER                  |                                    |
| 6. AUTHOR(S)                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           |                                    |                                     |                                            | 5d. PROJECT NUMBER                          |                                    |
|                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        |                                    |                                     |                                            | 5e. TASK NUMBER                             |                                    |
|                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        |                                    |                                     |                                            | 5f. WORK UNIT NUMBER                        |                                    |
| 7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)<br><b>Land Operations Division, DSTO Australia</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  |                                    |                                     |                                            | 8. PERFORMING ORGANIZATION<br>REPORT NUMBER |                                    |
| 9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                |                                    |                                     |                                            | 10. SPONSOR/MONITOR'S ACRONYM(S)            |                                    |
|                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        |                                    |                                     |                                            | 11. SPONSOR/MONITOR'S REPORT<br>NUMBER(S)   |                                    |
| 12. DISTRIBUTION/AVAILABILITY STATEMENT<br><b>Approved for public release, distribution unlimited</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  |                                    |                                     |                                            |                                             |                                    |
| 13. SUPPLEMENTARY NOTES<br><b>See also ADM001929. Proceedings, Held in Sydney, Australia on July 8-10, 2003., The original document contains color images.</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         |                                    |                                     |                                            |                                             |                                    |
| 14. ABSTRACT                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           |                                    |                                     |                                            |                                             |                                    |
| 15. SUBJECT TERMS                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      |                                    |                                     |                                            |                                             |                                    |
| 16. SECURITY CLASSIFICATION OF:                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        |                                    |                                     | 17. LIMITATION OF<br>ABSTRACT<br><b>UU</b> | 18. NUMBER<br>OF PAGES<br><b>22</b>         | 19a. NAME OF<br>RESPONSIBLE PERSON |
| a. REPORT<br><b>unclassified</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       | b. ABSTRACT<br><b>unclassified</b> | c. THIS PAGE<br><b>unclassified</b> |                                            |                                             |                                    |

## Background

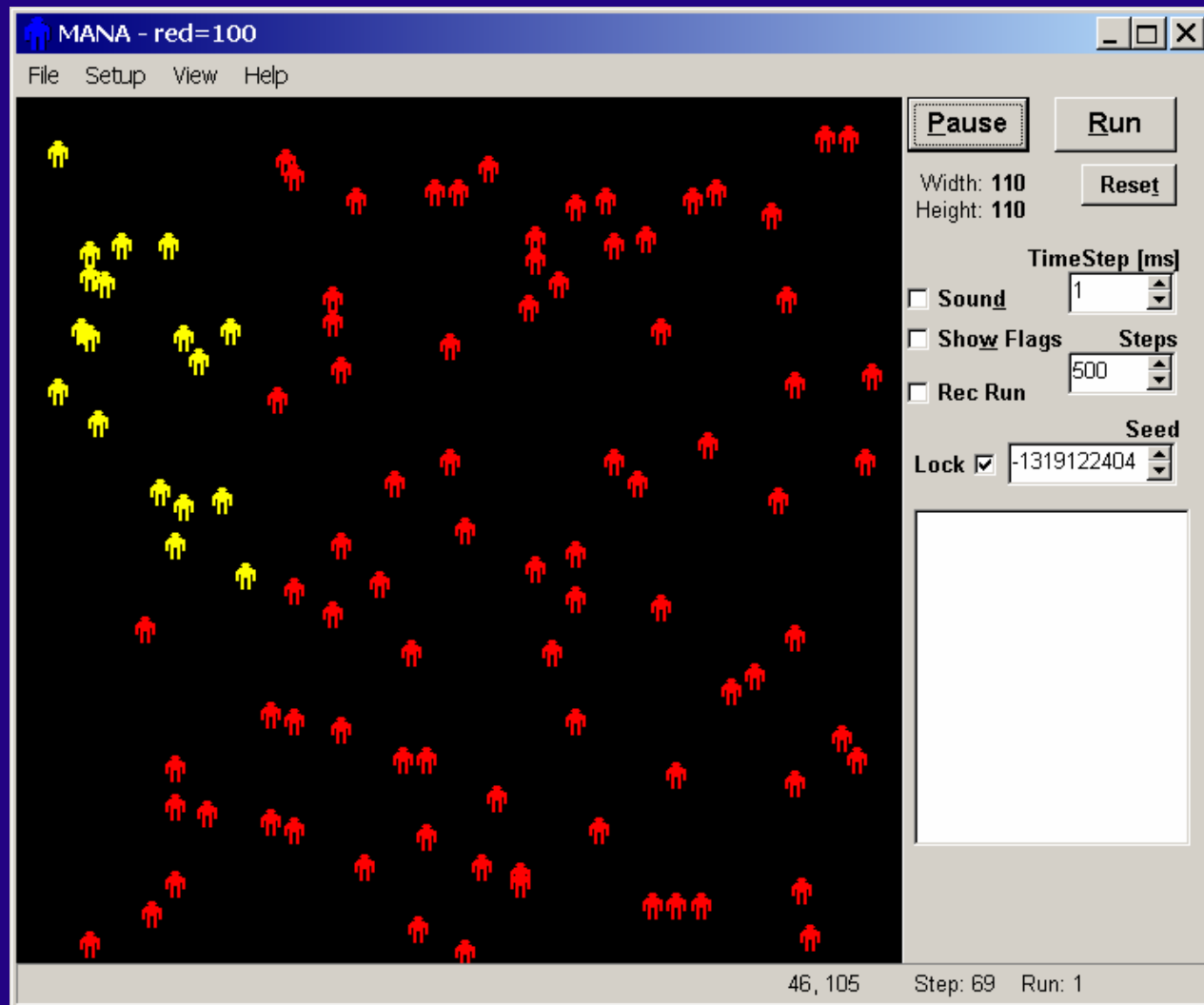
---

- Inspired by events of September 11, 2001 and the anthrax attacks soon thereafter
- Initial work led to invitation to Project Albert Emergency Working Group on Terrorism in Maui, Hawaii, January 2002
- While initial study focused on terrorism attack, the methodology and results are equally valid for treatable transmittable epidemics such as meningococcal meningitis or measles
- In fact, results are generally applicable to any system in which something (be it disease or information) is transmitted

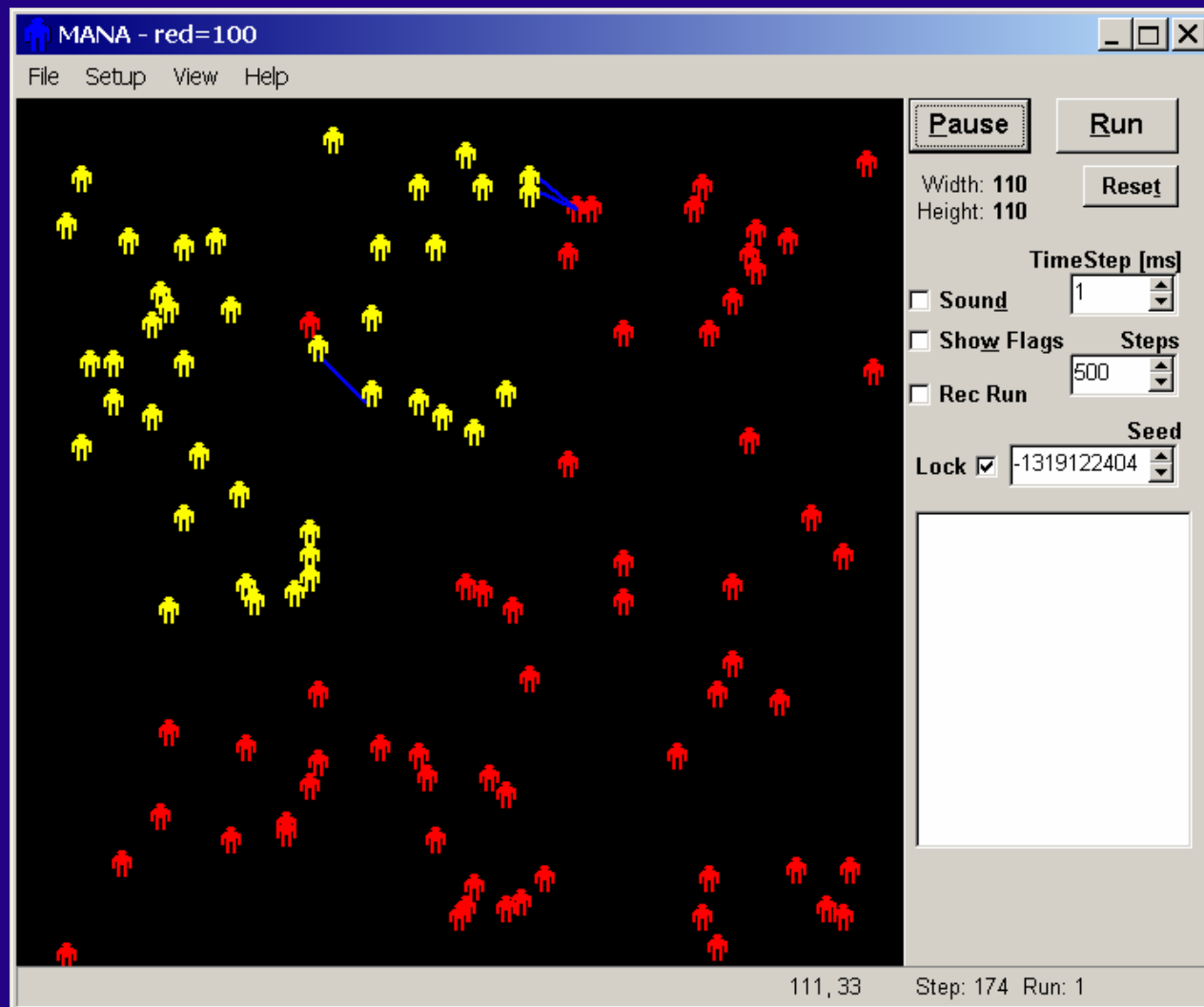
# SIR Model in MANA



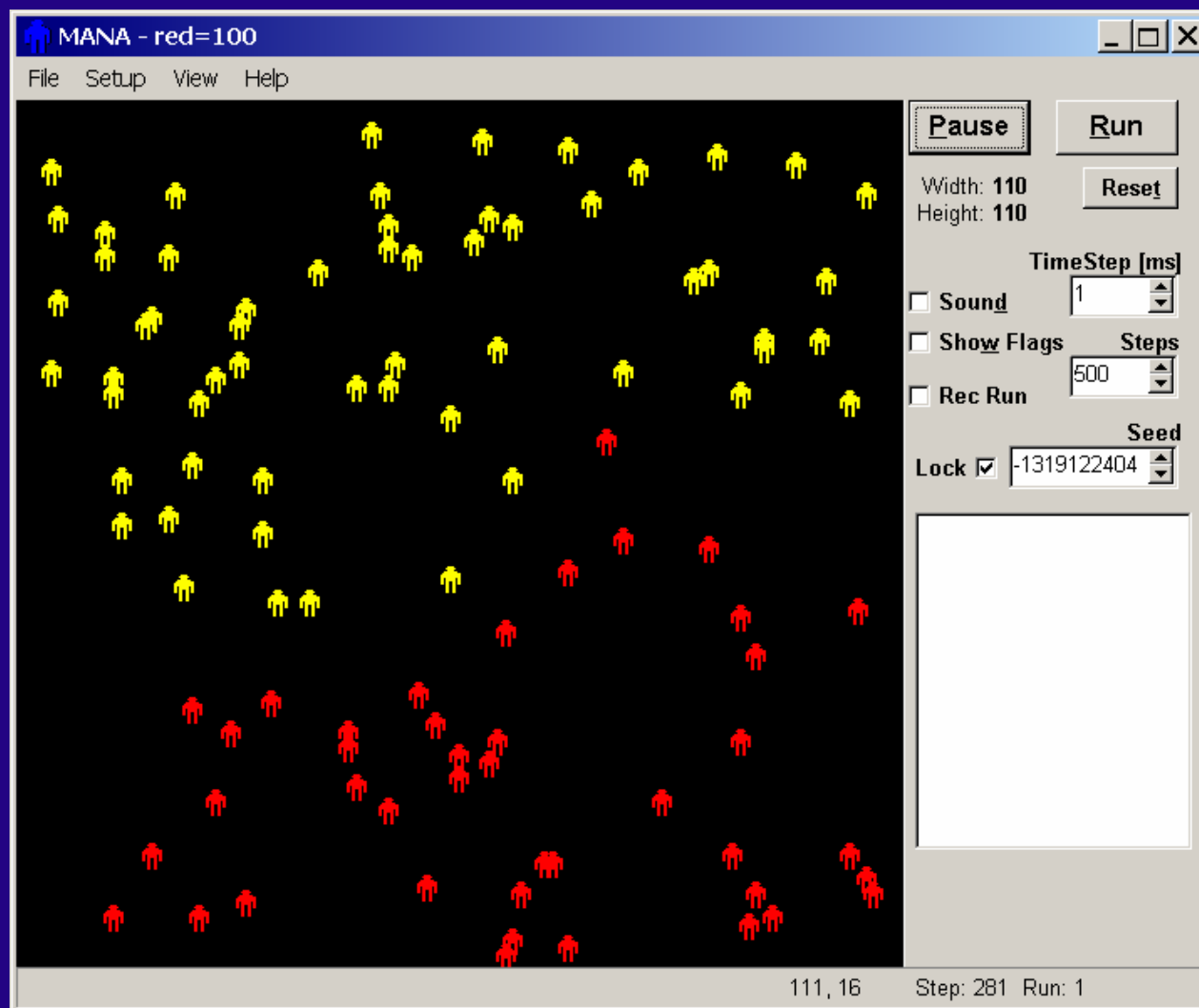
# SIR Model in MANA



# SIR Model in MANA



# SIR Model in MANA



## Inoculation

---

- At the time of the anthrax scare post 9/11 it was made clear that there was not enough vaccine to inoculate the entire population
- The question we examined is:  
“Given a limited supply of vaccine for a communicable disease, and sufficient time to effectively vaccinate, is there an optimal strategy to vaccinate a number of independent communities?”

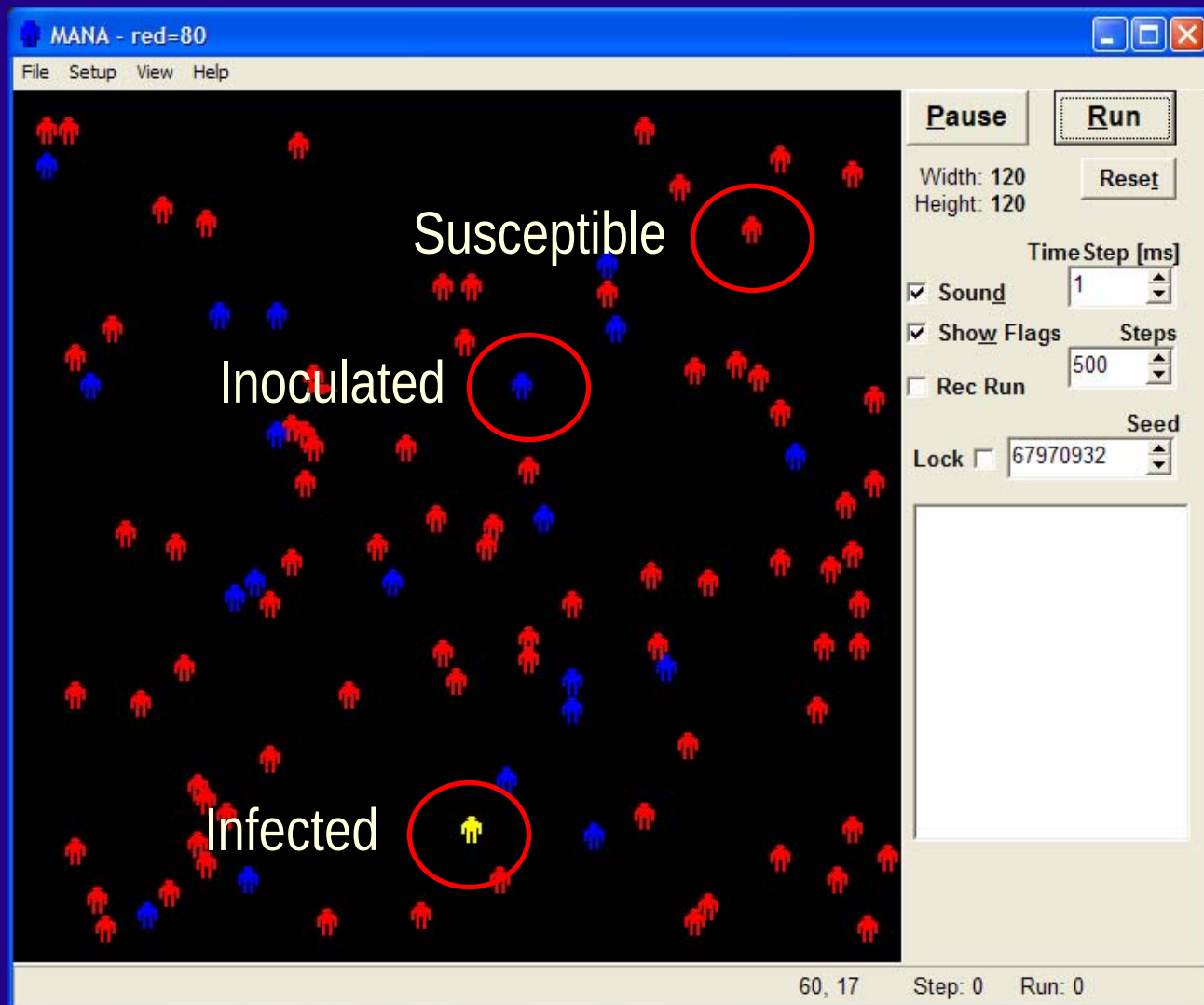


## The Method

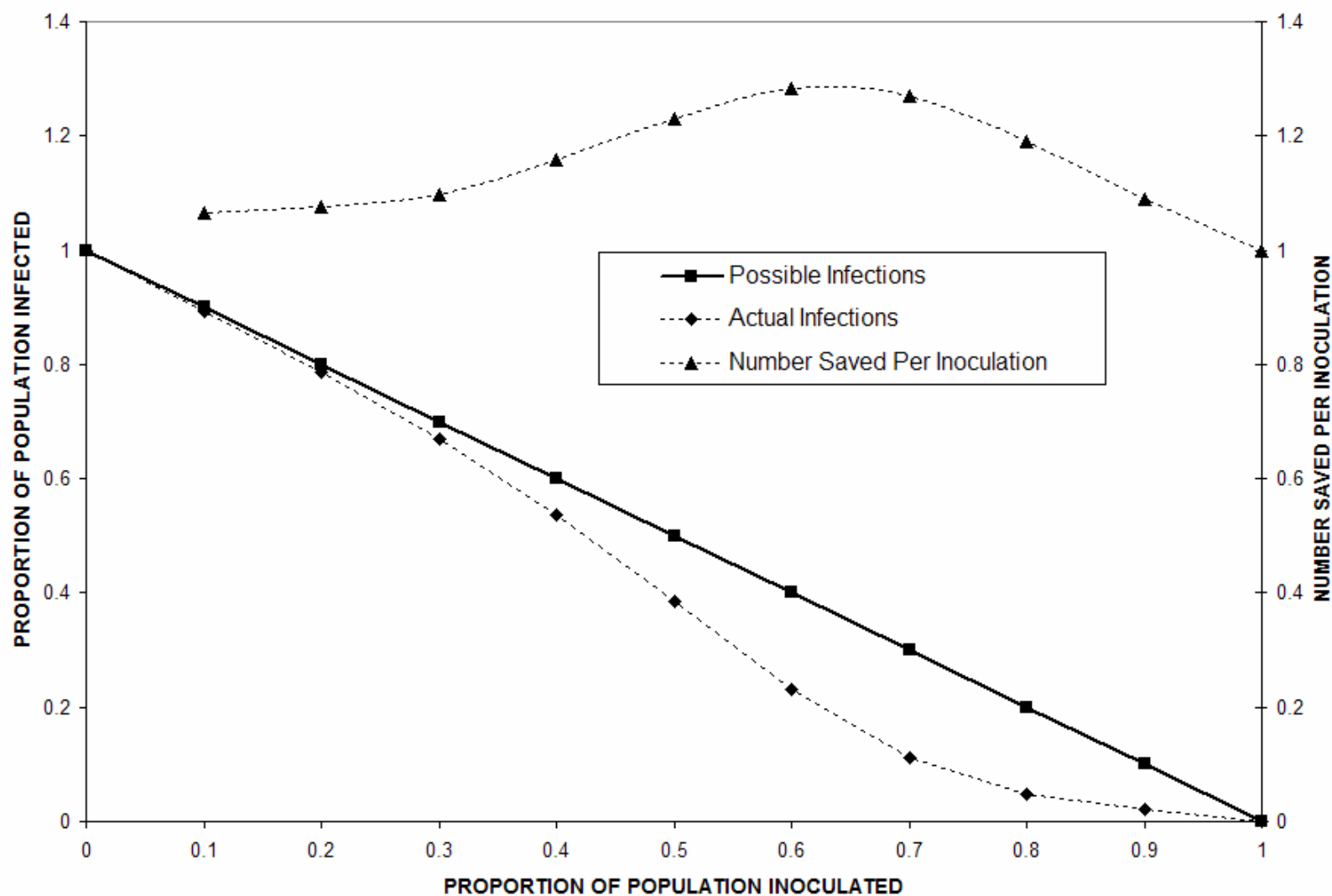
---

- The only factors varied were the proportion of inoculateds in the community and the contact number
- In MANA terms, agents were inoculated by turning them neutral, keeping the total number constant
- $\text{Susceptibles} + \text{Recovered} + \text{Infected} + \text{Inoculated} = 100$
- Contact Number was varied by decreasing the size of the play box
- All other factors were constant

# Inoculation in MANA

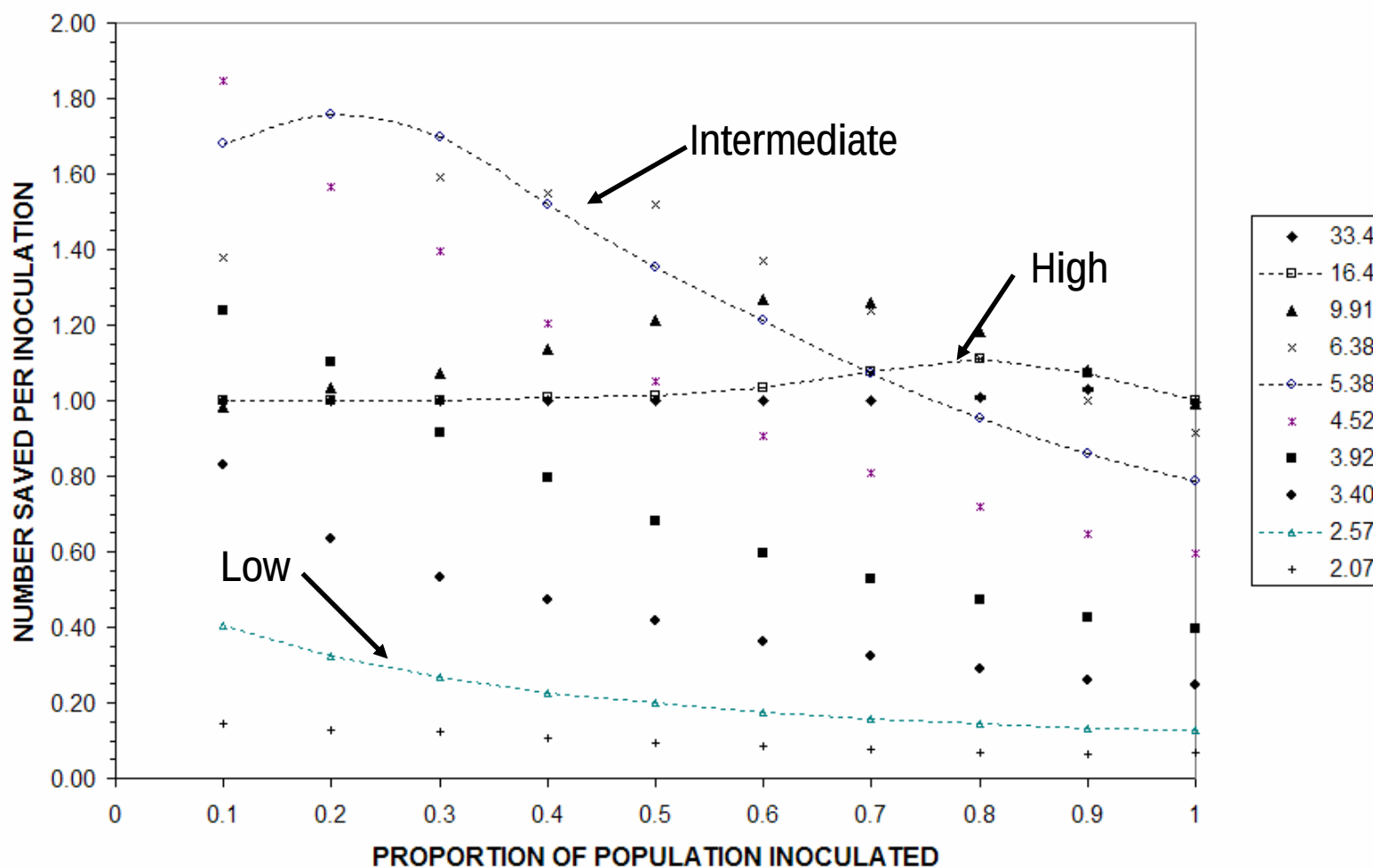


# Number Saved per Inoculation



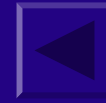


# Maximum Utility from Limited Vaccinations



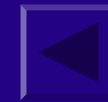
## Low Contact Number

---



- Number Saved per Inoculation (NPSI) is much less than 1
- Greatest NSPI occurs at low levels of inoculation
- With a number of communities at risk and limited inoculant the best strategy is to inoculate a small percentage from each community

## High Contact Number



- Number Saved per Inoculation (NPSI) is slightly greater than 1
- Greatest NSPI occurs at high but not maximum levels of inoculation
- Inoculating everybody cannot achieve an NSPI greater than 1
- With a number of communities at risk and limited inoculations the best strategy is to inoculate a large percentage from one community before moving on to the next



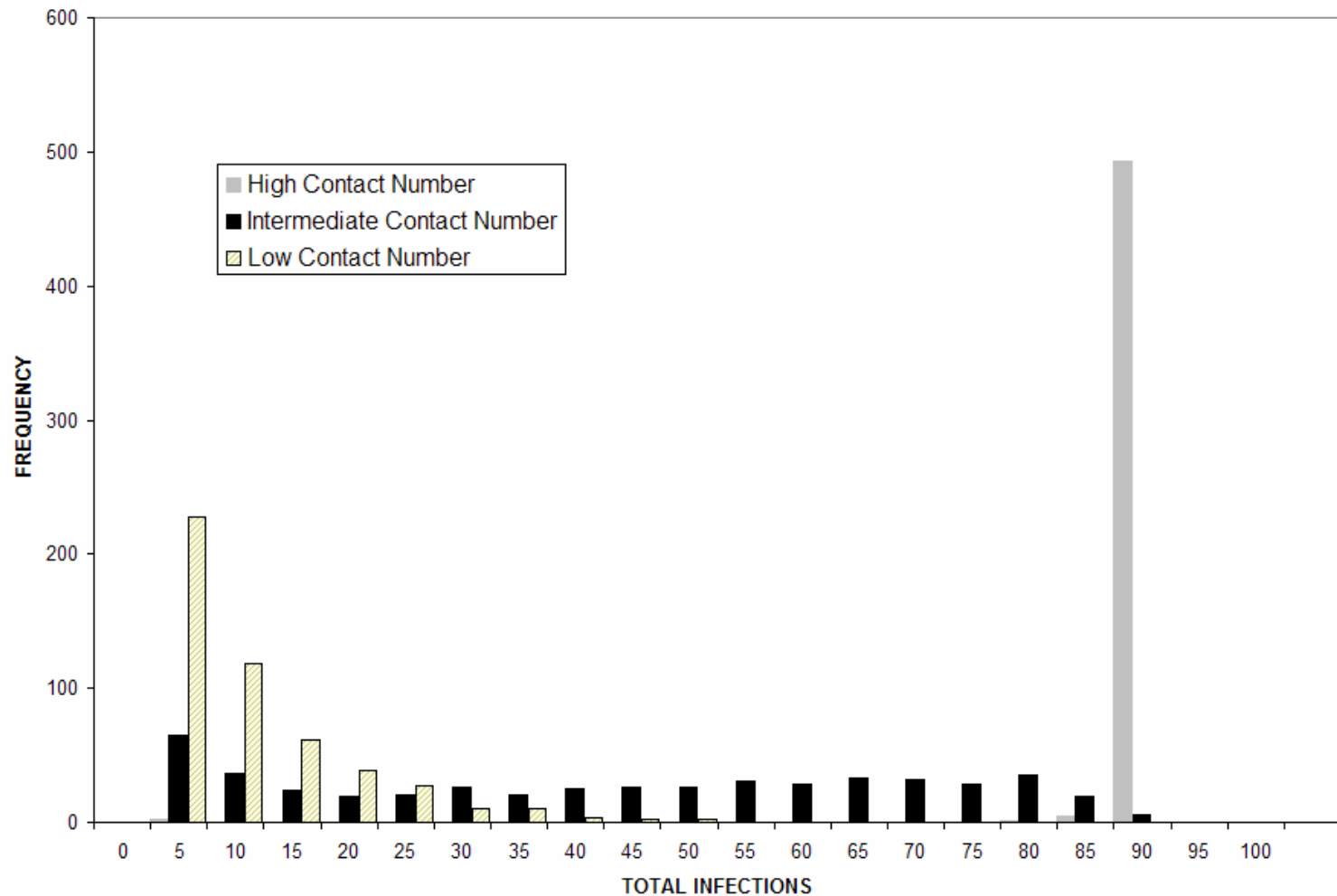
## Intermediate Contact Number

---



- Number Saved per Inoculation (NSPI) can be significantly greater than 1
- Greatest NSPI occurs at intermediate levels of inoculation, which varies significantly with contact number
- Added level of “Risk”
  - Flat Distribution of Infections
  - “Over-Vaccinating” significantly reduces the NSPI

# Distribution of Infections





## The Modified SIR Model

- The standard epidemiological equations can be modified to include inoculation

$$\begin{aligned}\frac{ds(t)}{dt} &= -bi(t)s(t) \\ \frac{di(t)}{dt} &= bi(t)s(t) - ki(t) \\ \frac{dr(t)}{dt} &= ki(t) \\ \frac{dv(t)}{dt} &= 0 \\ s + i + r + v &= 0\end{aligned}$$

- Where  $b$  is the individual contact number and  $k$  is the fraction each day that recover

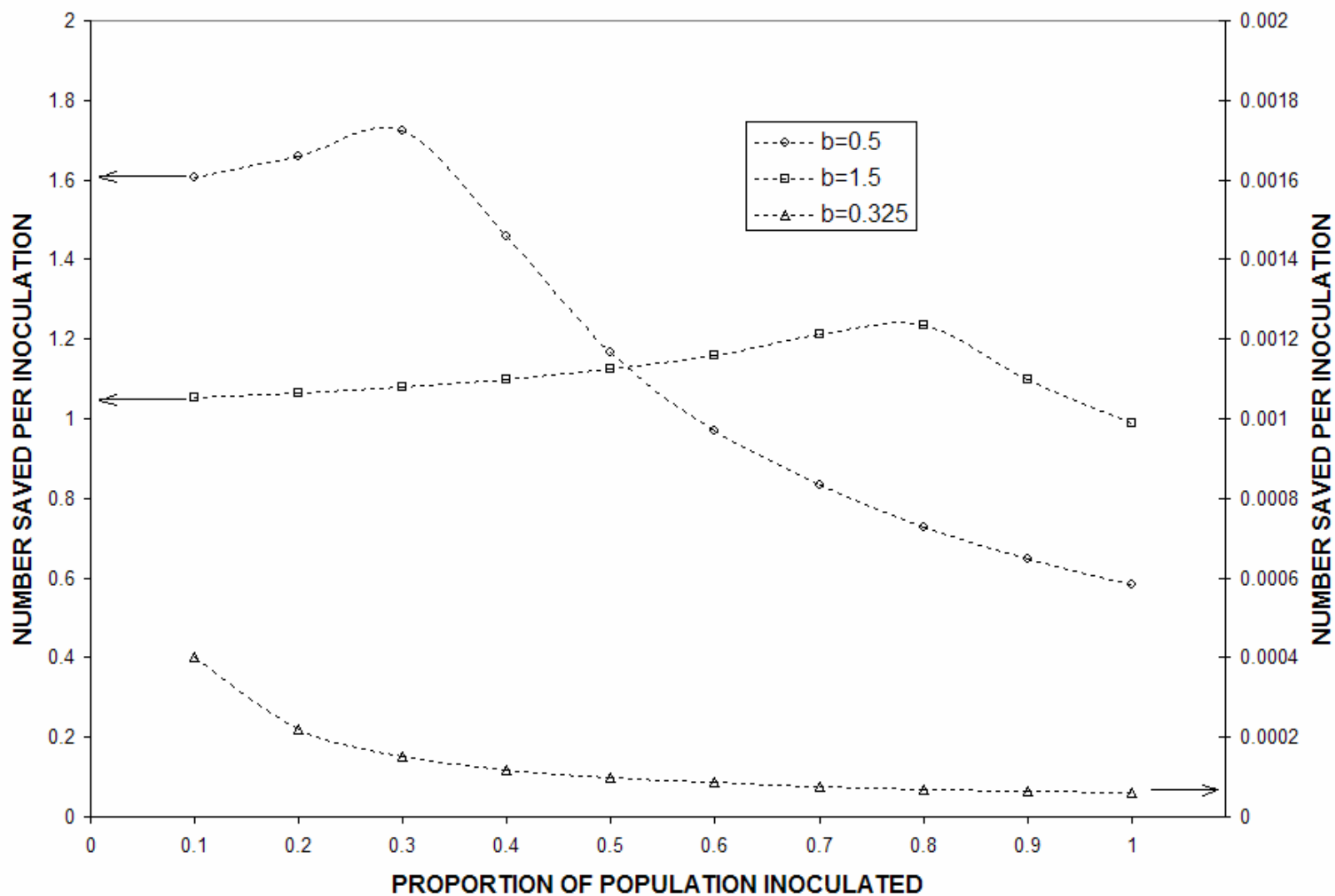
## The SIR Model

---

- Used data from the 1968-69 Hong Kong Flu Epidemic in New York City
- Population 7,900,000
- 1/3 of infected persons recover each day, as flu last for 3 days
- Vary Contact Number
- Critical Contact number when  $b=k=1/3$



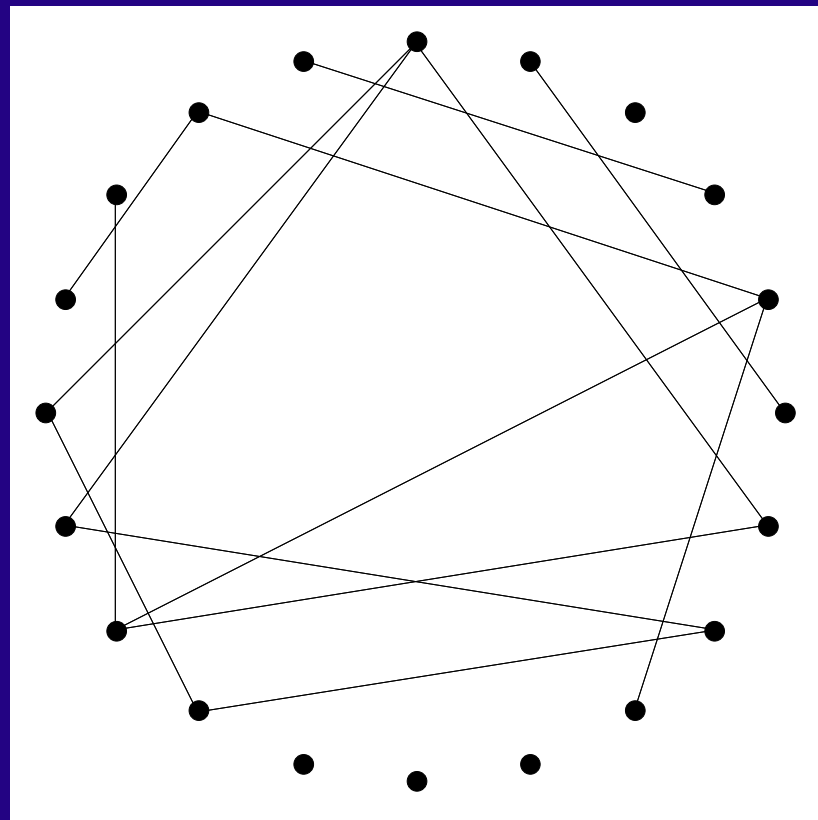
# Modified SIR Model



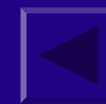


## Network Model

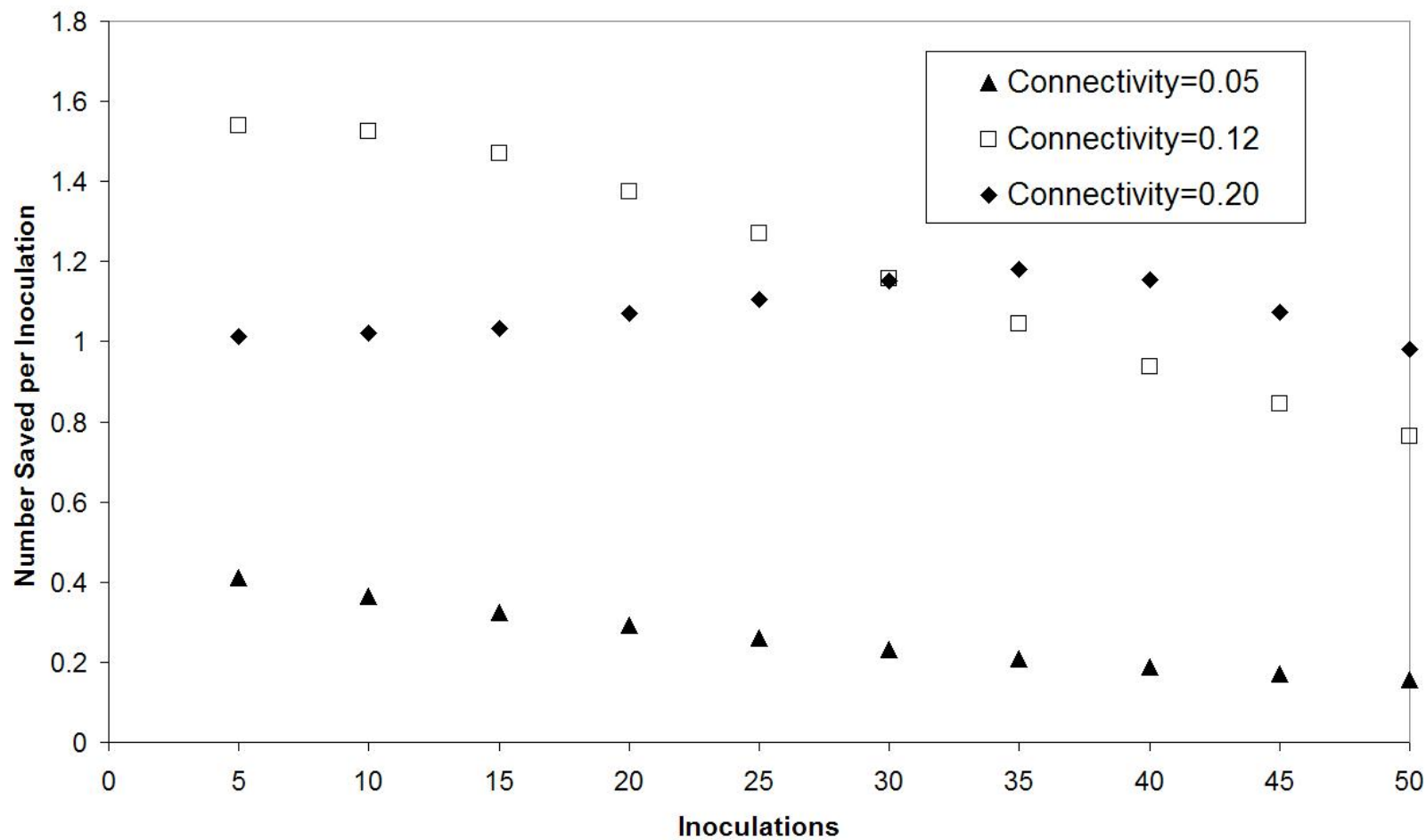
- Random Network
- Connections represent Contacts
- Assume disease is transmitted by contact with a 100% efficiency
- Nodes removed at random
- Examine the effect on average cluster size
- This technique allows ~ 20,000 – 50,000 clusters to be examined



# Network Model



Network Model - 50 Nodes



## Conclusions

---

- Demonstrates that “combat models” can be employed to examine significant non-military or non-combat related questions
- Gives insight into how best to distribute limited vaccines to prevent epidemics
- Trends confirmed by three independent methods
- Model can easily be extended to cover many network-based questions where something is transmitted from one entity to another

---

# QUESTIONS?