Agent-Based Modeling:
Population Health from the Bottom Up

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National Institutes of Health, July 13, 2007

Outline

- **Agent-Based Models**
- **Public Health Applications**

Features of Agent-Based Computational Models

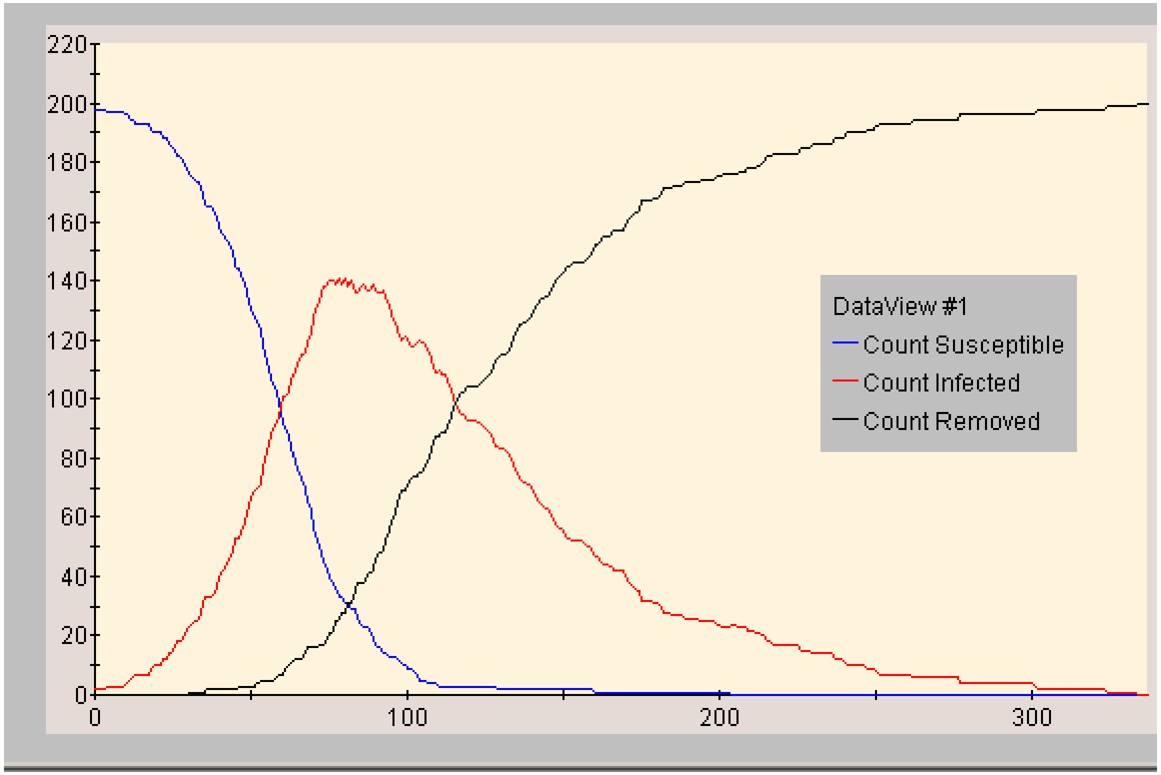
- **Heterogeneity**
  - No representative agent; no homogeneous pools, no aggregation
  - Every agent explicitly represented, and differ by:
  - Wealth, network, immunocompetence, memory, genetics, culture, ...
- **Autonomy**
- **Bounded Rationality**
  - Bounded Information
  - Bounded Computing
- **Explicit Space**
- **Local Interactions**
- **Non-Equilibrium Dynamics**
  - Tipping Phenomena

Today's Examples

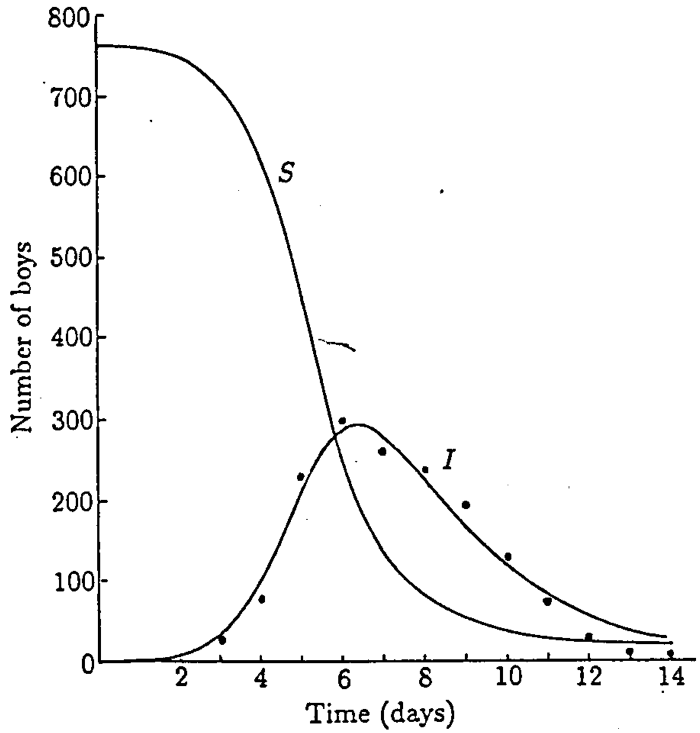
- Playground (warm-up)
- Town Scale
  - Smallpox
- City Scale
  - New Orleans Toxic Chemical)
- National Scale
  - U.S. smallpox
- Global Scale
  - MIDAS Pandemic Flu
- Network
  - Teen Smoking
  - Obesity

Toy Warm-Up. SIR. Playground Interactions (r=.15,b=.02).

Two.qt



Influenza Epidemic Data, 1978
English Boarding School



Influenza epidemic, boys boarding school. *British Medical Journal*, 4 March, 1978. Of 763 boys, 512 were confined to bed, 22 January-4 February, 1978.

- OK for very small-scale
- Well-mixed setting
- Simple bug
- Let’s add some complexity…

Example 1. Smallpox Model

- Developed with Donald Burke JHSPH for The Smallpox Working Group, Secretary's Council on Public Health Preparedness, HHS, founded and chaired by D. A. Henderson.
- Intensive regular meetings to arrive at reasoned assumptions about all biomedical and critical behavioral aspects

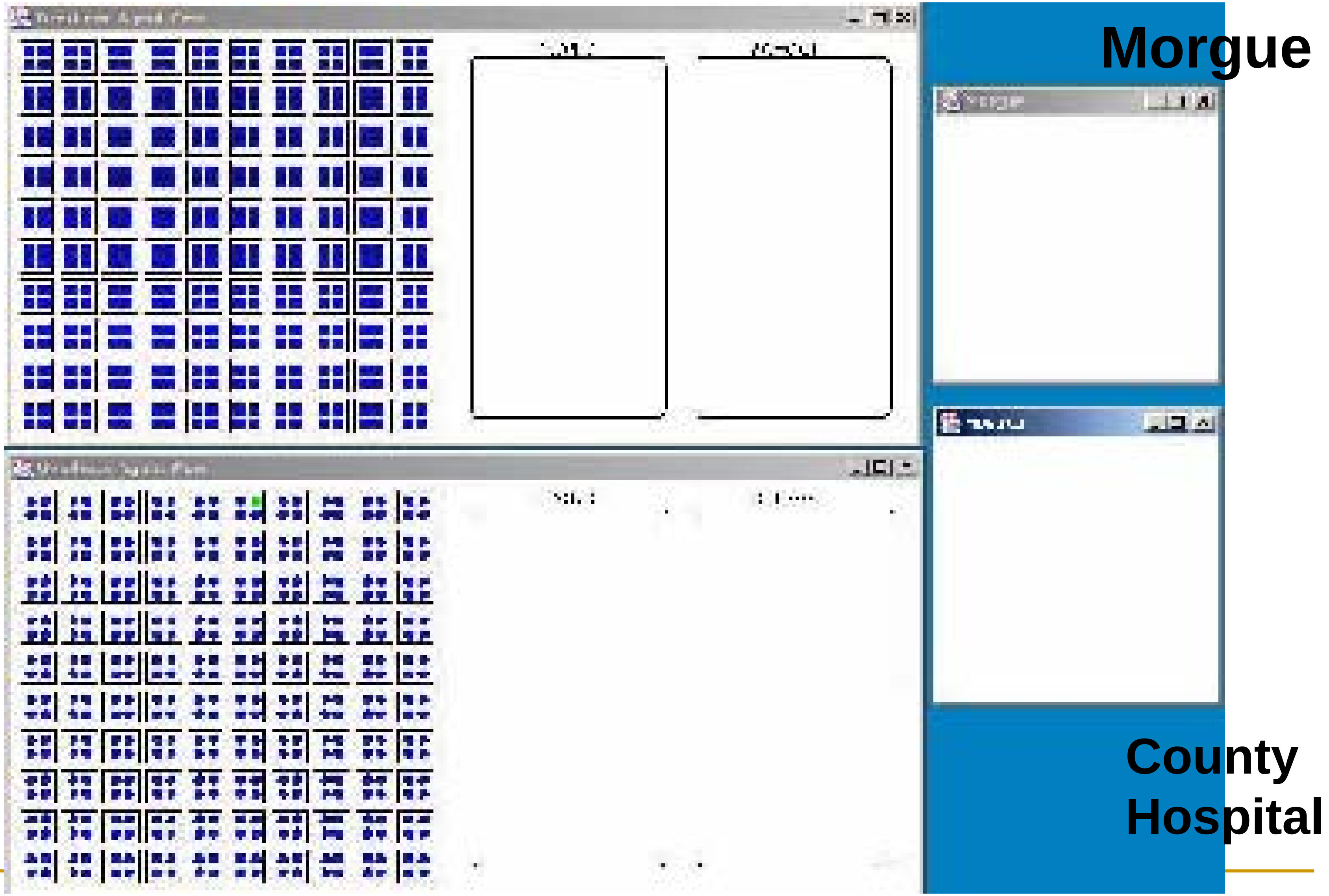
Basic Question

- What Resolution?
- Include Social Units the Loom Largest in Data:
  - Homes
  - Schools
  - Workplaces
  - Hospitals

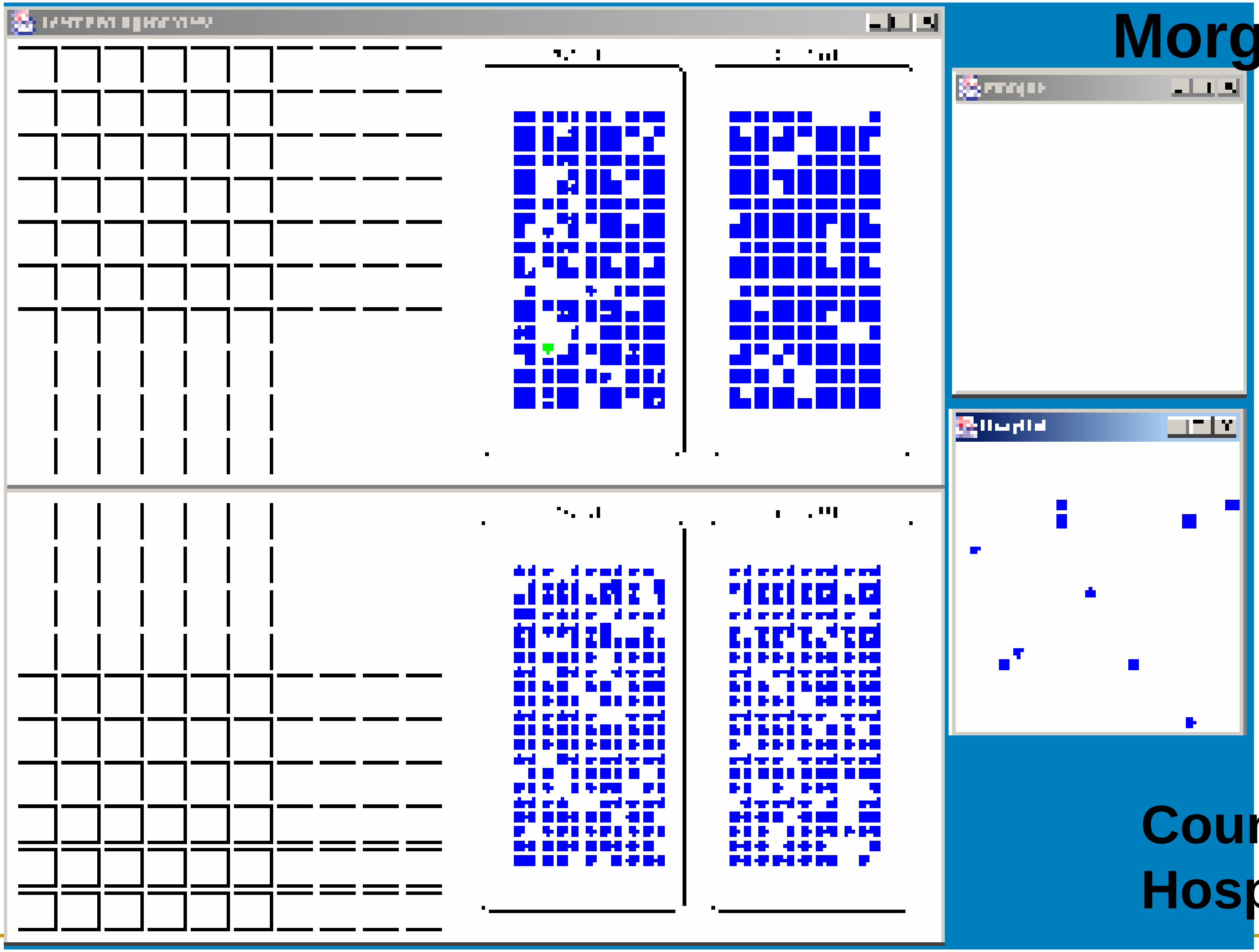
County-Level Model

- 2 Towns
- Per Town Assumptions
  - 400 people comprised of
  - 100 Households, each with 2 adults and 2 kids
  - Non-commuting adults work at the town workplace
  - 10% adults of commute to the other town's workplace
  - 5 adult hospital workers
  - Kids go to school in the town school
  - 1 workplace
  - 1 school
- 1 Common Hospital
  - 10 adult hospital workers
- 1 Common Morgue
- Day = Night = 10 Rounds
- Contacts Per Day: Home=3 , Work=10.

“Night-Time” = All individuals at home, not at work or school

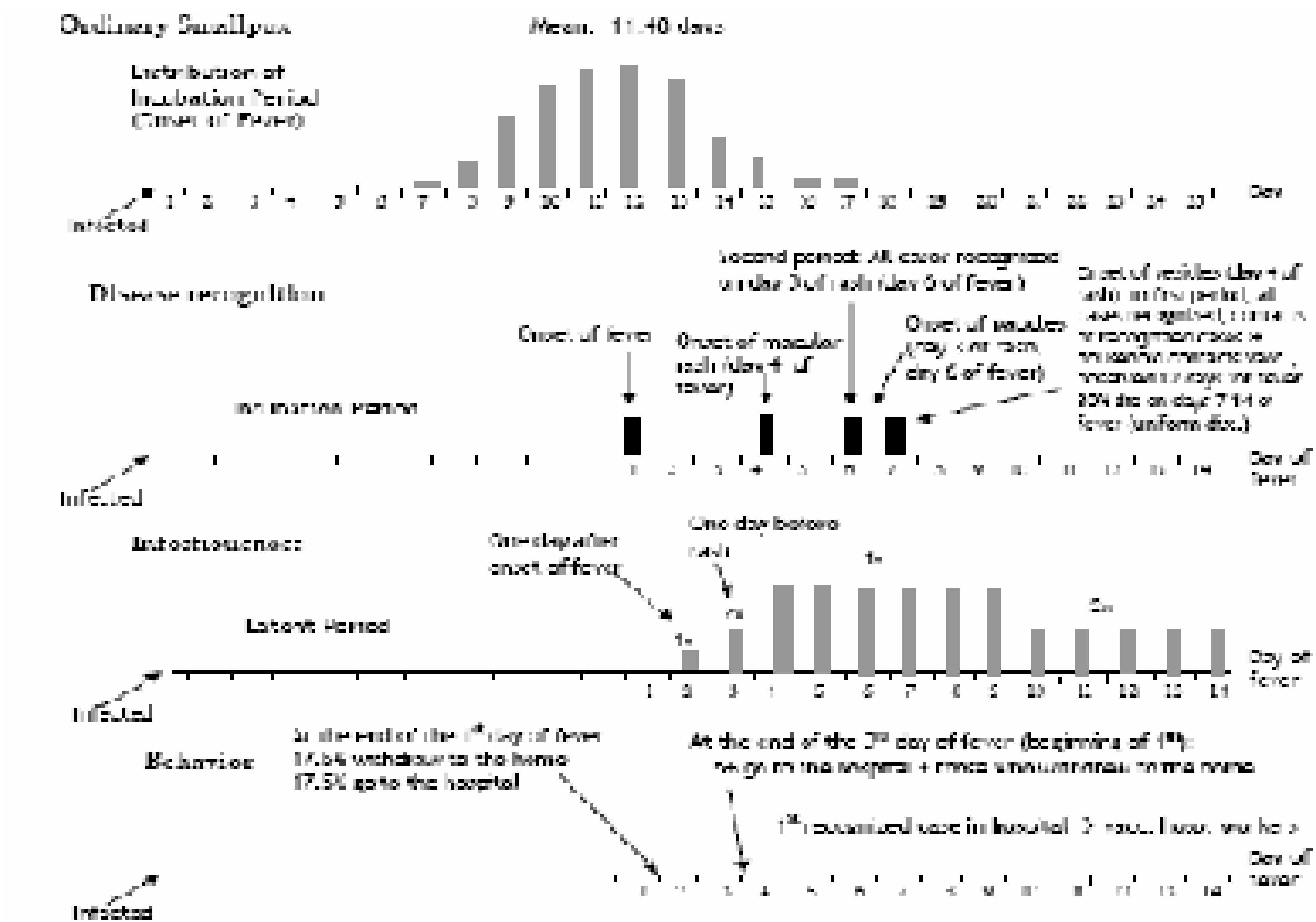


“Day-time” = All individuals are at work or school

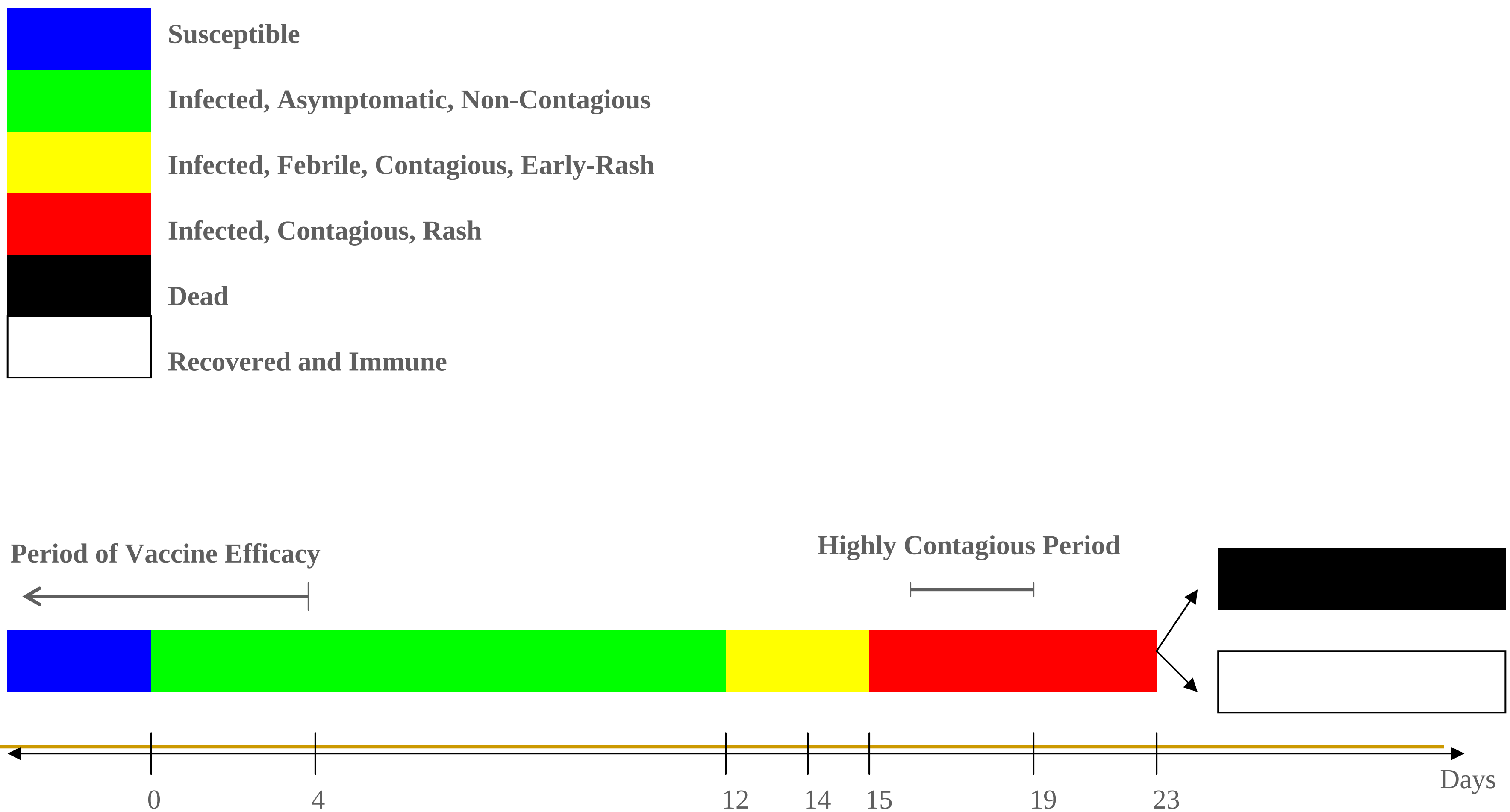


All individuals go home at night, and the cycle repeats every “day”

Ordinary Smallpox Natural History

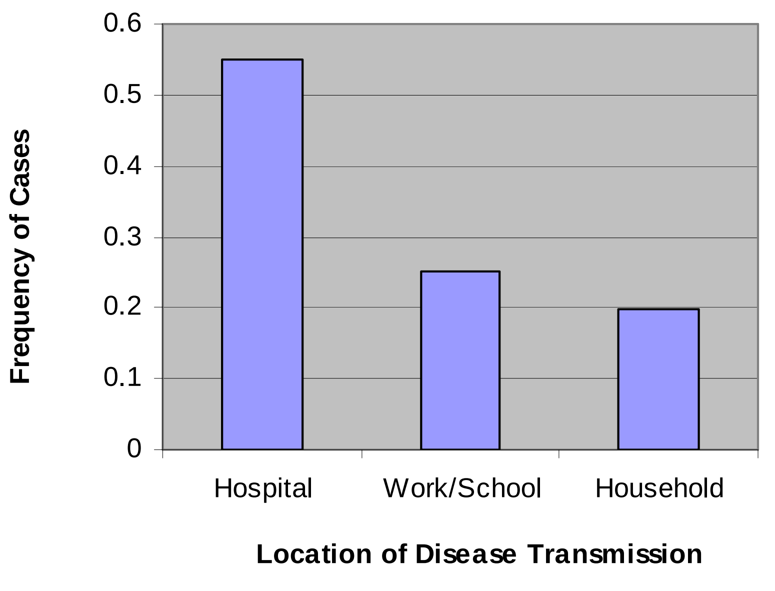


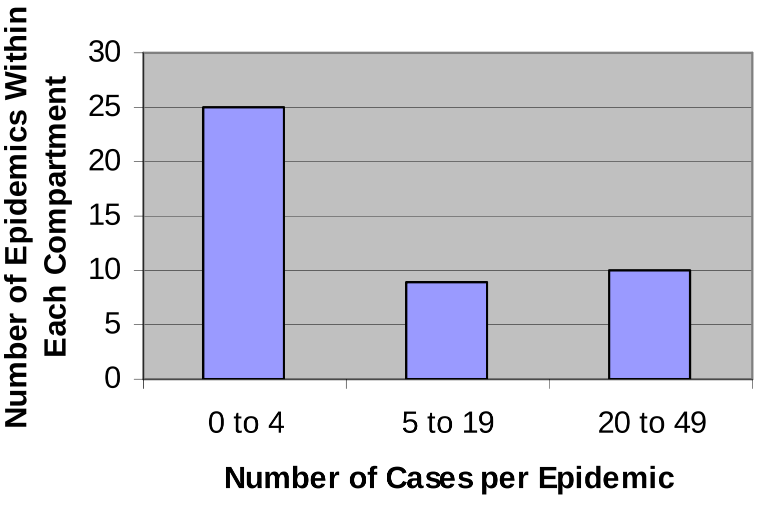
Simplified Progression of Smallpox



Calibration of smallpox model

- European data of 49 epidemics occurring between 1949-1971
- Two distributions



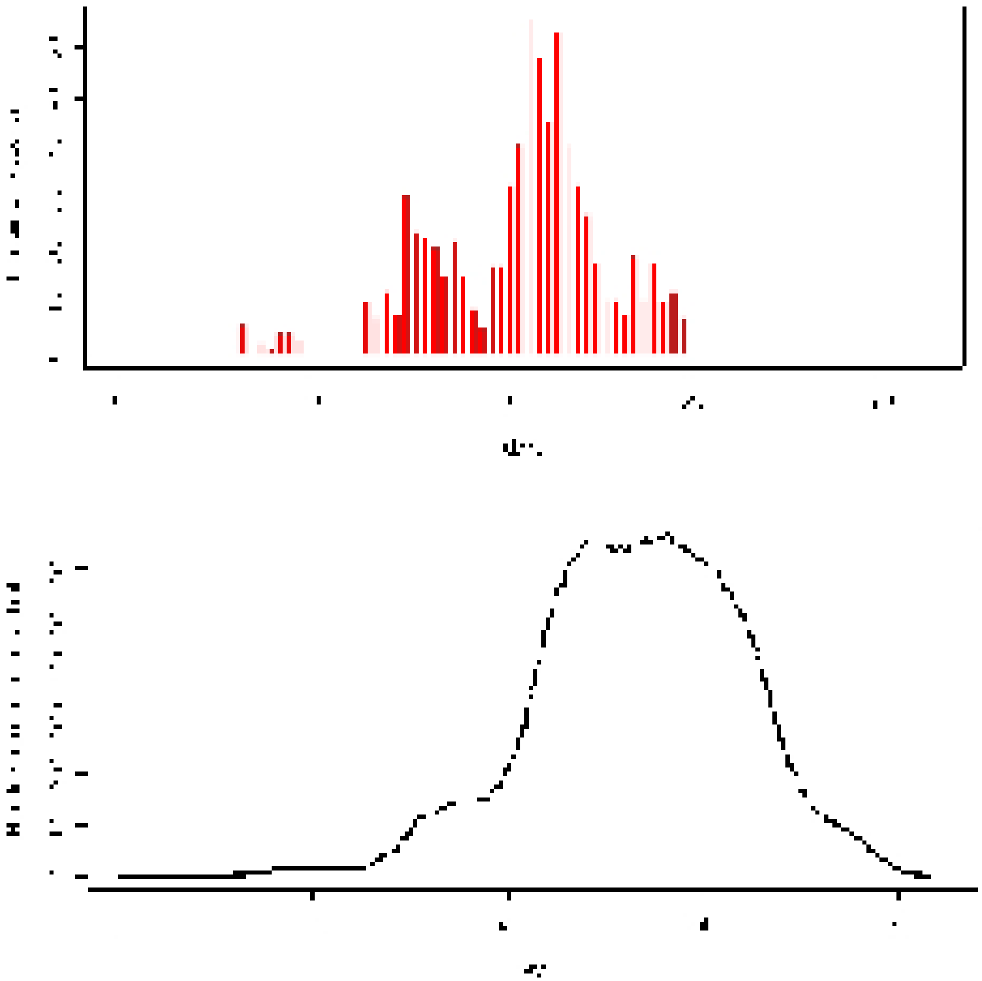


Base Case Run

- No Policy Interventions
- No Background Immunity
- One commuter index case starts the epidemic in Circletown; it spreads to Squaretown

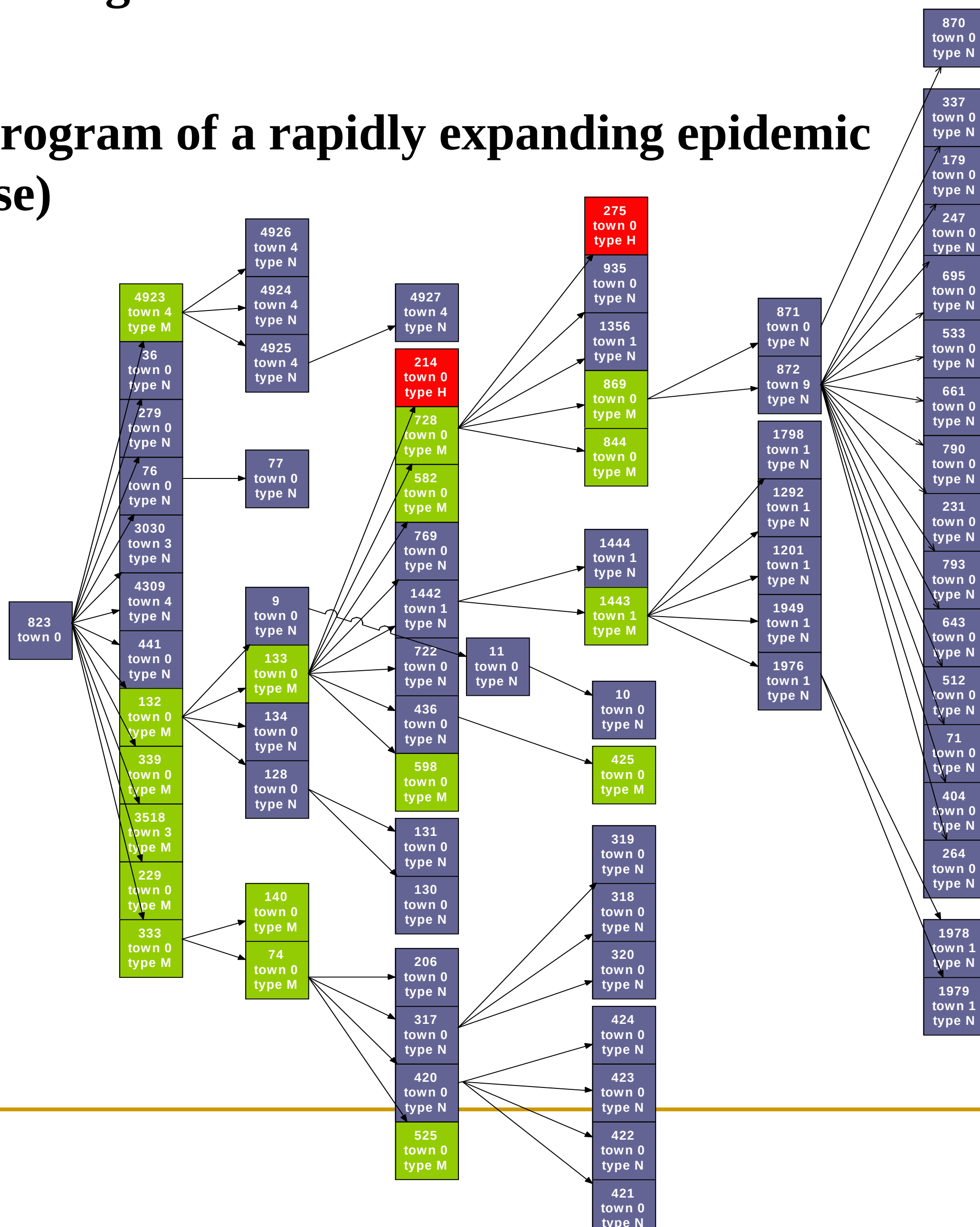
Smallpox Base Case

Typical Results for Base Case Run: Incidents per Day and Time Series of Cumulative Infected. 800 infected. 255 dead. As in pre-vaccine Europe.



Superspreaders: Agent model tracks every contact.

Contact dendrogram of a rapidly expanding epidemic (one index case)



Policy Interventions

- Trace vaccination
- Mass vaccination
- Hybrid strategies

Intervention 1: Contact Tracing

"Persons who had…close proximity contact (<2 meters=6.5 feet) with a confirmed or suspected smallpox patient after the patient developed fever and until all scabs have separated (no longer infectious.)"

Problem: Perfect contact tracing is difficult if you were…

Here

… Or Here

TWA NORTH AMERICA DESTINATIONS

- Conventional wisdom (bolstered by well-mixed ODE models) was that we'd lose "the race to trace," leaving only…

Intervention 2. Mass Vaccination

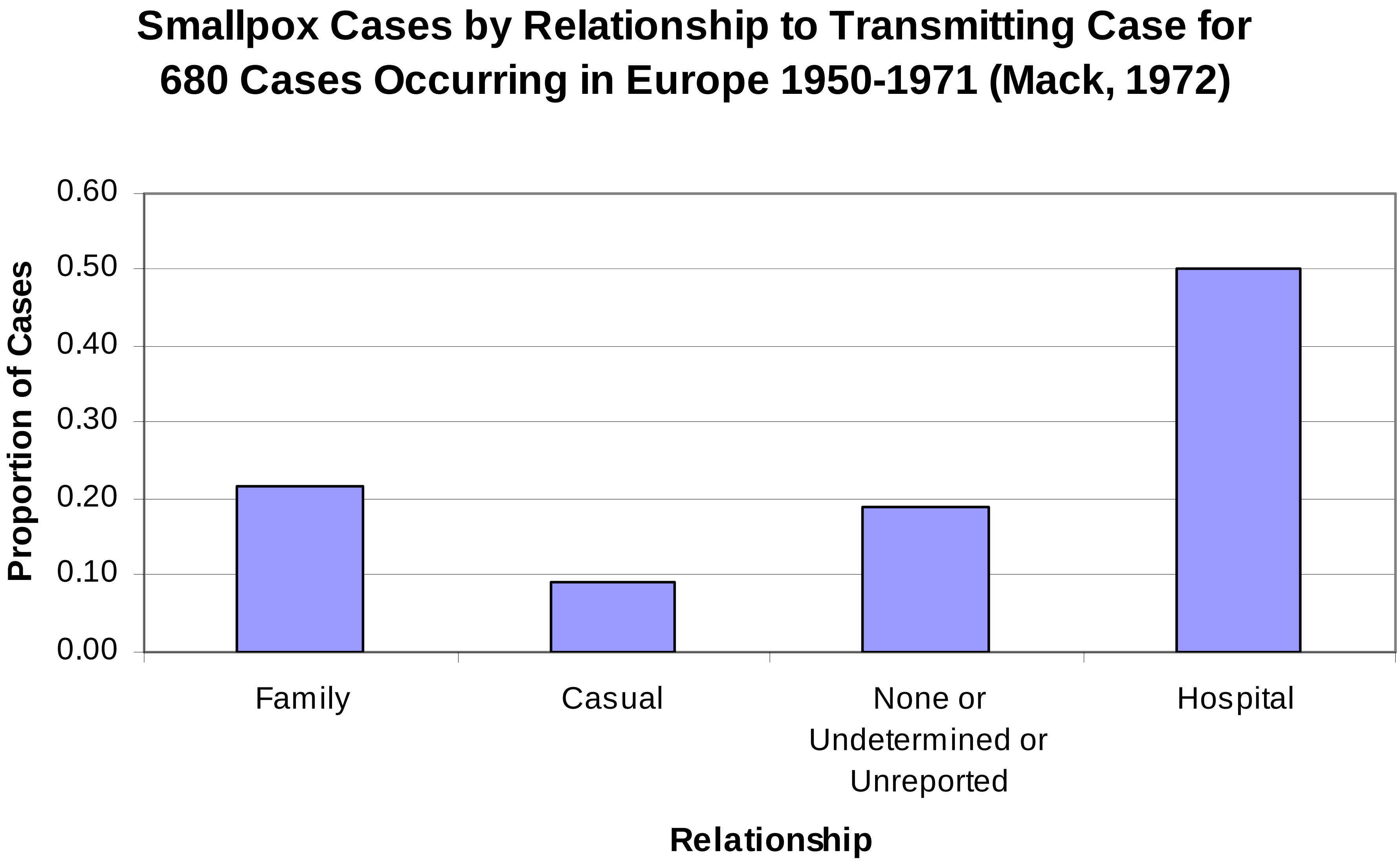
- **Problem 1: Vaccine may be fatal if you are immune suppressed**
  - **AIDS**
  - **Chemotherapy**
  - **Other (e.g., Infant)**

Intervention 2. Mass Vaccination

- **Problem 2: Serious vaccine side effects**

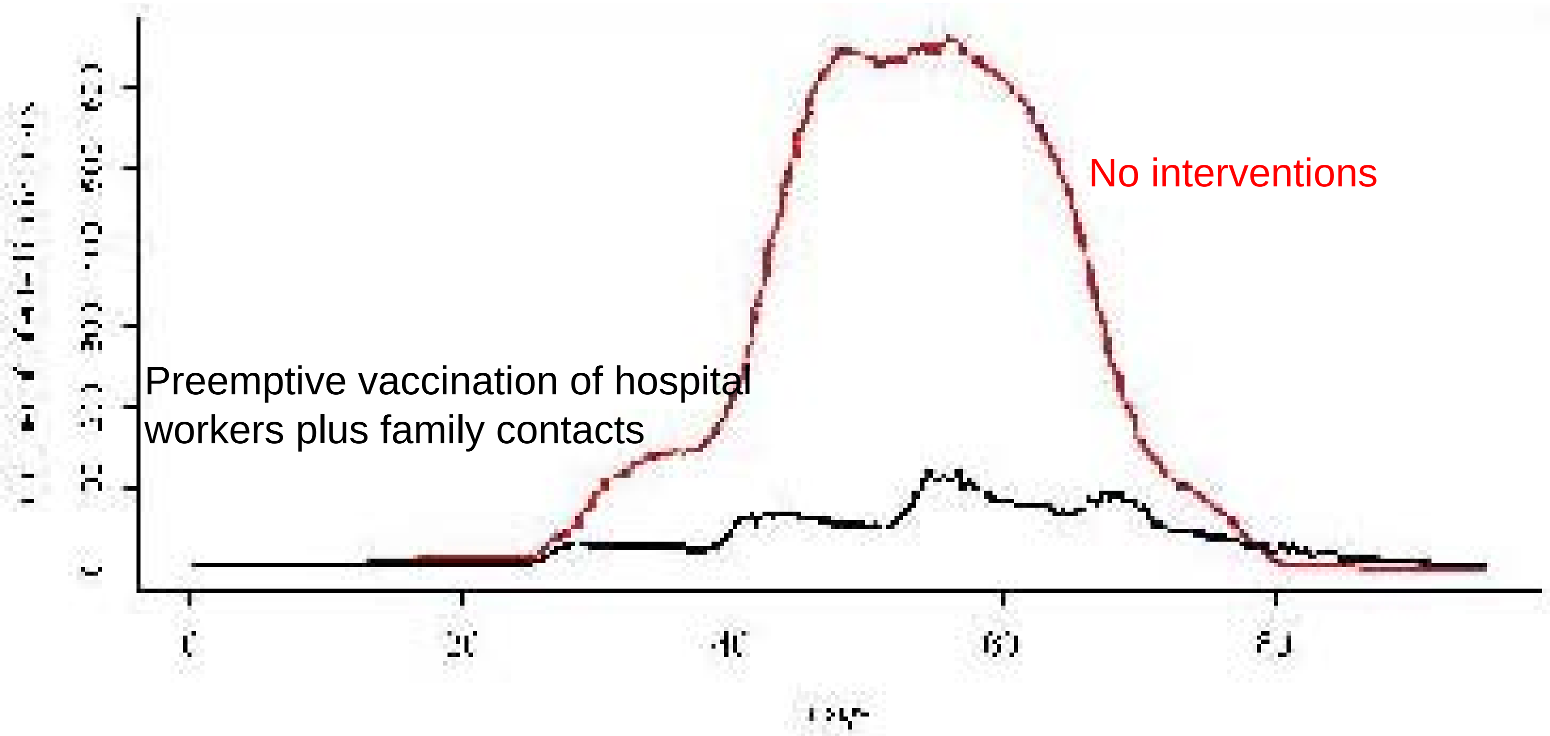
Policy Challenge

Design a policy that is more feasible than perfect trace vaccination, less risky than mass vaccination, and is highly effective in minimizing a smallpox epidemic.



Our model retrodicts this data, which suggests that vaccinating hospital + family would be effective. Is it?

Results of Hospital and Family Only (280 Dead vs. 45 Dead)



Extensions (PACER, NIH/MIDAS)

- **Vastly Increased Scale**
  - **50k Longini, et al; Burke et al**
  - **1.2m (Portland) Eubank et al**
  - **300m Parker et al**
- **Increased Biomedical Realism**
  - **Ordinary, Modified, Hemorrhagic variants**
- **Range of Social Structures**
- **Human Behavioral Responses (e.g.,distancing)**
- **Support The Basic Result (Epstein, et al, Brookings, 2004; Longini, et al, *IJID*, 2006; Burke, et.al, *AEM* 2006)**

Main Conclusion

- Mass vaccination unnecessary (and unduly risky)
- Close contact vaccination (S&C) can succeed
- Pre-attack vaccination of health care workers amplifies effect.

Example 2. City Level Toxic Chemical

- Collaborators: Dr. Bharat Soni. Chair, Dept of Mechanical Engineering, UAB.
- Highly realistic fluid dynamics
- Plausible human behavior
  - Mass psychology
  - Non-compliance
  - Flight
  - Congestion
- Design optimal response

New Orleans Model

Novelty

- The combination of high fidelity fluid dynamics and
- Behaviorally rich agent layer.
- Design optimal preparedness and response

Example 3. US National Model

- Lead Developer: J. Parker, CSED
  - PACER
  - MIDAS agent global
- 300 million individual agents
- Displayed on US map, resolved at the level of ZIP code
- Movement from zip *I* to zip *j* governed by a 4,000 x 4,000 travel matrix encoding a gravity model
- Demo with Smallpox
  - Susceptible: Black
  - Infected/Contagious: Red
  - Recovered or Dead: Blue

National: 300 million Agents

Applications

- National scale optimized containment strategy
  - Smallpox
  - TB
  - Flu…
- Linkage to Global Model…

Example 4. Global Pandemic Flu

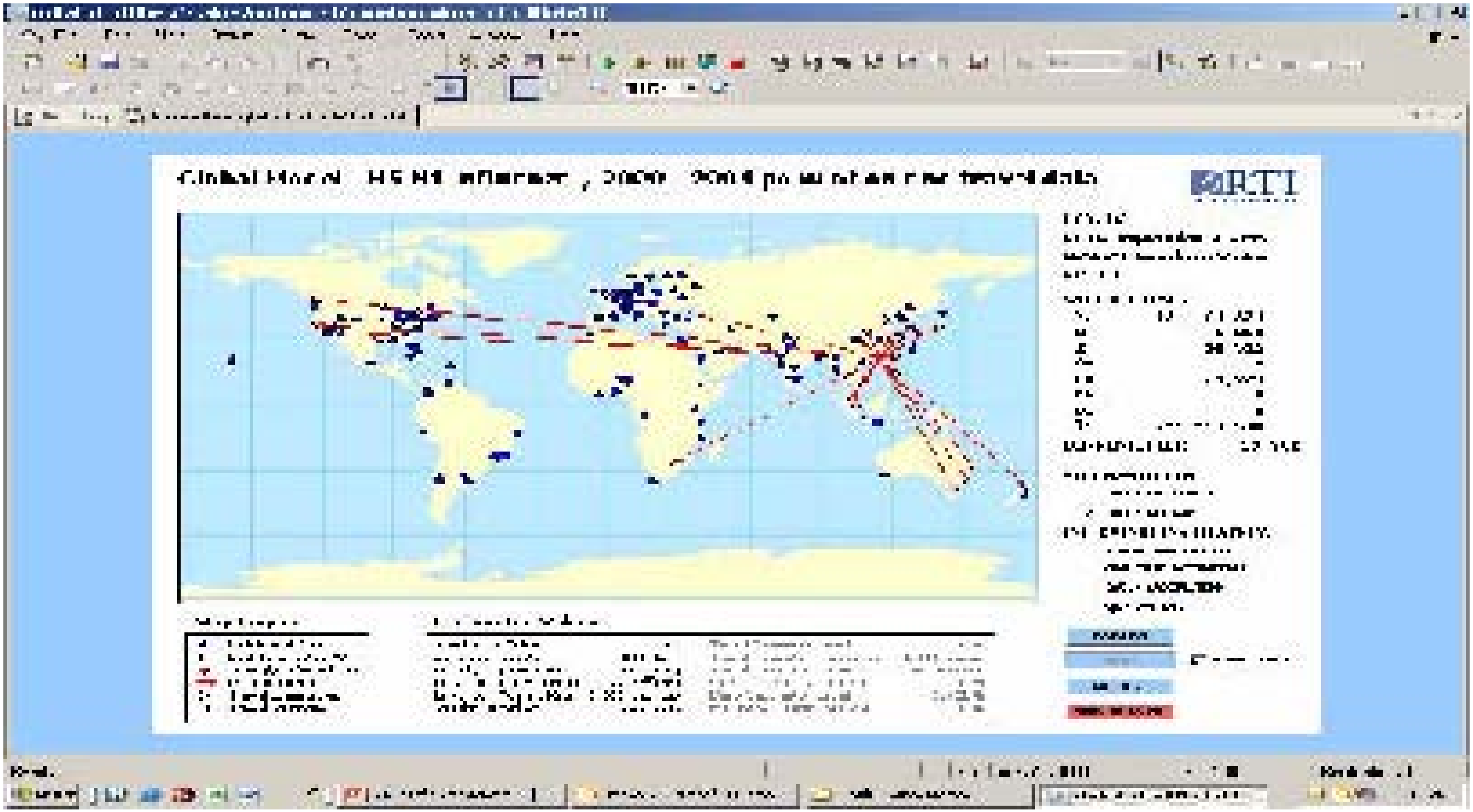
- NIH Global Pandemic Flu Model
- Director Dr. Joshua M. Epstein
- Dr. Georgiy Bobashev, Dr. Michael Goedecke, Dr. Feng Yu, Dr. Diane Wagener RTI/MIDAS
- Epstein, et al. May 2, 2007 *PLoS One*

Plan of Attack

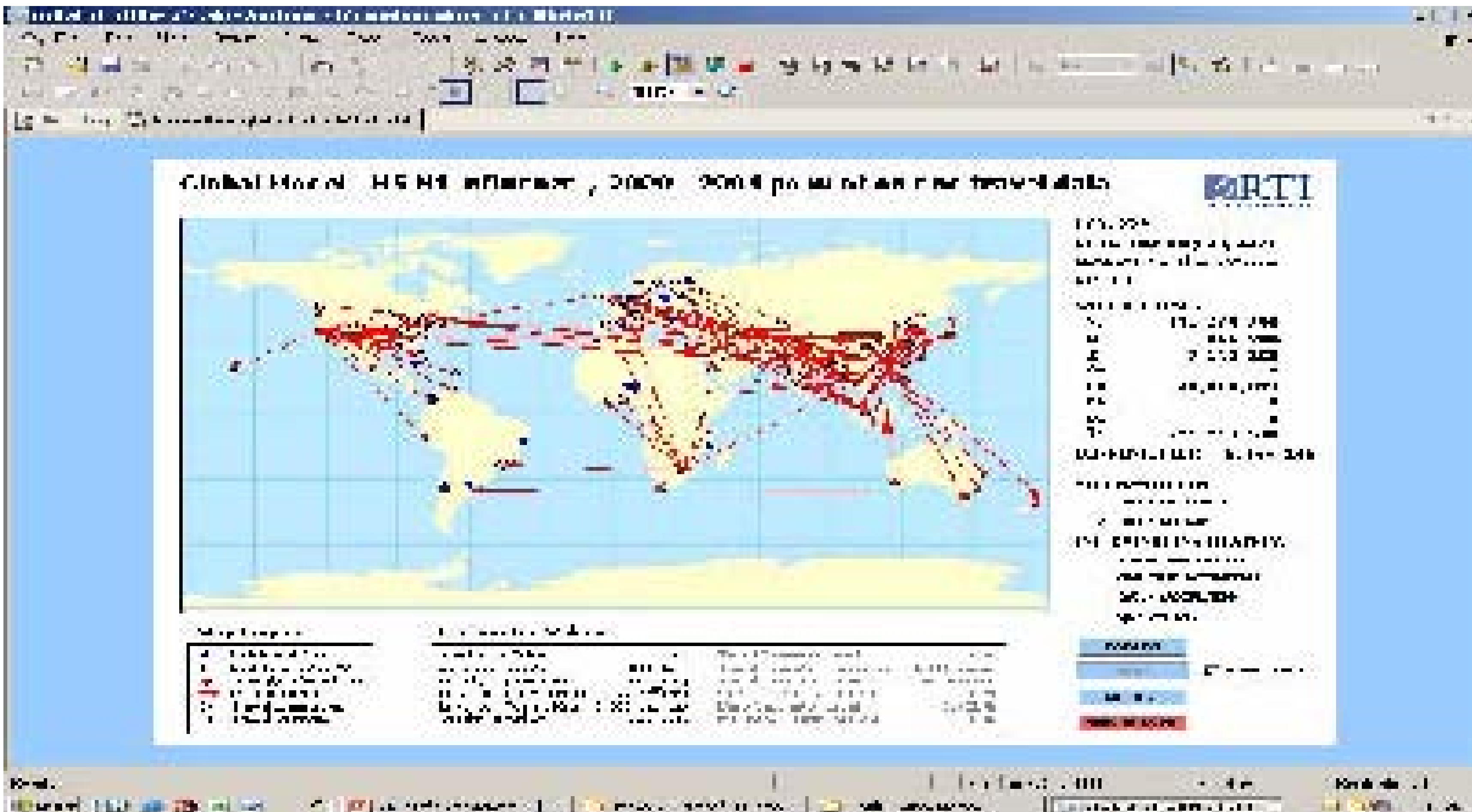
- 1968 Flu/1968 Pop and Trans.
- 1968 Flu/2000 Pop and Trans.
- Pandemic Flu/2000 Pop and Trans.
- So, we end up with…

Global Model : 155 Largest Cities

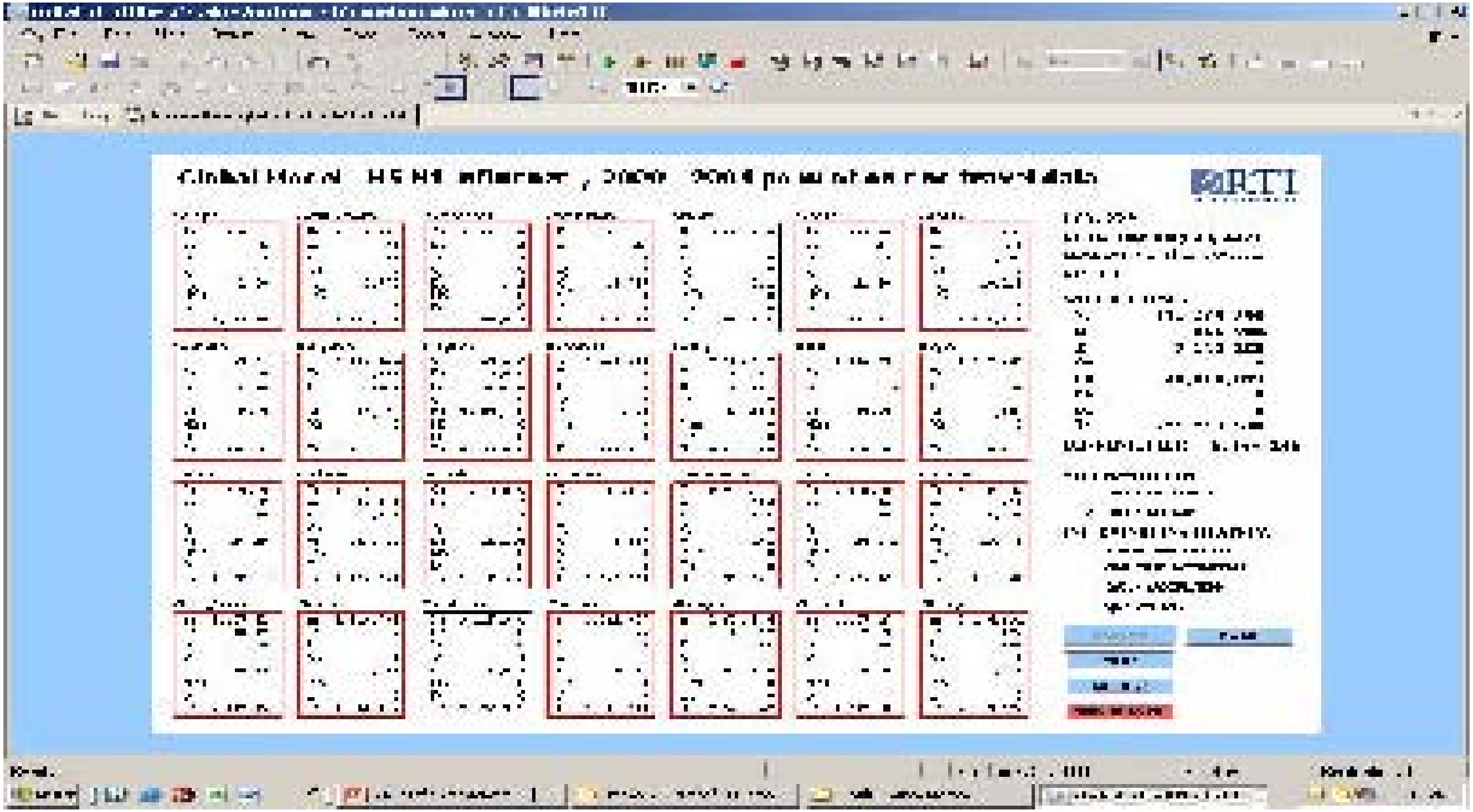
Geographic Spread



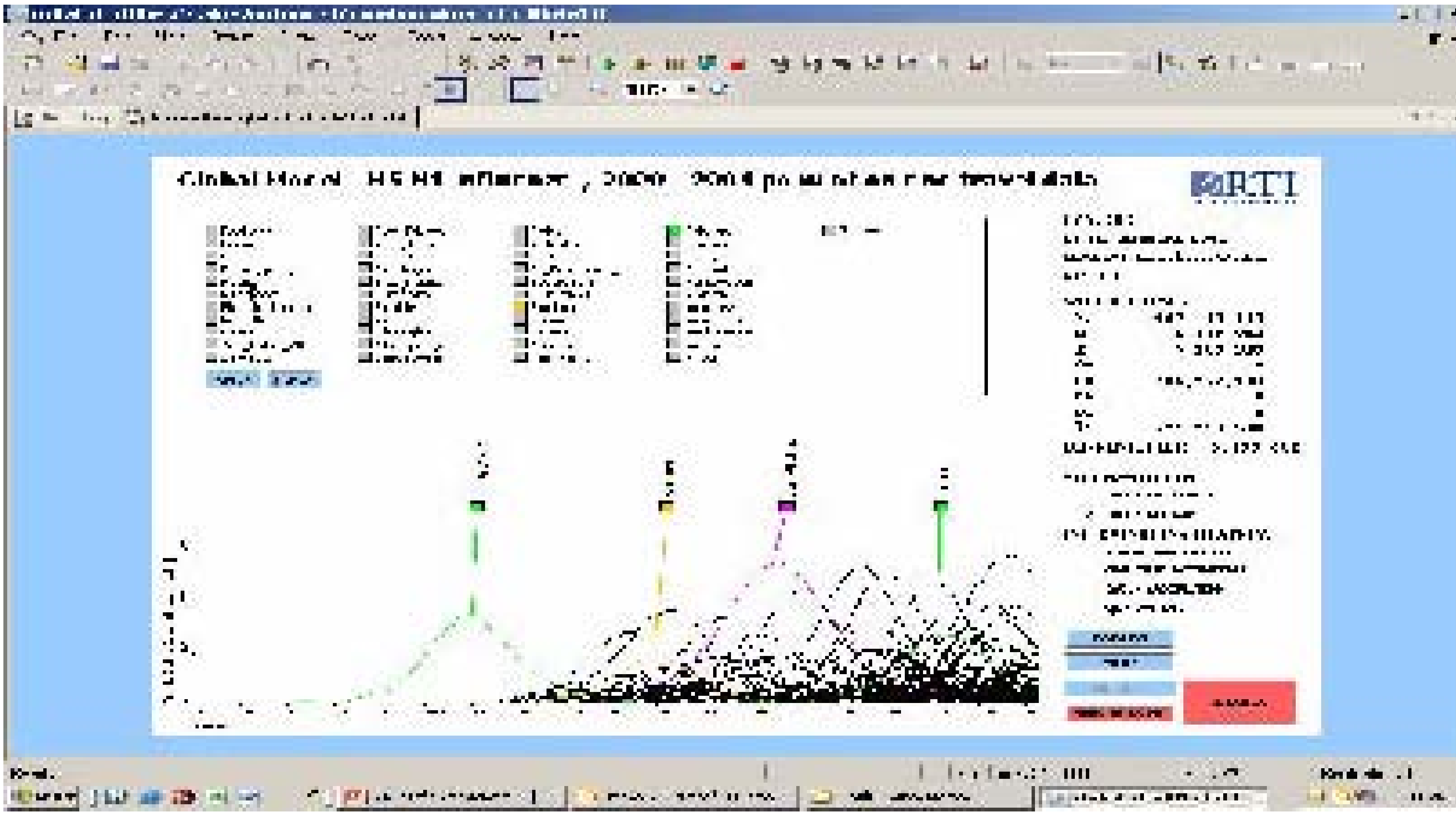
Geographic Spread (continued)



City-Specific Analyses



Global Time Series



- Two Scenarios:
  - Hong Kong Start
  - London Start

Hong Kong Start