# Complex Adaptive Systems of Systems (CASoS) Modeling and Engineering: Design of Community Containment for Pandemic Influenza

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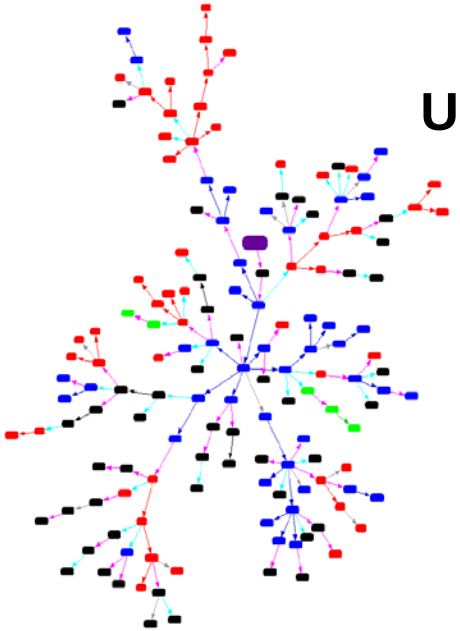

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*Slides pulled from presentations posted at:*
*http://www.sandia.gov/nisac/amti.html*
*http://www.sandia.gov/casos*

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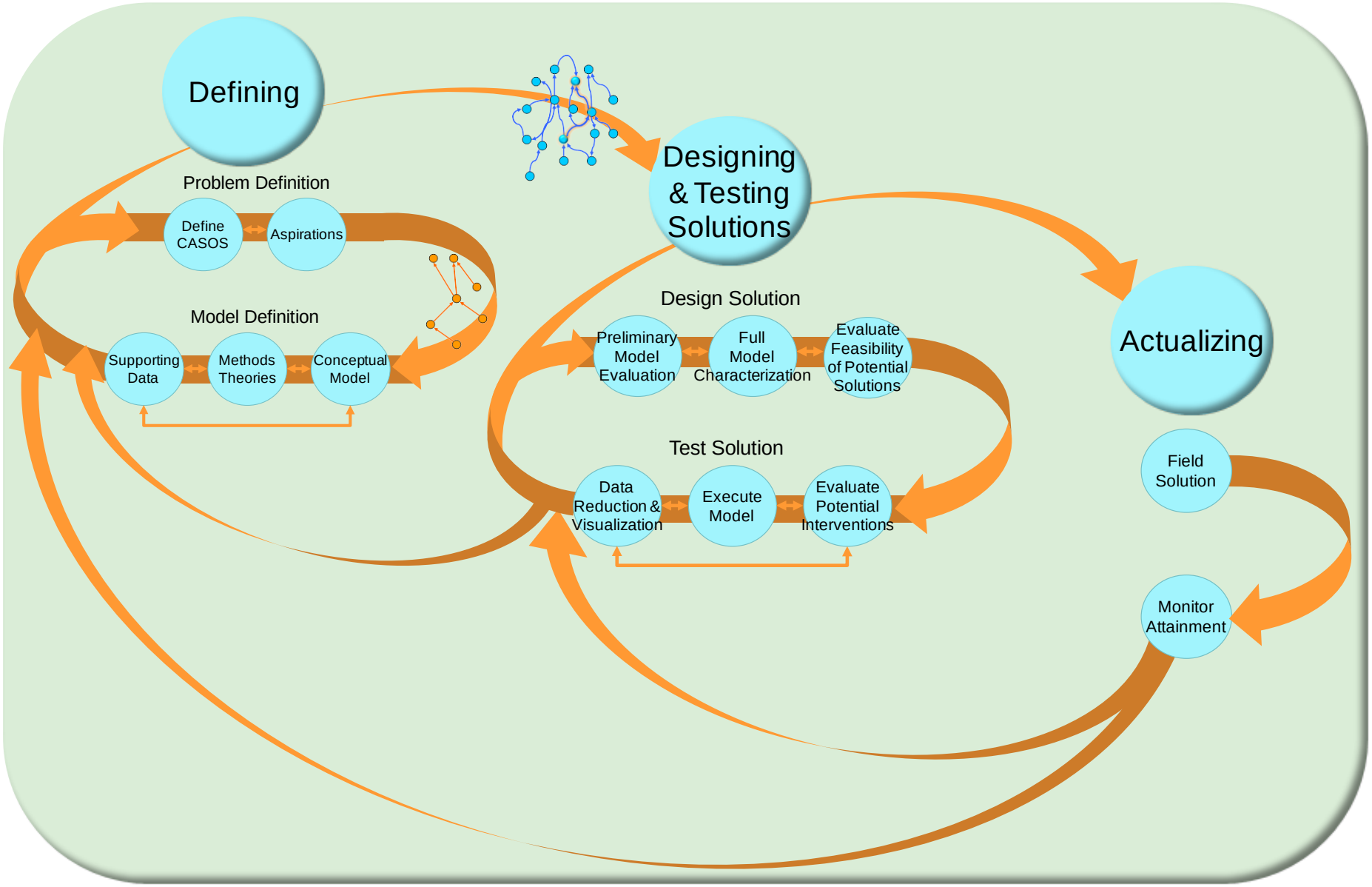
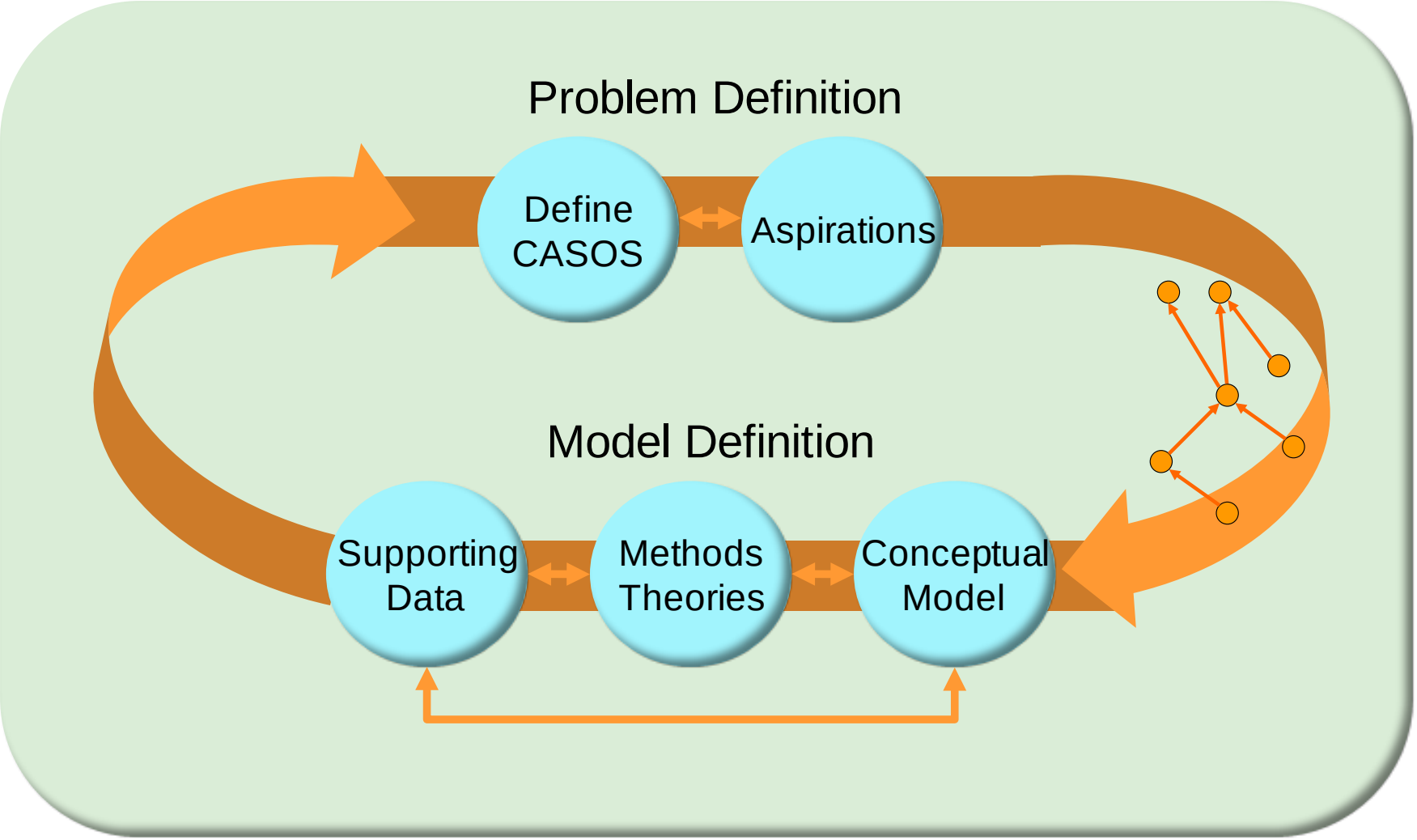
# CASoS Engineering Framework Components



# Defining Step of CASoS Engineering Framework



# Definition of the CASoS

- **System:** Global transmission network composed of person to person interactions beginning from the point of origin (within coughing distance, touching each other or surfaces…)
- **System of Systems:** People belong to and interact within many groups: Households, Schools, Workplaces, Transport (local to regional to global), etc., and health care systems, corporations and governments place controls on interactions at larger scales…
- **Complex:** many, many similar components (Billions of people on planet) and groups
- **Adaptive:** each culture has evolved different social interaction processes, each will react differently and adapt to the progress of the disease, this in turn causes the change in the pathway and even the genetic make-up of the virus

**HUGE UNCERTAINTY**

# Analogy with other Complex Systems

**Simple analog:**

- **Forest fires**: You can *build fire breaks* based on where people throw cigarettes… or you can *thin the forest* so no that matter where a cigarette is thrown, a percolating fire (like an epidemic) will not burn.

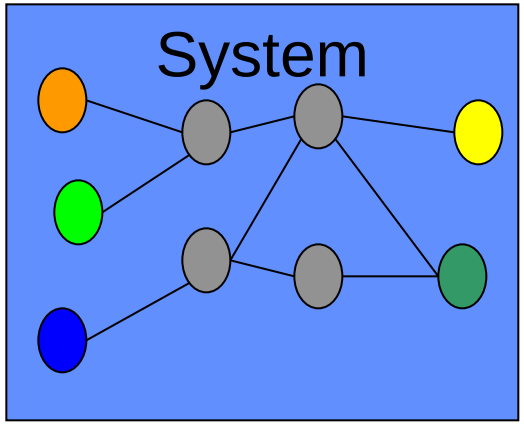
**Aspirations:**

- Could we target the social network within individual communities and thin it?
- Could we thin it intelligently so as to minimize impact and keep the economy rolling?

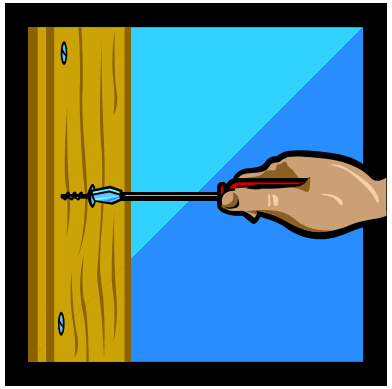
# Integration: Finding the right model

- There is no general-purpose model of any system
- A model describes a system for a purpose

What to we care about?




What can we do?



Model

Additional structure and details added *as needed*

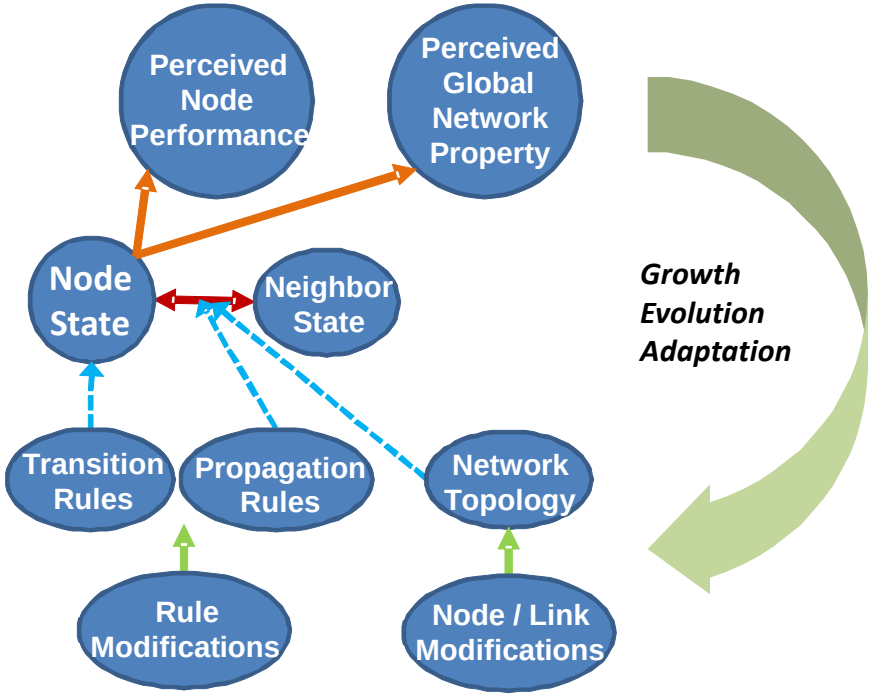
# Conceptual Lens for Modeling/Thinking

**Take any system and Abstract as:**

- Nodes (with a variety of “types”)
- Links or “connections” to other nodes (with a variety of “modes”)
- Local rules for Nodal and Link behavior
- Local Adaptation of Behavioral Rules
- “Global” forcing, Local dissipation

**Connect nodes appropriately to form a system (network)**

**Connect systems appropriately to form a System of Systems**

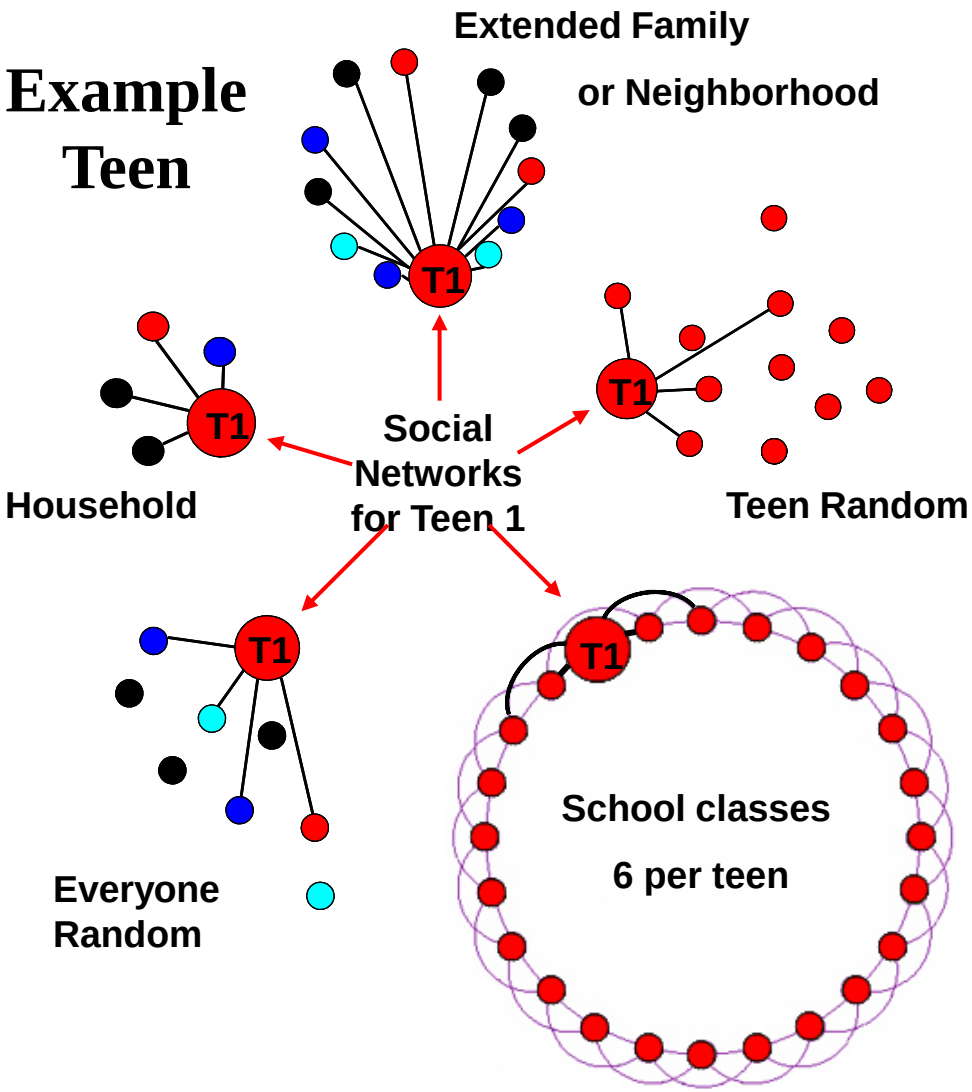


# Agent Age Classes and Social Network

## Agent classes

- Kids
- Teens
- Adults
- Seniors

## Example Teen




## Social Network

Groups

Links

Contact frequency

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| Group (and number of groups in Community) | Membership | Average # of links per member | Network type and parameters | Average Frequency of contact per link |
|---|---|---|---|---|
| **Non-Senior Households (2730)** | 1-2 adults<br>0-4 children<br>0-4 teens<br>Mean size 3.13 | 2.13 | Fully connected | 6 times a day |
| **Senior Households (742)** | 1-2 seniors<br>Mean size 1.75 | 0.75 | Fully connected | 6 times a day |
| **Extended families or Neighborhoods (800)** | 0-2 seniors<br>0-8 adults<br>0-8 teens<br>0-8 children<br>Mean size 12.5 | 11.5 | Fully connected | once a day |
| **Child classes (69)** | 1 class per child,<br>20-35 children in each class | 4 | Ring network with radius 2 | 6 times a day |
| **Child random (1)** | All children | 3 | Random network link density 3/1769 | once a day |
| **Teen classes (264)** | six classes per teen,<br>20-35 teens in each class | 4 | Ring network with radius 2 | once a day |
| **Teen random (1)** | All teens | 3 | Random network link density of 3/1129 | once a day |
| **Adult work (351)** | 1 work group per adult, 10-50 adults in each | 6 | Ring network with radius 3 | once a day |
| **Adult random (1)** | All adults | 3 | Random network link density of 3/5849 | once a day |
| **Senior gathering (156)** | 1 gathering per senior, 5-20 seniors in each | 4 | Ring network with radius 2 | once a day |
| **Senior random (1)** | All seniors | 3 | Random network link density of 3/1249 | once a day |
| **Over-all random (1)** | All age classes | 25 | Random network link density of 25/9999 | 1/25 a day |

# Transmission along network links

The probability that a contact will occur, $p_c$, in a small time interval, dt, along a link with contact frequency $v_c$ is:

$$p_c = v_c dt$$

The fraction of total contacts between two linked individuals that actually result in transmission is given by $I_D*I_R*I_A*S_P*S_A$ where $I_D$ is the infectivity of the disease, $S_P$ is the susceptibility of people to the disease (here taken as 1.0), $I_R$ is the relative infectivity of the infectious state that an agent is in, $I_A$ is the relative infectivity of the agent who is transmitting, and $S_A$ is the relative susceptibility of the agent receiving.

The probability of a disease transmission event along a given link between an infectious and a susceptible individual, $p_i$, is:

$$p_i = I_D I_R I_a S_D S_a v_c dt$$

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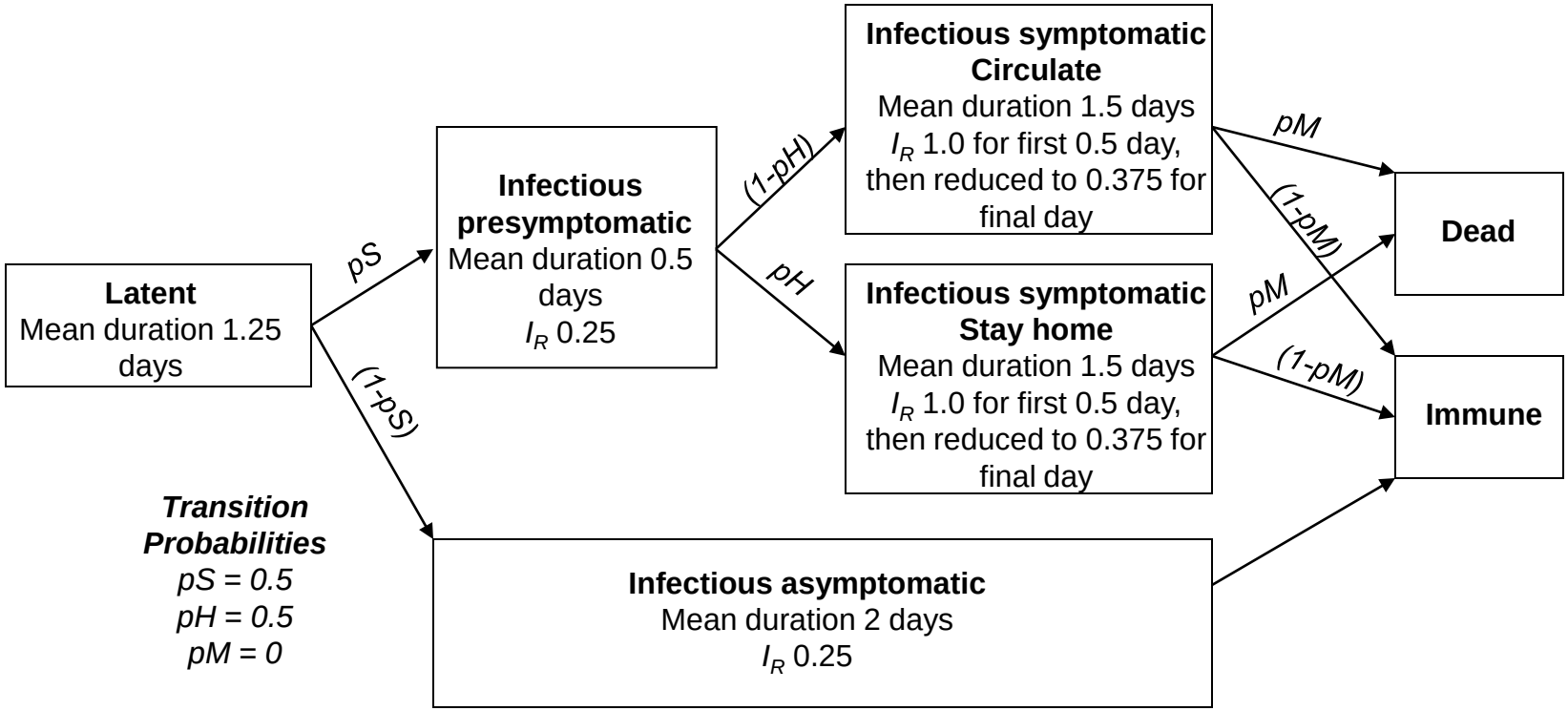
# Influenza Progression within an Individual Agent




Reflective of Ferguson 2005, Nature

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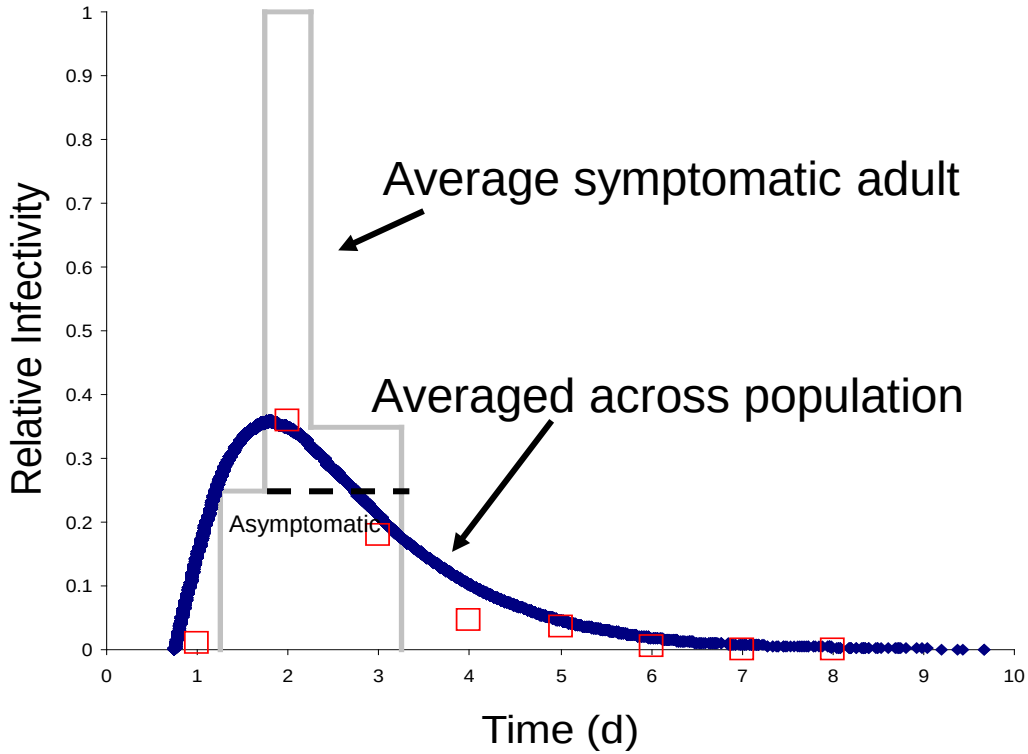
# Infectivity and Age class relative Infectivity




**Relative Values:**

Children ($I_a$=1.5)

Teens ($I_a$=1.25)

Adults ($I_a$=1)

Seniors ($I_a$=1)

Disease Infectivity as a function of time

-red boxes scaled viral shedding data from Hayden et al 1998

-gray boxes as represented here in the model

-blue Infectivity averaged across population

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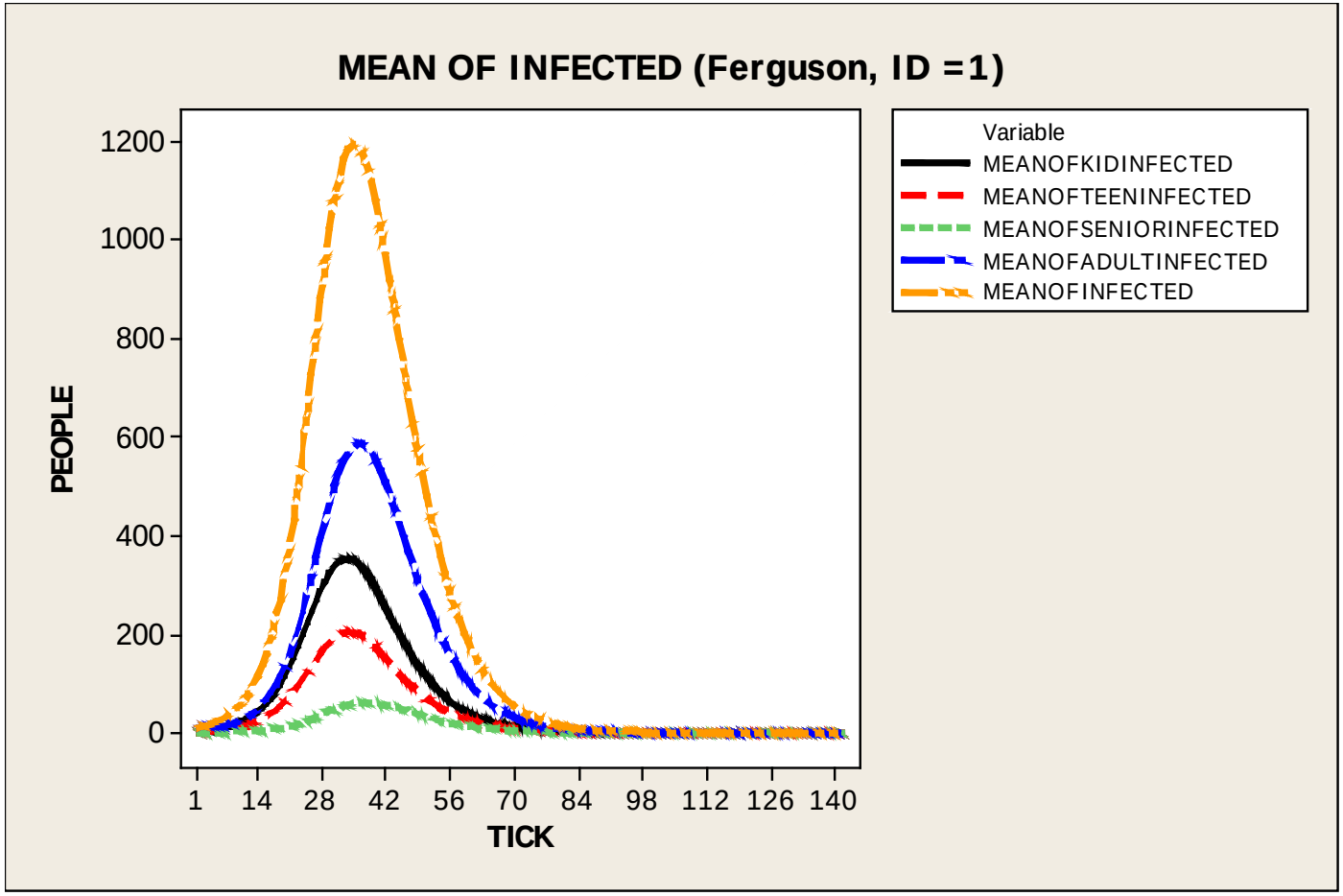
# Base Case for attack rate ~50%




ID tuned to yield desired attack rate

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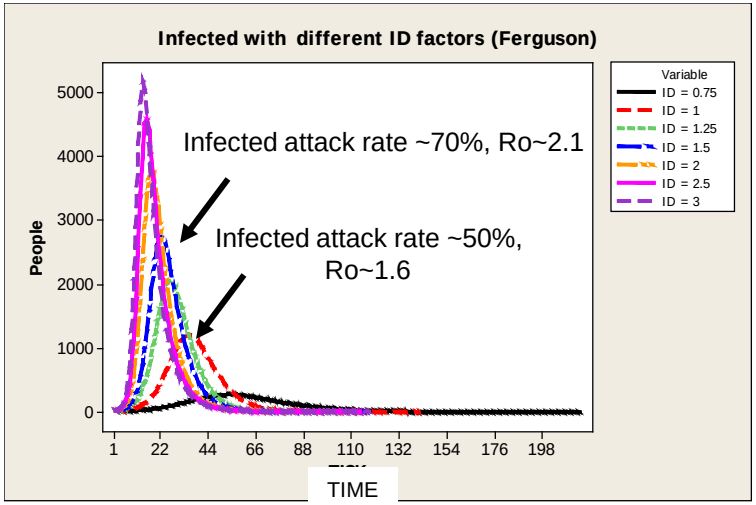
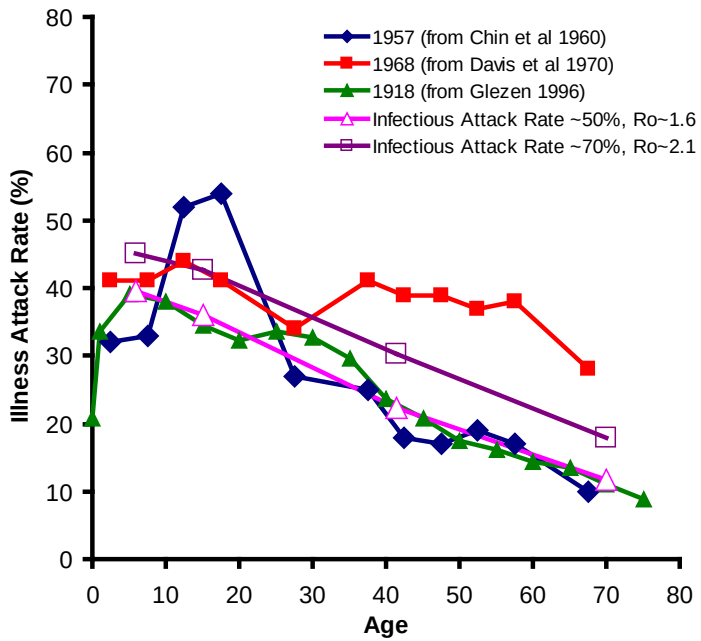
# Unmitigated Results




## Infectious Contact Fraction

| Context | ~50 % ~Ro1.6 | ~70 % ~Ro2.1 |
|---|---|---|
| Households | 40% | 40% |
| Neighborhoods/extended families | 22% | 26% |
| School | 23% | 19% |
| Work | 7% | 6% |
| Senior Groups | 1% | 2% |
| All Extra & Clubs & Random | 8% | 8% |

- Calibration only to disease infectivity $I_D$
- Further calibration/specialization to social contexts of interest/ importance easy

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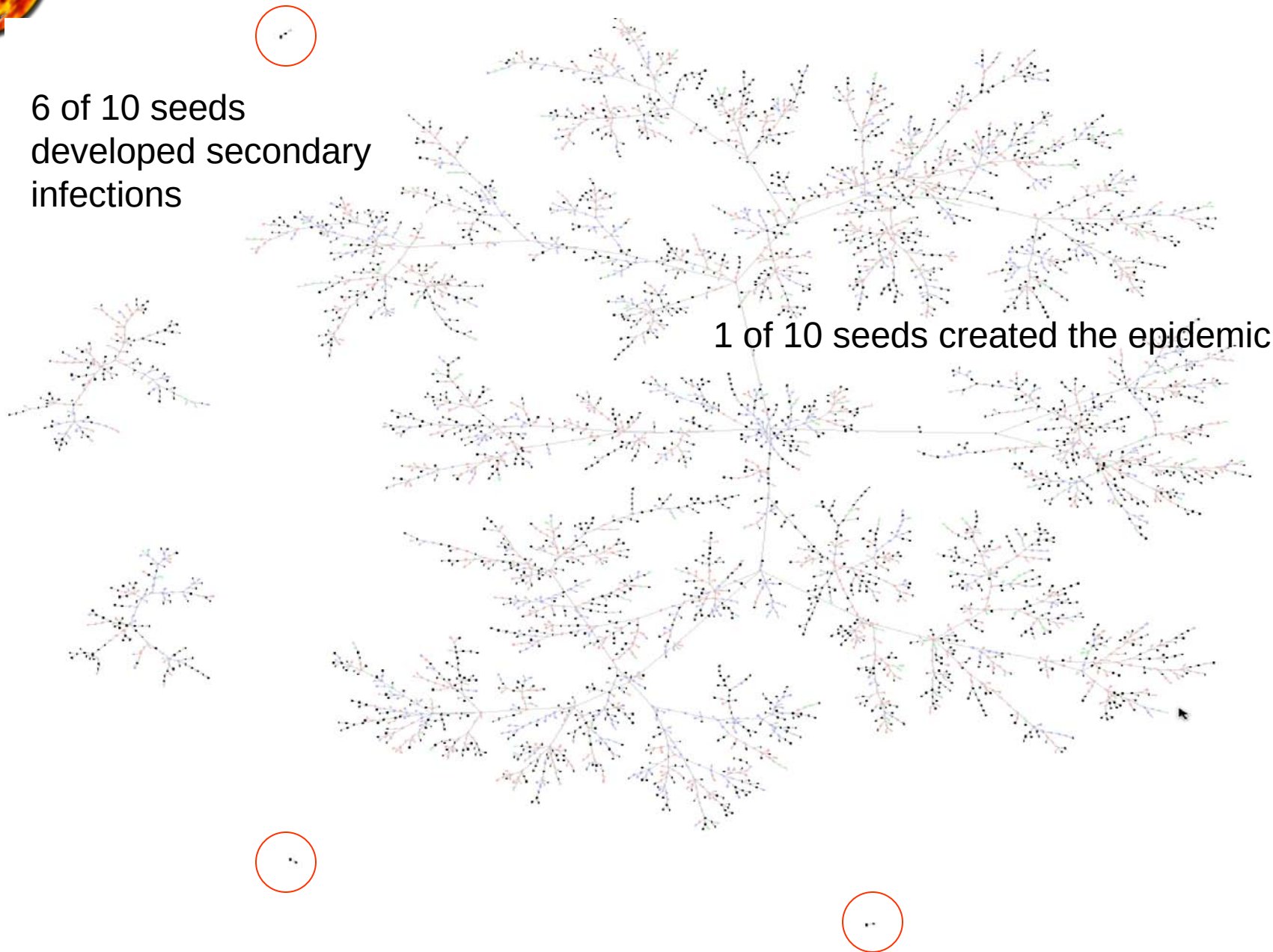
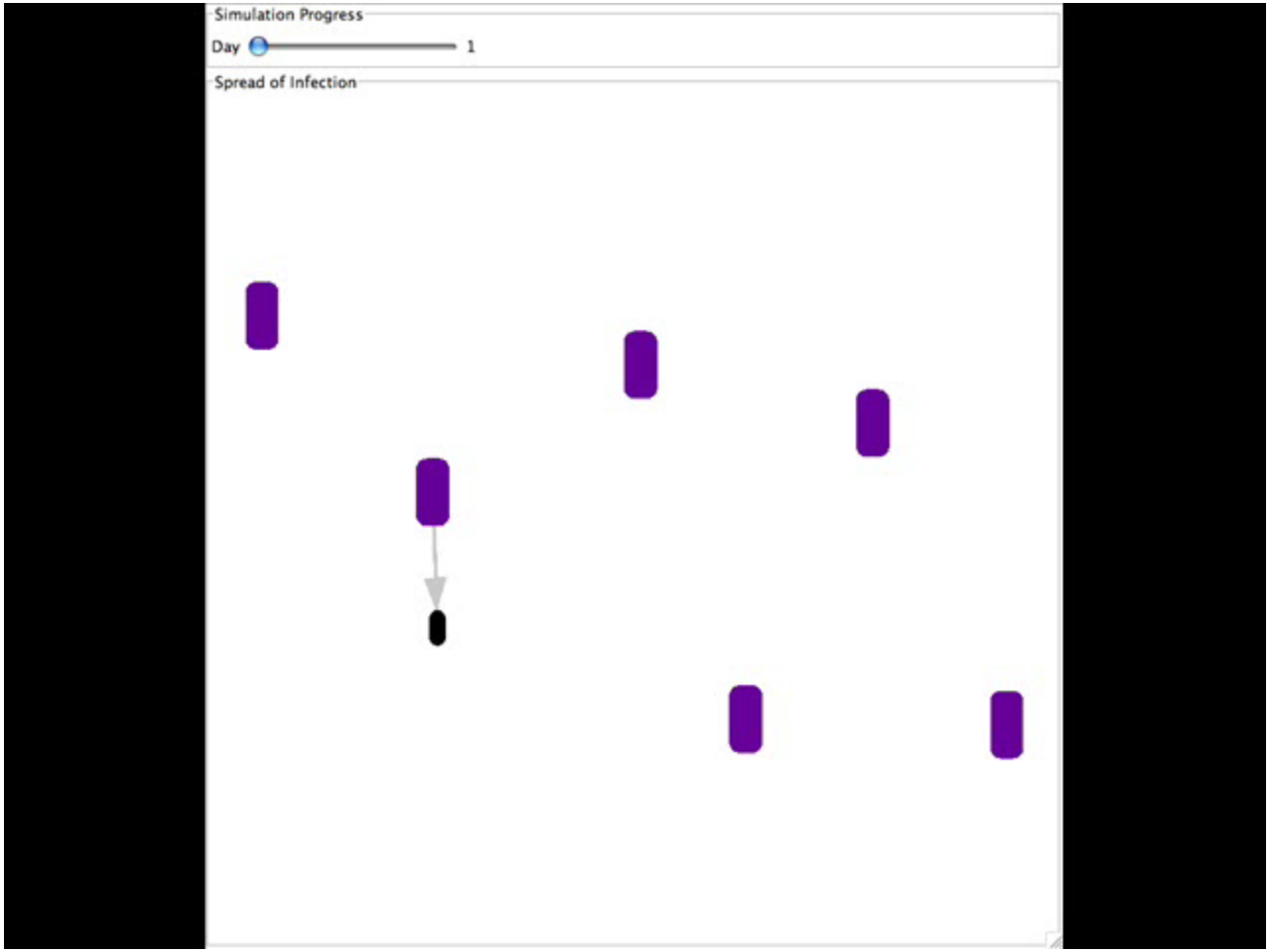
# Final Network of Infected

6 of 10 seeds developed secondary infections



1 of 10 seeds created the epidemic

# Animation of first 20 days, 10 Adult Seeds




Adult Seeds (large blue), Adults (black), Children (red), Teens (blue), Seniors (green)

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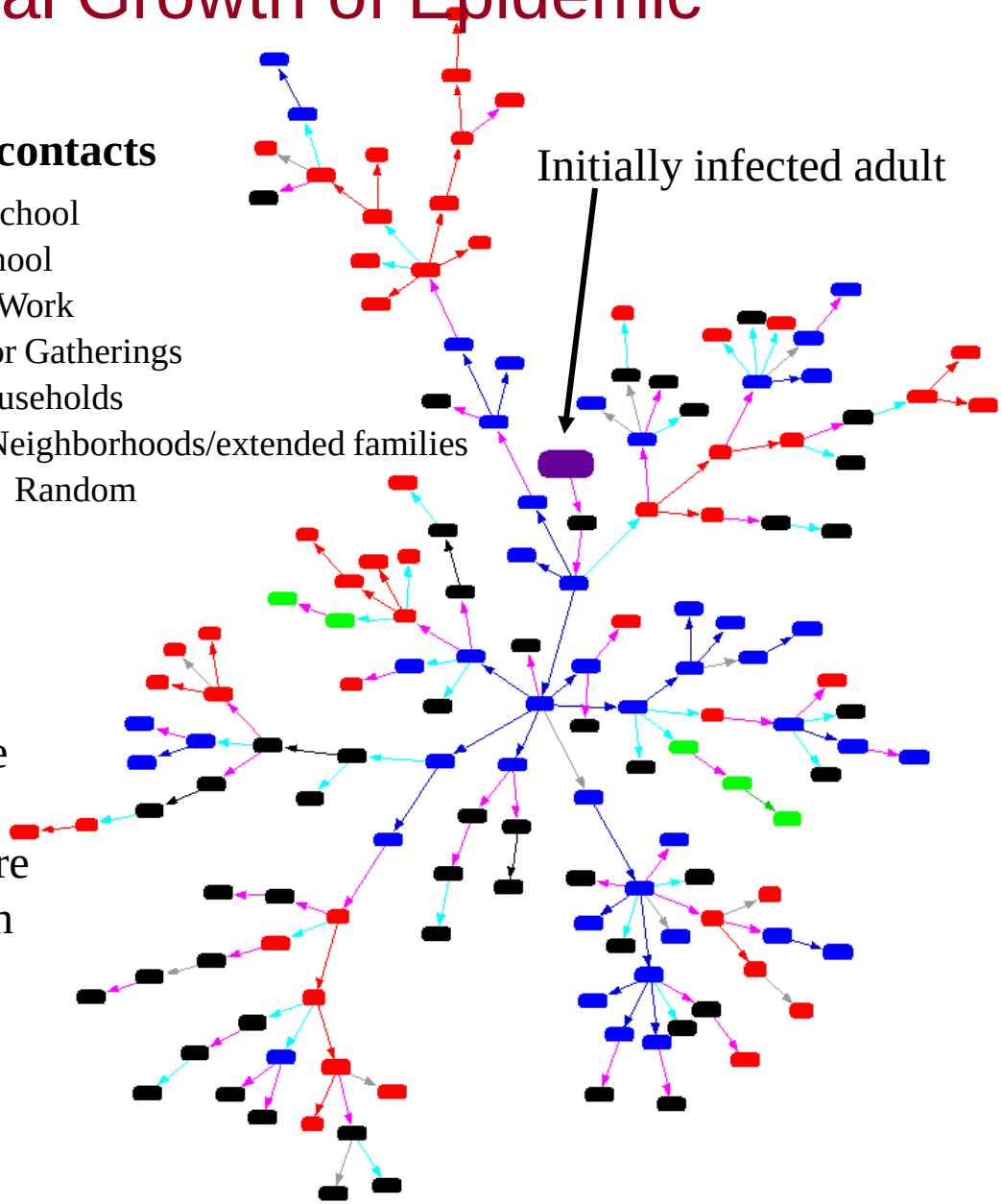
# Initial Growth of Epidemic

**Agents**

- Initially infected adult
- child
- teenager
- adult
- senior

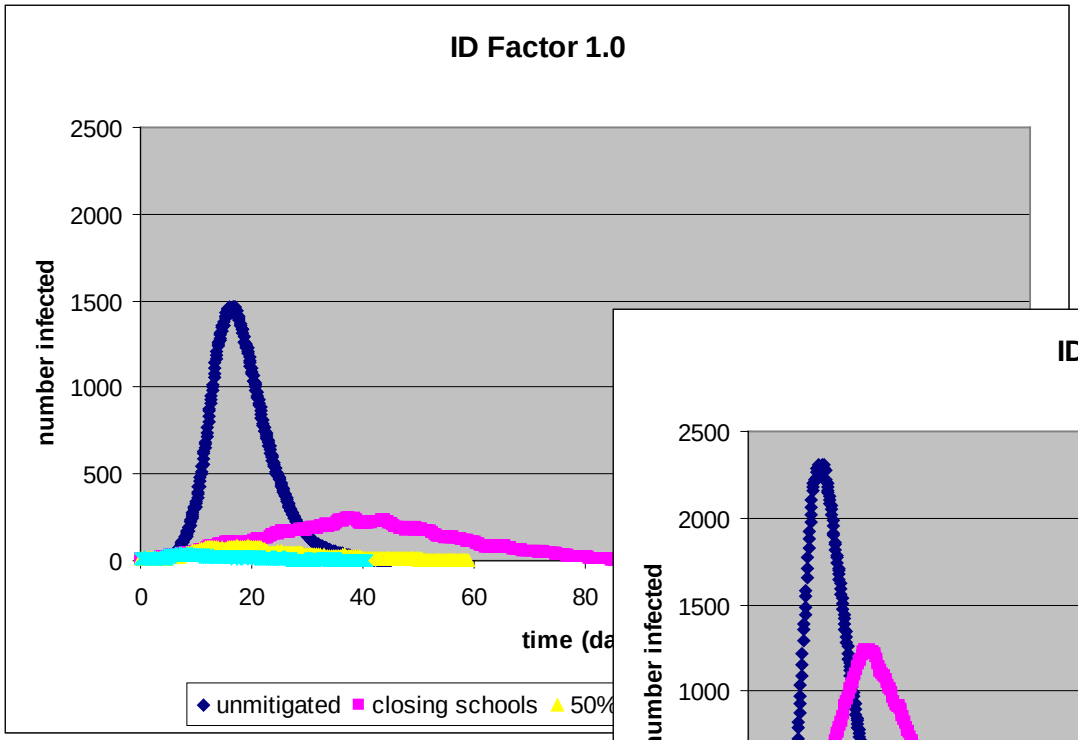
**Infectious contacts**

- Children School
- Teens School
- Adults Work
- Senior Gatherings
- Households
- Neighborhoods/extended families
- Random

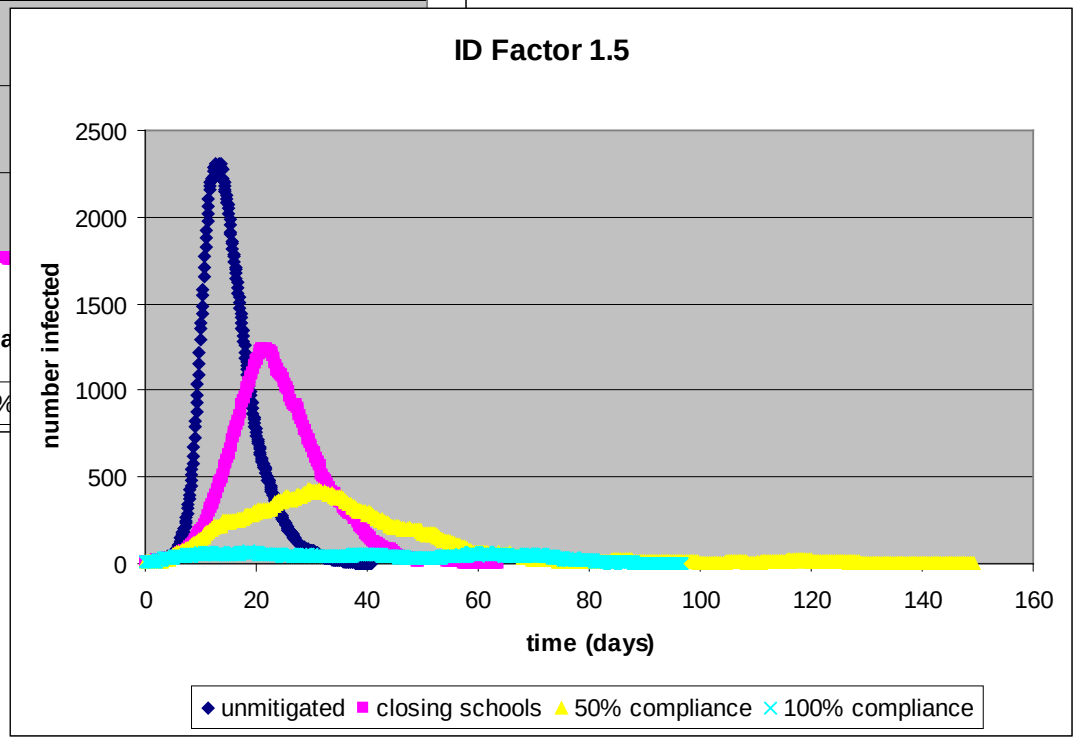



Trace the spread of the disease: From the initial seed, two household contacts (light purple arrows) brings influenza to the High School (blue arrows) where it spreads like wildfire. Children and teens form the backbone of the infectious contact network and are critical to its spread.

# Closing Schools and Keeping the Kids Home




1958-like




1918-like

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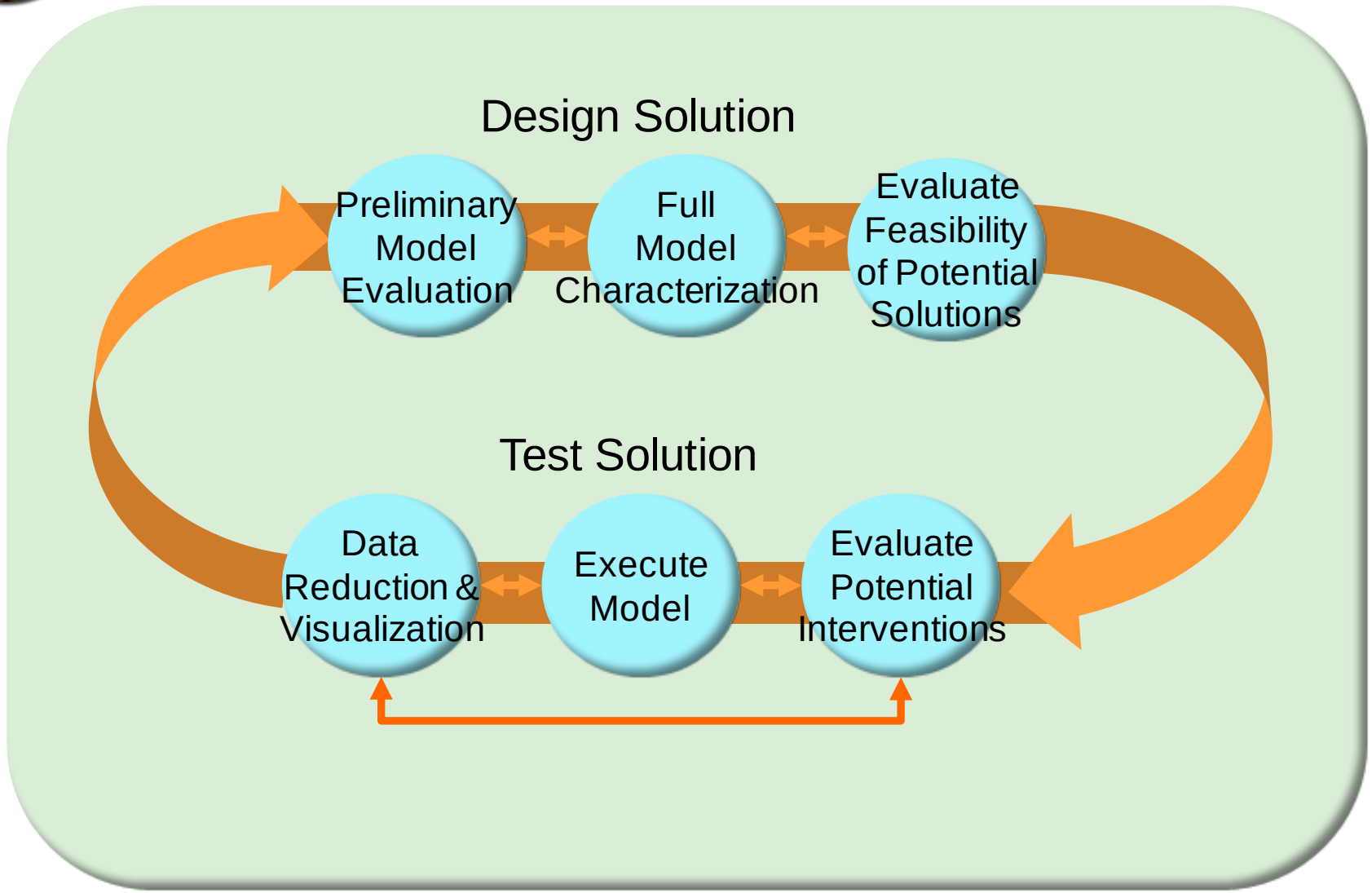
# CASoS Design and Test

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# Base Community Containment Strategies

| Code | | Description |
|---|---|---|
| **S** | Close Schools | Schools closed, **all school contacts reduced by 90%**, household contacts doubled |
| **CTsd** | Social Distance Children and Teenagers | Kids & Teens social distancing, **all non-school and non-household contacts with or between children and teens reduced by 90%**, household contacts doubled |
| **ASsd** | Social Distance Adults and Seniors | Adults & Seniors social distancing, **all non-household non-work contacts with or between adults and seniors reduced by 90%, work contacts reduced by 50%**, household contacts doubled |
| **Q** | Home Quarantine | Household Quarantine for 10 days once an individual is diagnosed, **all non-household contacts for all household members reduced by 90%**, household contacts doubled |
| **T** | Antiviral Treatment | Antiviral Treatment, **90% of people** given antiviral course immediately after diagnosed, reduces infectivity by 60% (from Ferguson et al., 2006) |
| **P** | Home antiviral prophylaxis | Antiviral Prophylaxis, **90% of household members** given antiviral for 10 days immediately after individual is diagnosed, reduces susceptibility by 30%, and if they are infected: reduces probability of symptomatic by 65%, reduces infectivity by 60% (from Ferguson et al., 2006) |
| **Pex** | Extended antiviral prophylaxis | Extended Antiviral Prophylaxis, **90% of linked persons** within households, classes, work, and neighborhoods/extended families are given antiviral immediately for 10 days after person is diagnosed, reduces susceptibility by 30%, and if they are infected: reduces probability of symptomatic by 65%, reduces infectivity by 60% (from Ferguson et al., 2006) |

Note that **P** necessarily contains **T**, and **Pex** necessarily contains **T** and **P**

**When imposed, all mitigation strategies begin the day after 10 individuals are diagnosed within the community**

64 combinations for one compliance, threshold …

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# Design Process

1. **Simulate spread** with networked agent-based approach:
   - explicit social contact network (current: stylized community of 10000)
   - influenza disease manifestation (current: scaled normal flu)
2. **Implement containment strategies**:
   - modify contact network for social distancing or home quarantine
   - modify agent's disease response for antiviral influence
3. **Define and run matrix** of containment strategy combinations (thousands of combinations, millions of simulations)
4. **Weigh effectiveness of strategy combination** (e.g., attack rate, peak symptomatic) in context of constraints (e.g., antiviral courses available, days adults at home)
5. **Evaluate results in light of model sensitivity and uncertainty** (e.g., disease manifestation, infectivity, virulence, social contact network…)

# Base Simulation Matrix

- **2 disease manifestations**: (Ferguson-like, Longini-like)
- **7 disease infectivities** about a base case (yielding an infected attack rate of 50%) by factors of 0.75, 1.0 = basecase, 1.25, 1.5, 2.0, 2.5 and 3.0
- **2 boundary conditions** for external contact and instigation (open or closed)
- **8 community containment strategies** applied individually or in combination (64 combinations) with **4 vaccination strategies**
- **1 diagnosis rate** (80%) and **2 compliances** (60%, 90%) for social distancing, antiviral treatment and antiviral prophylaxis
- **2 implementation thresholds** (after 10 or 40 diagnosed)
- Each combination **run 100 times** with varying realizations of social contact network and initial adults infected (**2.86M runs**)
- For each, **measure** the number infected, symptomatic, their peaks, number antiviral courses, days adults are confined at home, who infects whom, etc, and put everything in a data base

Current: Expanding around base matrix for variation of social contact network…

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# Queries yield Lots and Lots of Tables…

## Tens of thousands of scenarios can be queried by input or output values

**TABLE 1: 90% compliance**

Green indicates those combinations that yielded an infected attack rate < 10%

| ID Factor | | None | ASsd | CTsd | CTsd,ASsd | S | S, ASsd | S,CTsd | ,CTsd,ASs |
|---|---|---|---|---|---|---|---|---|---|
| 0.75 | None | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | T | 532 | 313 | 133 | 99 | 63 | 52 | 45 | 36 |
| | Q | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | P | 565 | 374 | 174 | 162 | 132 | 123 | 93 | 74 |
| | Q,T | 187 | 94 | 69 | 53 | 41 | 46 | 39 | 39 |
| | Q,P | 462 | 254 | 159 | 150 | 138 | 127 | 108 | 0 |
| | Pex | 1729 | 1387 | 1155 | 1223 | 841 | 873 | 781 | 738 |
| | Q,Pex | 1633 | 1328 | 909 | 1044 | 818 | 955 | 0 | 0 |
| 1.00 | None | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | T | 1470 | 1108 | 1006 | 639 | 272 | 138 | 50 | 47 |
| | Q | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | P | 3389 | 2409 | 1285 | 670 | 341 | 234 | 112 | 119 |
| | Q,T | 1025 | 666 | 303 | 184 | 102 | 79 | 49 | 46 |
| | Q,P | 2877 | 1894 | 798 | 529 | 241 | 173 | 120 | 114 |
| | Pex | 8574 | 4903 | 2529 | 2107 | 1262 | 1306 | 862 | 779 |
| | Q,Pex | 5329 | 3803 | 2128 | 1539 | 1250 | 1240 | 946 | 831 |
| 1.25 | None | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| | [illegible] | 4620 | 3653 | 3376 | 2477 | 1526 | 776 | 153 | [illegible] |
| | [illegible] | 1547 | 1224 | 1076 | 791 | 423 | 232 | 64 | [illegible] |
| | [illegible] | 4247 | 3308 | 2635 | 1810 | 970 | 533 | 163 | [illegible] |
| | [illegible] | 16570 | 12893 | 8435 | 5351 | 3293 | 2149 | 1272 | [illegible] |
| | [illegible] | 13791 | 8744 | 4500 | 3856 | 2485 | 2045 | 1149 | [illegible] |
| 1.50 | [illegible] | 0 | 0 | 0 | 0 | 0 | 0 | 0 | [illegible] |
| | [illegible] | 2357 | 1816 | 2061 | 1626 | 1842 | 1395 | 161 | [illegible] |
| | [illegible] | 0 | 0 | 0 | 0 | 0 | 0 | 0 | [illegible] |
| | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| | Q,P | 4971 | 4037 | 3959 | 3097 | 2875 | 1738 | 235 | 178 |
| | Pex | 20107 | 16967 | 16480 | 12079 | 8289 | 5409 | 1754 | 1425 |
| | Q,Pex | 18442 | 14344 | 10581 | 7503 | 5089 | 3609 | 1565 | 1378 |
| 2.00 | None | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | T | 2809 | 2163 | 2596 | 2061 | 2574 | 2119 | 1131 | 219 |
| | Q | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | P | 6089 | 5010 | 5609 | 4661 | 5392 | 4413 | 1203 | 381 |
| | Q,T | 2400 | 1963 | 2174 | 1784 | 2058 | 1665 | 525 | 200 |
| | Q,P | 5833 | 4818 | 5206 | 4344 | 4953 | 3959 | 926 | 385 |
| | Pex | 20514 | 18475 | 21802 | 18732 | 20682 | 16061 | 4005 | 2539 |
| | Q,Pex | 21477 | 18204 | 19861 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 2.50 | None | 0 | 0 | 0 | 0 | [illegible] | [illegible] | [illegible] | [illegible] |
| | T | 3078 | 2384 | 2908 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| | Q | 0 | 0 | 0 | 0 | [illegible] | [illegible] | [illegible] | [illegible] |
| | P | 6538 | 5414 | 6189 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| | Q,T | 2733 | 2228 | 2529 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| | Q,P | 6318 | 5279 | 5917 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| | Pex | 18310 | 17666 | 21498 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| | Q,Pex | 20894 | 19080 | 22206 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 3.00 | None | 0 | 0 | 0 | 0 | [illegible] | [illegible] | [illegible] | [illegible] |
| | T | 3237 | 2542 | 3109 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| | Q | 0 | 0 | 0 | 0 | [illegible] | [illegible] | [illegible] | [illegible] |
| | P | 6814 | 5686 | 6545 | 5546 | 6625 | 5897 | 5101 | 2237 |
| | Q,T | 2955 | 2415 | 2784 | 2339 | 2820 | 2482 | 2141 | 1207 |
| | Q,P | 6631 | 5591 | 6333 | 5389 | 6388 | 5664 | 4656 | 2082 |
| | Pex | 16493 | 16296 | 19847 | 18201 | 21345 | 20446 | 19721 | 7815 |
| | Q,Pex | 19365 | 17885 | 22663 | 19297 | 22655 | 19841 | 16060 | 7195 |

**TABLE 2: 90% compliance, trickle**

Green indicates those combinations that yielded an infected attack rate < 10%

| ID Factor | | None | ASsd | CTsd | CTsd,ASsd | S | S, ASsd | S,CTsd | ,CTsd,ASs |
|---|---|---|---|---|---|---|---|---|---|
| 0.75 | None | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | T | 797 | 579 | 452 | 329 | 233 | 194 | 129 | 116 |
| | Q | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | P | 1721 | 1185 | 851 | 722 | 545 | 498 | 342 | 309 |
| | Q,T | 493 | 343 | 276 | 229 | 179 | 161 | 123 | 115 |
| | Q,P | 1402 | 961 | 791 | 623 | 509 | 458 | 335 | 317 |
| | Pex | 6831 | 5842 | 5148 | 4502 | 3683 | 3444 | 2578 | 2416 |
| | Q,Pex | 6123 | 5283 | 4539 | 4226 | 3518 | 3278 | 2524 | 2321 |
| 1.00 | None | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | T | 1547 | 1198 | 1142 | 877 | 643 | 456 | 194 | 152 |
| | Q | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | P | 3654 | 2783 | 2213 | 1726 | 1117 | 853 | 456 | 394 |
| | Q,T | 1143 | 880 | 667 | 547 | 370 | 304 | 175 | 149 |
| | Q,P | 3252 | 2424 | 1757 | 1344 | 938 | 767 | 457 | 384 |
| | Pex | 14481 | 11676 | 9591 | 8020 | 6469 | 5511 | 3525 | 3123 |
| | Q,Pex | 12475 | 10206 | 8006 | 6682 | 5793 | 5029 | 3506 | 3087 |
| 1.25 | None | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | T | 2039 | 1598 | 1721 | 1350 | 1350 | 988 | 298 | 209 |
| | Q | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | P | 4765 | 3809 | 3715 | 2961 | 2456 | 1778 | 656 | 511 |
| | Q,T | 1619 | 1295 | 1233 | 983 | 802 | 597 | 252 | 203 |
| | Q,P | 4423 | 3490 | 3160 | 2505 | 1972 | 1462 | 627 | 487 |
| | Pex | 20074 | 17047 | 15711 | 12725 | 10794 | 8902 | 4854 | 3955 |
| | Q,Pex | 18270 | 15087 | 13079 | 10388 | 9019 | 7744 | 4610 | 3970 |
| 1.50 | None | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | T | 2388 | 1852 | 2111 | 1682 | 1917 | 1510 | 520 | 277 |
| | Q | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | P | 5422 | 4426 | 4649 | 3799 | 3860 | 2883 | 947 | 600 |
| | Q,T | 1969 | 1608 | 1642 | 1349 | 1350 | 1045 | 380 | 267 |
| | Q,P | 5109 | 4160 | 4217 | 3433 | 3377 | 2539 | 899 | 615 |
| | Pex | 22360 | 19818 | 20580 | 17172 | 16194 | 13088 | 6543 | 5054 |
| | Q,Pex | 21647 | 19169 | 17914 | 14716 | 13156 | 10953 | 6142 | 4821 |
| 2.00 | None | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | T | 2821 | 2198 | 2613 | 2099 | 2596 | 2171 | 1346 | 537 |
| | Q | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | P | 6168 | 5097 | 5695 | 4783 | 5520 | 4580 | 2307 | 1079 |
| | Q,T | 2431 | 1996 | 2212 | 1846 | 2110 | 1758 | 928 | 516 |
| | Q,P | 5901 | 4923 | 5358 | 4477 | 5117 | 4215 | 1961 | 1034 |
| | Pex | 22129 | 20862 | 24303 | 21437 | 23569 | 20476 | 11626 | 7465 |
| | P | 6856 | 5750 | 6589 | 5623 | 6666 | 5974 | 5249 | 2814 |
| | Q,T | 2957 | 2437 | 2814 | 2367 | 2840 | 2502 | 2234 | 1396 |
| | Q,P | 6690 | 5628 | 6373 | 5459 | 6441 | 5750 | 4907 | 2693 |
| | Pex | 17457 | 17549 | 21421 | 20337 | 22905 | 22229 | 23882 | 15083 |
| | Q,Pex | 21158 | 20262 | 24523 | 22159 | 24796 | 23187 | 21813 | 14493 |

**TABLE 3: 60% compliance**

Green indicates those combinations that yielded an infected attack rate < 10%

| ID Factor | | None | ASsd | CTsd | CTsd,ASsd | S | S, ASsd | S,CTsd | ,CTsd,ASs |
|---|---|---|---|---|---|---|---|---|---|
| 0.75 | None | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | T | 365 | 348 | 300 | 224 | 36 | 33 | 30 | 27 |
| | Q | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | P | 689 | 515 | 483 | 469 | 96 | 83 | 82 | 83 |
| | Q,T | 213 | 188 | 174 | 145 | 31 | 34 | 25 | 24 |
| | Q,P | 471 | 407 | 418 | 274 | 97 | 81 | 77 | 85 |
| | Pex | 1455 | 1270 | 1327 | 1327 | 496 | 582 | 528 | 521 |
| | Q,Pex | 1336 | 1198 | 1206 | 1008 | 569 | 668 | 517 | 501 |
| 1.00 | None | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | T | 978 | 921 | 942 | 856 | 227 | 150 | 59 | 46 |
| | Q | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | P | 2627 | 2473 | 2465 | 2253 | 344 | 249 | 134 | 111 |
| | Q,T | 838 | 808 | 805 | 754 | 89 | 80 | 48 | 43 |
| | Q,P | 2371 | 2287 | 2200 | 2072 | 267 | 209 | 126 | 106 |
| | Pex | 10153 | 9001 | 8424 | 6833 | 1175 | 1053 | 734 | 747 |
| | Q,Pex | 8035 | 6921 | 6467 | 5139 | 1043 | 871 | 691 | 743 |
| 1.25 | None | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | T | 1333 | 1229 | 1300 | 1184 | 882 | 741 | 225 | 141 |
| | Q | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | P | 3560 | 3341 | 3456 | 3221 | 1947 | 1424 | 351 | 255 |
| | Q,T | 1193 | 1151 | 1187 | 1107 | 643 | 509 | 175 | 111 |
| | Q,P | 3329 | 3208 | 3264 | 3074 | 1477 | 1077 | 327 | 253 |
| | Pex | 14039 | 13618 | 13849 | 12710 | 4458 | 3506 | 1272 | 1161 |
| | Q,Pex | 13231 | 12725 | 12961 | 12110 | 3064 | 2365 | 1203 | 1149 |
| 1.50 | None | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | T | 1574 | 1438 | 1537 | 1405 | 1301 | 1160 | 832 | 582 |
| | Q | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | P | 4091 | 3871 | 4017 | 3766 | 3147 | 2777 | 1544 | 920 |
| | Q,T | 1432 | 1372 | 1424 | 1352 | 1088 | 981 | 699 | 520 |
| | Q,P | 3906 | 3759 | 3868 | 3679 | 2866 | 2519 | 1328 | 850 |
| | Pex | 15196 | 14563 | 15461 | 14805 | 11869 | 9767 | 3882 | 2722 |
| | Q,Pex | 14992 | 14672 | 15204 | 14897 | 9585 | 7305 | 3114 | 2350 |
| 2.00 | None | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | T | 1882 | 1712 | 1844 | 1696 | 1765 | 1639 | 1513 | 1279 |
| | Q | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | P | 4717 | 4451 | 4665 | 4413 | 4408 | 4089 | 3681 | 3075 |
| | Q,T | 1757 | 1678 | 1747 | 1664 | 1596 | 1509 | 1389 | 1245 |
| | Q,P | 4554 | 4402 | 4536 | 4359 | 4180 | 3939 | 3492 | 3045 |
| | Pex | 14974 | 14673 | 15601 | 15106 | 16875 | 15928 | 14649 | 12299 |
| | P | 5281 | 5021 | 5235 | 5012 | 5220 | 5041 | 4974 | 4654 |
| | Q,T | 2088 | 1999 | 2066 | 1996 | 2041 | 1987 | 1958 | 1860 |
| | Q,P | 5188 | 5014 | 5155 | 5005 | 5104 | 4957 | 4885 | 4631 |
| | Pex | 12895 | 12935 | 13471 | 13445 | 15957 | 15856 | 17353 | 17160 |
| | Q,Pex | 13186 | 13326 | 13728 | 13715 | 16404 | 16273 | 17395 | 17097 |

**TABLE 4: 60% compliance, trickle**

Green indicates those combinations that yielded an infected attack rate < 10%

| ID Factor | | None | ASsd | CTsd | CTsd,ASsd | S | S, ASsd | S,CTsd | ,CTsd,ASs |
|---|---|---|---|---|---|---|---|---|---|
| 0.75 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| | [illegible] | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | [illegible] | 1319 | 1233 | 1179 | 1080 | 427 | 404 | 316 | 293 |
| | [illegible] | 414 | 389 | 384 | 348 | 139 | 125 | 103 | 99 |
| | [illegible] | 1152 | 1112 | 1068 | 919 | 400 | 377 | 295 | 286 |
| | [illegible] | 5627 | 5530 | 5067 | 4690 | 2627 | 2558 | 2059 | 1927 |
| | [illegible] | 4939 | 4978 | 4780 | 4358 | 2475 | 2400 | 1985 | 1882 |
| 1.00 | [illegible] | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | [illegible] | 1023 | 959 | 1004 | 905 | 478 | 396 | 215 | 182 |
| | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| | Q,T | 895 | 864 | 875 | 822 | 340 | 295 | 194 | 173 |
| | Q,P | 2615 | 2472 | 2491 | 2289 | 863 | 785 | 501 | 453 |
| | Pex | 11876 | 11570 | 11839 | 10576 | 5018 | 4571 | 3274 | 3049 |
| | Q,Pex | 11015 | 10551 | 10488 | 9763 | 4560 | 4254 | 3243 | 2963 |
| 1.25 | None | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | T | 1365 | 1253 | 1326 | 1221 | 973 | 840 | 517 | 388 |
| | Q | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | P | 3645 | 3445 | 3557 | 3315 | 2318 | 1972 | 1117 | 886 |
| | Q,T | 1227 | 1173 | 1220 | 1141 | 762 | 681 | 427 | 363 |
| | Q,P | 3446 | 3322 | 3394 | 3217 | 2005 | 1721 | 1038 | 823 |
| | Pex | 15336 | 14859 | 15439 | 14663 | 9917 | 8751 | 5685 | 4815 |
| | Q,Pex | 14838 | 14489 | 14702 | 14199 | 8794 | 7557 | 5177 | 4634 |
| 1.50 | None | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | T | 1586 | 1454 | 1563 | 1433 | 1343 | 1208 | 928 | 726 |
| | Q | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | P | 4143 | 3926 | 4093 | 3851 | 3357 | 2987 | 2108 | 1663 |
| | Q,T | 1461 | 1399 | 1451 | 1379 | 1153 | 1053 | 831 | 694 |
| | Q,P | 3969 | 3827 | 3935 | 3757 | 3072 | 2781 | 1940 | 1599 |
| | Pex | 16366 | 15994 | 16650 | 16096 | 14634 | 13450 | 9560 | 8030 |
| | Q,Pex | 16315 | 15867 | 16753 | 16051 | 13086 | 12061 | 8904 | 7645 |
| 2.00 | None | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | T | 1884 | 1725 | 1858 | 1708 | 1785 | 1660 | 1542 | 1325 |
| | Q | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | P | 4754 | 4490 | 4695 | 4462 | 4449 | 4174 | 3804 | 3294 |
| | Q,T | 1773 | 1691 | 1757 | 1685 | 1625 | 1540 | 1429 | 1301 |
| | Q,P | 4611 | 4437 | 4572 | 4405 | 4244 | 4013 | 3660 | 3238 |
| | Pex | 15618 | 15339 | 16347 | 15922 | 18133 | 17448 | 16774 | 15209 |
| | P | 5280 | 5057 | 5244 | 5021 | 5237 | 5069 | 5024 | 4721 |
| | Q,T | 2088 | 2004 | 2077 | 2001 | 2048 | 1986 | 1962 | 1875 |
| | Q,P | 5201 | 5036 | 5180 | 5024 | 5129 | 4995 | 4932 | 4687 |
| | Pex | 13207 | 13286 | 13820 | 13779 | 16384 | 16503 | 18034 | 18011 |
| | Q,Pex | 13635 | 13634 | 14212 | 14108 | 17038 | 17104 | 18188 | 18202 |

# Infected attack rate of ~70%, Ro~2.1, ~1918-19

**TABLE 1: (%), 90% compliance**

Green indicates those combinations that yielded an infected attack rate < 10%

| ID Factor | | None | ASsd | CTsd | CTsd,ASsd | S | S, ASsd | S,CTsd | ,CTsd,ASs |
|---|---|---|---|---|---|---|---|---|---|
| 0.75 | None | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | T | 5 | 3 | 1 | 1 | 1 | 1 | 0 | 0 |
| | Q | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | P | 6 | 4 | 2 | 2 | 1 | 1 | 1 | 1 |
| | Q,T | 2 | 1 | 1 | 1 | 0 | 0 | 0 | 0 |
| | Q,P | 5 | 3 | 2 | 2 | 1 | 1 | 1 | 0 |
| | Pex | 17 | 14 | 12 | 12 | 8 | 9 | 8 | 7 |
| | Q,Pex | 16 | 13 | 9 | 10 | 8 | 10 | 0 | 0 |
| 1.00 | None | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | T | 15 | 11 | 10 | 6 | 3 | 1 | 1 | 0 |
| | Q | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | P | 34 | 24 | 13 | 7 | 3 | 2 | 1 | 1 |
| | Q,T | 10 | 7 | 3 | 2 | 1 | 1 | 0 | 0 |
| | Q,P | 29 | 19 | 8 | 5 | 2 | 2 | 1 | 1 |
| | Pex | 86 | 49 | 25 | 21 | 13 | 13 | 9 | 8 |
| | Q,Pex | 53 | 38 | 21 | 15 | 12 | 12 | 9 | 8 |
| 1.25 | None | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | T | 20 | 15 | 17 | 13 | 12 | 8 | 1 | 1 |
| | Q | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | P | 46 | 37 | 34 | 25 | 15 | 8 | 2 | 1 |
| | Q,T | 15 | 12 | 11 | 8 | 4 | 2 | 1 | 1 |
| | Q,P | 42 | 33 | 26 | 18 | 10 | 5 | 2 | 1 |
| | Pex | 166 | 129 | 84 | 54 | 33 | 21 | 13 | 11 |
| | Q,Pex | 138 | 87 | 45 | 39 | 25 | 20 | 11 | 11 |
| 1.50 | None | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | T | 24 | 18 | 21 | 16 | 18 | 14 | 2 | 1 |
| | Q | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | P | 53 | 43 | 44 | 36 | 35 | 23 | 3 | 2 |
| | Q,T | 19 | 15 | 16 | 12 | 12 | 8 | 1 | 1 |
| | Q,P | 50 | 40 | 40 | 31 | 29 | 17 | 2 | 2 |
| | Pex | 201 | 170 | 165 | 121 | 83 | 54 | 18 | 14 |
| | Q,Pex | 184 | 143 | 106 | 75 | 51 | 36 | 16 | 14 |
| 2.00 | None | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | T | 28 | 22 | 26 | 21 | 26 | 21 | 11 | 2 |
| | Q | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | P | 61 | 50 | 56 | 47 | 54 | 44 | 12 | 4 |
| | Q,T | 24 | 20 | 22 | 18 | 21 | 17 | 5 | 2 |
| | Q,P | 58 | 48 | 52 | 43 | 50 | 40 | 9 | 4 |
| | Pex | 205 | 185 | 218 | 187 | 207 | 161 | 40 | 25 |
| | Q,Pex | 215 | 182 | 199 | 155 | 164 | 119 | 35 | 24 |
| 2.50 | None | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | T | 31 | 24 | 29 | 23 | 29 | 25 | 21 | 7 |
| | Q | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | P | 65 | 54 | 62 | 52 | 62 | 54 | 36 | 11 |
| | Q,T | 27 | 22 | 25 | 21 | 25 | 22 | 15 | 6 |
| | Q,P | 63 | 53 | 59 | 50 | 59 | 50 | 31 | 9 |
| | Pex | 183 | 177 | 215 | 194 | 224 | 200 | 104 | 44 |
| | Q,Pex | 209 | 191 | 222 | 191 | 221 | 177 | 79 | 43 |
| 3.00 | None | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | T | 32 | 25 | 31 | 25 | 32 | 28 | 26 | 13 |
| | Q | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | P | 68 | 57 | 65 | 55 | 66 | 59 | 51 | 22 |
| | Q,T | 30 | 24 | 28 | 23 | 28 | 25 | 21 | 12 |
| | Q,P | 66 | 56 | 63 | 54 | 64 | 57 | 47 | 21 |
| | Pex | 165 | 163 | 198 | 182 | 213 | 204 | 197 | 78 |
| | Q,Pex | 194 | 179 | 227 | 193 | 227 | 198 | 161 | 72 |

**TABLE 2: (%), 90% compliance, trickle**

Green indicates those combinations that yielded an infected attack rate < 10%

| ID Factor | | None | ASsd | CTsd | CTsd,ASsd | S | S, ASsd | S,CTsd | ,CTsd,ASs |
|---|---|---|---|---|---|---|---|---|---|
| 0.75 | None | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | T | 8 | 6 | 5 | 3 | 2 | 2 | 1 | 1 |
| | Q | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | P | 17 | 12 | 9 | 7 | 5 | 5 | 3 | 3 |
| | Q,T | 5 | 3 | 3 | 2 | 2 | 2 | 1 | 1 |
| | Q,P | 14 | 10 | 8 | 6 | 5 | 5 | 3 | 3 |
| | Pex | 68 | 58 | 51 | 45 | 37 | 34 | 26 | 24 |
| | Q,Pex | 61 | 53 | 45 | 42 | 35 | 33 | 25 | 23 |
| 1.00 | None | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | T | 15 | 12 | 11 | 9 | 6 | 5 | 2 | 2 |
| | Q | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | P | 37 | 28 | 22 | 17 | 11 | 9 | 5 | 4 |
| | Q,T | 11 | 9 | 7 | 5 | 4 | 3 | 2 | 1 |
| | Q,P | 33 | 24 | 18 | 13 | 9 | 8 | 5 | 4 |
| | Pex | 145 | 117 | 96 | 80 | 65 | 55 | 35 | 31 |
| | Q,Pex | 125 | 102 | 80 | 67 | 58 | 50 | 35 | 31 |
| 1.25 | None | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | T | 20 | 16 | 17 | 14 | 14 | 10 | 3 | 2 |
| | Q | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | P | 48 | 38 | 37 | 30 | 25 | 18 | 7 | 5 |
| | Q,T | 16 | 13 | 12 | 10 | 8 | 6 | 3 | 2 |
| | Q,P | 44 | 35 | 32 | 25 | 20 | 15 | 6 | 5 |
| | Pex | 201 | 170 | 157 | 127 | 108 | 89 | 49 | 40 |
| | Q,Pex | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 1.50 | None | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| | T | 24 | 19 | 21 | 17 | 19 | 15 | 5 | 3 |
| | Q | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | P | 54 | 44 | 46 | 38 | 39 | 29 | 9 | 6 |
| | Q,T | 20 | 16 | 16 | 13 | 14 | 10 | 4 | 3 |
| | Q,P | 51 | 42 | 42 | 34 | 34 | 25 | 9 | 6 |
| | Pex | 224 | 198 | 206 | 172 | 162 | 131 | 65 | 51 |
| | Q,Pex | 216 | 192 | 179 | 147 | 132 | 110 | 61 | 48 |
| 2.00 | None | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | T | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| | Q | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| | P | 62 | 51 | 57 | 48 | 55 | 46 | 23 | 11 |
| | Q,T | 24 | 20 | 22 | 18 | 21 | 18 | 9 | 5 |
| | Q,P | 59 | 49 | 54 | 45 | 51 | 42 | 20 | 10 |
| | Pex | 221 | 209 | 243 | 214 | 236 | 205 | 116 | 75 |
| | Q,Pex | 239 | 213 | 237 | 203 | 212 | 183 | 104 | 75 |
| 2.50 | None | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | T | 31 | 24 | 29 | 23 | 30 | 25 | 21 | 10 |
| | Q | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | P | 66 | 55 | 62 | 53 | 63 | 55 | 41 | 18 |
| | Q,T | 27 | 23 | 26 | 22 | 26 | 22 | 17 | 9 |
| | Q,P | 64 | 54 | 60 | 51 | 60 | 52 | 36 | 18 |
| | Pex | 197 | 192 | 234 | 219 | 245 | 226 | 187 | 110 |
| | Q,Pex | 233 | 214 | 251 | 226 | 247 | 220 | 165 | 106 |
| 3.00 | None | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | T | 33 | 26 | 31 | 25 | 32 | 28 | 26 | 15 |
| | Q | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | P | 69 | 57 | 66 | 56 | 67 | 60 | 52 | 28 |
| | Q,T | 30 | 24 | 28 | 24 | 28 | 25 | 22 | 14 |
| | Q,P | 67 | 56 | 64 | 55 | 64 | 58 | 49 | 27 |
| | Pex | 175 | 175 | 214 | 203 | 229 | 222 | 239 | 151 |
| | Q,Pex | 212 | 203 | 245 | 222 | 248 | 232 | 218 | 145 |

**TABLE 3: (%), 60% compliance**

Green indicates those combinations that yielded an infected attack rate < 10%

| ID Factor | | None | ASsd | CTsd | CTsd,ASsd | S | S, ASsd | S,CTsd | ,CTsd,ASs |
|---|---|---|---|---|---|---|---|---|---|
| 0.75 | None | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | T | 4 | 3 | 3 | 2 | 0 | 0 | 0 | 0 |
| | Q | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | P | 7 | 5 | 5 | 5 | 1 | 1 | 1 | 1 |
| | Q,T | 2 | 2 | 2 | 1 | 0 | 0 | 0 | 0 |
| | Q,P | 5 | 4 | 4 | 3 | 1 | 1 | 1 | 1 |
| | Pex | 15 | 13 | 13 | 13 | 5 | 6 | 5 | 5 |
| | Q,Pex | 13 | 12 | 12 | 10 | 6 | 7 | 5 | 5 |
| 1.00 | None | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | T | 10 | 9 | 9 | 9 | 2 | 2 | 1 | 0 |
| | Q | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | P | 26 | 25 | 25 | 23 | 3 | 2 | 1 | 1 |
| | Q,T | 8 | 8 | 8 | 8 | 1 | 1 | 0 | 0 |
| | Q,P | 24 | 23 | 22 | 21 | 3 | 2 | 1 | 1 |
| | Pex | 102 | 90 | 84 | 68 | 12 | 11 | 7 | 7 |
| | Q,Pex | 80 | 69 | 65 | 51 | 10 | 9 | 7 | 7 |
| 1.25 | None | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | T | 13 | 12 | 13 | 12 | 9 | 7 | 2 | 1 |
| | Q | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | P | 36 | 33 | 35 | 32 | 19 | 14 | 4 | 3 |
| | Q,T | 12 | 12 | 12 | 11 | 6 | 5 | 2 | 1 |
| | Q,P | 33 | 32 | 33 | 31 | 15 | 11 | 3 | 3 |
| | Pex | 140 | 136 | 138 | 127 | 45 | 35 | 13 | 12 |
| | Q,Pex | 132 | 127 | 130 | 121 | 31 | 24 | 12 | 11 |
| 1.50 | None | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | T | 16 | 14 | 15 | 14 | 13 | 12 | 8 | 6 |
| | Q | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | P | 41 | 39 | 40 | 38 | 31 | 28 | 15 | 9 |
| | Q,T | 14 | 14 | 14 | 14 | 11 | 10 | 7 | 5 |
| | Q,P | 39 | 38 | 39 | 37 | 29 | 25 | 13 | 8 |
| | Pex | 152 | 146 | 155 | 148 | 119 | 98 | 39 | 27 |
| | Q,Pex | 150 | 147 | 152 | 149 | 96 | 73 | 31 | 24 |
| 2.00 | None | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | T | 19 | 17 | 18 | 17 | 18 | 16 | 15 | 13 |
| | Q | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | P | 47 | 45 | 47 | 44 | 44 | 41 | 37 | 31 |
| | Q,T | 18 | 17 | 17 | 17 | 16 | 15 | 14 | 12 |
| | Q,P | 46 | 44 | 45 | 44 | 42 | 39 | 35 | 30 |
| | Pex | 150 | 147 | 156 | 151 | 169 | 159 | 146 | 123 |
| | Q,Pex | 152 | 149 | 156 | 153 | 163 | 153 | 135 | 114 |
| 2.50 | None | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | T | 21 | 19 | 20 | 19 | 20 | 19 | 18 | 17 |
| | Q | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | P | 51 | 48 | 50 | 48 | 49 | 47 | 45 | 41 |
| | Q,T | 20 | 19 | 19 | 19 | 19 | 18 | 18 | 16 |
| | Q,P | 50 | 48 | 49 | 48 | 48 | 46 | 44 | 41 |
| | Pex | 138 | 138 | 145 | 143 | 169 | 167 | 175 | 165 |
| | Q,Pex | 142 | 141 | 146 | 146 | 170 | 167 | 172 | 164 |
| 3.00 | None | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | T | 22 | 20 | 21 | 20 | 21 | 20 | 20 | 19 |
| | Q | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | P | 53 | 50 | 52 | 50 | 52 | 50 | 50 | 47 |
| | Q,T | 21 | 20 | 21 | 20 | 20 | 20 | 20 | 19 |
| | Q,P | 52 | 50 | 52 | 50 | 51 | 50 | 49 | 46 |
| | Pex | 129 | 129 | 135 | 134 | 160 | 159 | 174 | 172 |
| | Q,Pex | 132 | 133 | 137 | 137 | 164 | 163 | 174 | 171 |

**TABLE 4: (%), 60% compliance, trickle**

Green indicates those combinations that yielded an infected attack rate < 10%

| ID Factor | | None | ASsd | CTsd | CTsd,ASsd | S | S, ASsd | S,CTsd | ,CTsd,ASs |
|---|---|---|---|---|---|---|---|---|---|
| 0.75 | None | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | T | 5 | 5 | 5 | 4 | 2 | 1 | 1 | 1 |
| | Q | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | P | 13 | 12 | 12 | 11 | 4 | 4 | 3 | 3 |
| | Q,T | 4 | 4 | 4 | 3 | 1 | 1 | 1 | 1 |
| | Q,P | 12 | 11 | 11 | 9 | 4 | 4 | 3 | 3 |
| | Pex | 56 | 55 | 51 | 47 | 26 | 26 | 21 | 19 |
| | Q,Pex | 49 | 50 | 48 | 44 | 25 | 24 | 20 | 19 |
| 1.00 | None | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | T | 10 | 10 | 10 | 9 | 5 | 4 | 2 | 2 |
| | Q | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | P | 28 | 26 | 27 | 25 | 11 | 9 | 5 | 5 |
| | Q,T | 9 | 9 | 9 | 8 | 3 | 3 | 2 | 2 |
| | Q,P | 26 | 25 | 25 | 23 | 9 | 8 | 5 | 5 |
| | Pex | 119 | 116 | 118 | 106 | 50 | 46 | 33 | 30 |
| | Q,Pex | 110 | 106 | 105 | 98 | 46 | 43 | 32 | 30 |
| 1.25 | None | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | T | 14 | 13 | 13 | 12 | 10 | 8 | 5 | 4 |
| | Q | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | P | 36 | 34 | 36 | 33 | 23 | 20 | 11 | 9 |
| | Q,T | 12 | 12 | 12 | 11 | 8 | 7 | 4 | 4 |
| | Q,P | 34 | 33 | 34 | 32 | 20 | 17 | 10 | 8 |
| | Pex | 153 | 149 | 154 | 147 | 99 | 88 | 57 | 48 |
| | Q,Pex | 148 | 145 | 147 | 142 | 88 | 76 | 52 | 46 |
| 1.50 | None | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | T | 16 | 15 | 16 | 14 | 13 | 12 | 9 | 7 |
| | Q | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | P | 41 | 39 | 41 | 39 | 34 | 30 | 21 | 17 |
| | Q,T | 15 | 14 | 15 | 14 | 12 | 11 | 8 | 7 |
| | Q,P | 40 | 38 | 39 | 38 | 31 | 28 | 19 | 16 |
| | Pex | 164 | 160 | 166 | 161 | 146 | 135 | 96 | 80 |
| | Q,Pex | 163 | 159 | 168 | 161 | 131 | 121 | 89 | 76 |
| 2.00 | None | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | T | 19 | 17 | 19 | 17 | 18 | 17 | 15 | 13 |
| | Q | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | P | 48 | 45 | 47 | 45 | 44 | 42 | 38 | 33 |
| | Q,T | 18 | 17 | 18 | 17 | 16 | 15 | 14 | 13 |
| | Q,P | 46 | 44 | 46 | 44 | 42 | 40 | 37 | 32 |
| | Pex | 156 | 153 | 163 | 159 | 181 | 174 | 168 | 152 |
| | Q,Pex | 162 | 159 | 166 | 163 | 179 | 172 | 159 | 146 |
| 2.50 | None | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | T | 21 | 19 | 20 | 19 | 20 | 19 | 19 | 17 |
| | Q | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | P | 51 | 48 | 50 | 48 | 50 | 47 | 46 | 42 |
| | Q,T | 20 | 19 | 20 | 19 | 19 | 18 | 18 | 17 |
| | Q,P | 50 | 48 | 49 | 48 | 48 | 46 | 45 | 42 |
| | Pex | 144 | 142 | 150 | 148 | 178 | 176 | 187 | 182 |
| | Q,Pex | 148 | 148 | 155 | 151 | 183 | 179 | 187 | 177 |
| 3.00 | None | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | T | 22 | 20 | 21 | 20 | 21 | 21 | 20 | 19 |
| | Q | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | P | 53 | 51 | 52 | 50 | 52 | 51 | 50 | 47 |
| | Q,T | 21 | 20 | 21 | 20 | 20 | 20 | 20 | 19 |
| | Q,P | 52 | 50 | 52 | 50 | 51 | 50 | 49 | 47 |
| | Pex | 132 | 133 | 138 | 138 | 164 | 165 | 180 | 180 |
| | Q,Pex | 136 | 136 | 142 | 141 | 170 | 171 | 182 | 182 |

# Strategy Combination Table

**Network focused**

**Case based**

| | None | ASsd | CTsd | CTs dASsd | S | S ASsd | S CTsd | S CTs dASsd |
|---|---|---|---|---|---|---|---|---|
| **None** | | | | | | | | |
| **T** | | | | | | | | |
| **Q** | | | | | | | | |
| **P** | | | | | | | | |
| **Q,T** | | | | | | | | |
| **Q,P** | | | | | | | | |
| **Pex** | | | | | | | | |
| **Q,Pex** | | | | | | | | |

All measures shown will be averages of those simulations of 100 that yielded > 1% of the population infected

**T**: antiviral Treatment
**P**: home antiviral Prophylaxis
**Pex**: Extended antiviral Prophylaxis
**Q**: home Quarantine

**ASsd**: Adult & Senior social distancing
**CTsd**: Child & Teen social distancing
**S**: School closure

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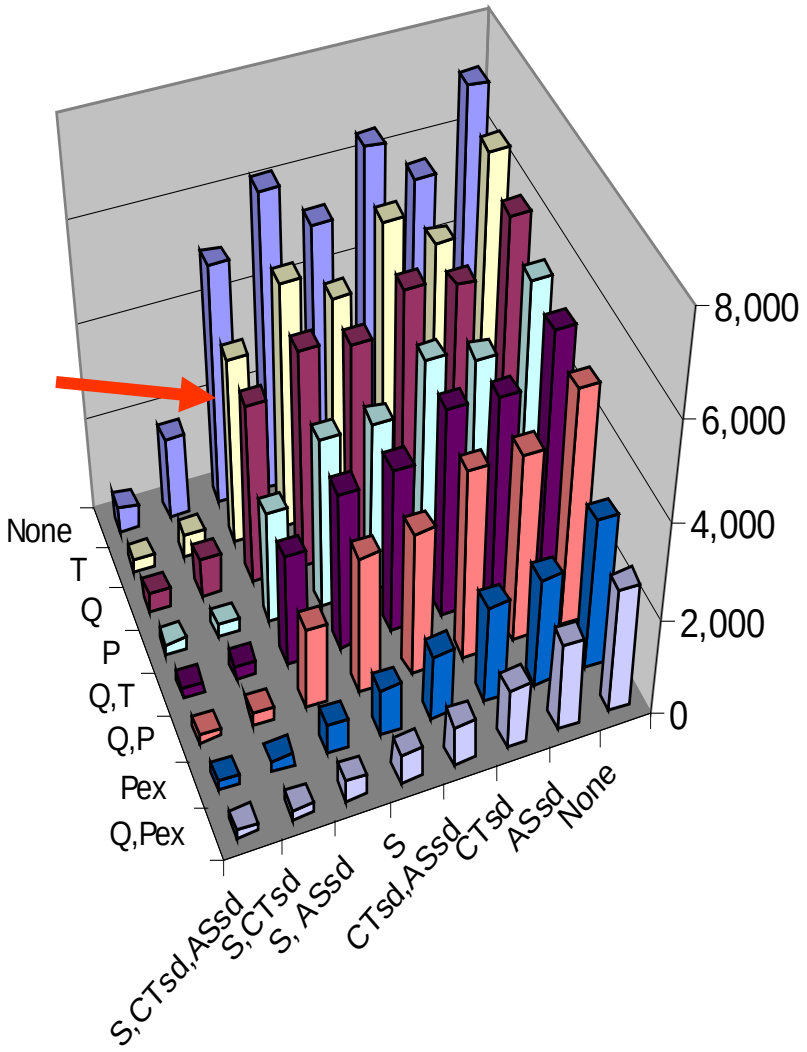
# Total Infected

**ID factor 1.5, Compliance 90%**

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# Infected Attack Rate*

## Network focused

**Case based**

| | None | ASsd | CTsd | CTs dASsd | S | S ASsd | S CTsd | S CTs dASsd |
|---|---|---|---|---|---|---|---|---|
| **None** | 71 | 56 | 65 | 53 | 62 | 50 | 17 | 5 |
| **T** | 66 | 50 | 57 | 45 | 51 | 39 | 4 | 3 |
| **Q** | 60 | 50 | 51 | 44 | 45 | 37 | 8 | 4 |
| **P** | 55 | 43 | 45 | 36 | 35 | 23 | 3 | 2 |
| **Q,T** | 53 | 43 | 43 | 35 | 33 | 23 | 3 | 2 |
| **Q,P** | 49 | 40 | 39 | 30 | 29 | 17 | 2 | 2 |
| **Pex** | 32 | 23 | 20 | 14 | 10 | 6 | 2 | 2 |
| **Q,Pex** | 26 | 18 | 12 | 8 | 6 | 4 | 2 | 2 |

**T**: antiviral Treatment
**P**: home antiviral Prophylaxis
**Pex**: Extended antiviral Prophylaxis
**Q**: home Quarantine

**ASsd**: Adult & Senior social distancing
**CTsd**: Child & Teen social distancing
**S**: School closure

* Infected attack rate is expressed as a percent of total population and is twice the illness attack rate

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# Constraining by Infected Attack Rate

Table colored for Infected Attack Rate < 10% and < 25%

Case based

| | None | ASsd | CTsd | CTs dASsd | S | S ASsd | S CTsd | S CTs dASsd |
|---|---|---|---|---|---|---|---|---|
| **None** | 71 | 56 | 65 | 53 | 62 | 50 | 17 | 5 |
| **T** | 66 | 50 | 57 | 45 | 51 | 39 | 4 | 3 |
| **Q** | 60 | 50 | 51 | 44 | 45 | 37 | 8 | 4 |
| **P** | 55 | 43 | 45 | 36 | 35 | 23 | 3 | 2 |
| **Q,T** | 53 | 43 | 43 | 35 | 33 | 23 | 3 | 2 |
| **Q,P** | 49 | 40 | 39 | 30 | 29 | 17 | 2 | 2 |
| **Pex** | 32 | 23 | 20 | 14 | 10 | 6 | 2 | 2 |
| **Q,Pex** | 26 | 18 | 12 | 8 | 6 | 4 | 2 | 2 |

**T**: antiviral Treatment
**P**: home antiviral Prophylaxis
**Pex**: Extended antiviral Prophylaxis
**Q**: home Quarantine

**ASsd**: Adult & Senior social distancing
**CTsd**: Child & Teen social distancing
**S**: School closure

**Infected attack rate < 10%** **Infected attack rate < 25%**

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# Options without Antivirals

3 Options below 10%, 1 more below 25%

Case based

| | None | ASsd | CTsd | CTs dASsd | S | S ASsd | S CTsd | S CTs dASsd |
|---|---|---|---|---|---|---|---|---|
| **None** | 71 | 56 | 65 | 53 | 62 | 50 | 17 | 5 |
| **T** | 66 | 50 | 57 | 45 | 51 | 39 | 4 | 3 |
| **Q** | 60 | 50 | 51 | 44 | 45 | 37 | 8 | 4 |
| **P** | 55 | 43 | 45 | 36 | 35 | 23 | 3 | 2 |
| **Q,T** | 53 | 43 | 43 | 35 | 33 | 23 | 3 | 2 |
| **Q,P** | 49 | 40 | 39 | 30 | 29 | 17 | 2 | 2 |
| **Pex** | 32 | 23 | 20 | 14 | 10 | 6 | 2 | 2 |
| **Q,Pex** | 26 | 18 | 12 | 8 | 6 | 4 | 2 | 2 |

**T**: antiviral Treatment
**P**: home antiviral Prophylaxis
**Pex**: Extended antiviral Prophylaxis
**Q**: home Quarantine

**ASsd**: Adult & Senior social distancing
**CTsd**: Child & Teen social distancing
**S**: School closure

**Infected attack rate < 10%** **Infected attack rate < 25%**

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# Adding Antivirals*

Segmenting by 4% antiviral coverage (today) and 25% (planned 3rd Q 2007)

**Case based**

| | None | ASsd | CTsd | CTs dASsd | S | S ASsd | S CTsd | S CTs dASsd |
|---|---|---|---|---|---|---|---|---|
| **None** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **T** | 24 | 18 | 21 | 16 | 18 | 14 | 2 | 1 |
| **Q** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **P** | 53 | 43 | 44 | 36 | 35 | 23 | 3 | 2 |
| **Q,T** | 19 | 15 | 16 | 12 | 12 | 8 | 1 | 1 |
| **Q,P** | 50 | 40 | 40 | 31 | 29 | 17 | 2 | 2 |
| **Pex** | 201 | 170 | 165 | 121 | 83 | 54 | 18 | 14 |
| **Q,Pex** | 184 | 143 | 106 | 75 | 51 | 36 | 16 | 14 |

**T**: antiviral Treatment
**P**: home antiviral Prophylaxis
**Pex**: Extended antiviral Prophylaxis
**Q**: home Quarantine

**ASsd**: Adult & Senior social distancing
**CTsd**: Child & Teen social distancing
**S**: School closure

*percent coverage of population (# courses/10000)

**Infected attack rate < 10%**

**Infected attack rate < 25%**

**4% Antiviral coverage**

**25% Antiviral coverage**

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# Constraining Options

Intersecting tables for Infected Attack Rate and Antiviral Courses

**Case based**

| | None | ASsd | CTsd | CTs dASsd | S | S ASsd | S CTsd | S CTs dASsd |
|---|---|---|---|---|---|---|---|---|
| **None** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **T** | 24 | 18 | 21 | 16 | 18 | 14 | 2 | 1 |
| **Q** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **P** | 53 | 43 | 44 | 36 | 35 | 23 | 3 | 2 |
| **Q,T** | 19 | 15 | 16 | 12 | 12 | 8 | 1 | 1 |
| **Q,P** | 50 | 40 | 40 | 31 | 29 | 17 | 2 | 2 |
| **Pex** | 201 | 170 | 165 | 121 | 83 | 54 | 18 | 14 |
| **Q,Pex** | 184 | 143 | 106 | 75 | 51 | 36 | 16 | 14 |

**T**: antiviral Treatment
**P**: home antiviral Prophylaxis
**Pex**: Extended antiviral Prophylaxis
**Q**: home Quarantine

**ASsd**: Adult & Senior social distancing
**CTsd**: Child & Teen social distancing
**S**: School closure

**Infected attack rate < 10%**
**Infected attack rate < 25%**
**4% Antiviral coverage**
**25% Antiviral coverage**

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# Superimposing Adult Days Home*

Adults stay home when sick, tending sick or sent home from school children

**Case based**

| | None | ASsd | CTsd | CTs dASsd | S | S ASsd | S CTsd | S CTs dASsd |
|---|---|---|---|---|---|---|---|---|
| **None** | 3 | 2 | 3 | 2 | 17 | 18 | 28 | 17 |
| **T** | 3 | 2 | 2 | 2 | 19 | 20 | 17 | 12 |
| **Q** | 6 | 5 | 5 | 4 | 22 | 23 | 21 | 15 |
| **P** | 3 | 2 | 2 | 2 | 24 | 25 | 13 | 11 |
| **Q,T** | 6 | 5 | 5 | 4 | 26 | 26 | 13 | 11 |
| **Q,P** | 6 | 5 | 5 | 3 | 27 | 25 | 13 | 11 |
| **Pex** | 2 | 1 | 1 | 1 | 23 | 19 | 12 | 11 |
| **Q,Pex** | 4 | 3 | 2 | 1 | 18 | 15 | 11 | 10 |

**T**: antiviral Treatment
**P**: home antiviral Prophylaxis
**Pex**: Extended antiviral Prophylaxis
**Q**: home Quarantine

**ASsd**: Adult & Senior social distancing
**CTsd**: Child & Teen social distancing
**S**: School closure

*Averaged over entire adult population

**Infected attack rate < 10%**

**Infected attack rate < 25%**

**4% Antiviral coverage**

**25% Antiviral coverage**

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# Pre-Pandemic Vaccine?

7% coverage, 50% efficacy, superposition on Adult Days Home*

**Case based**

| | None | ASsd | CTsd | CTs dASsd | S | S ASsd | S CTsd | S CTs dASsd |
|---|---|---|---|---|---|---|---|---|
| **None** | 3 | 2 | 3 | 2 | 17 | 18 | 25 | 15 |
| **T** | 3 | 2 | 2 | 2 | 20 | 22 | 14 | 11 |
| **Q** | 6 | 5 | 5 | 4 | 23 | 23 | 18 | 14 |
| **P** | 3 | 2 | 2 | 2 | 26 | 25 | 13 | 11 |
| **Q,T** | 5 | 4 | 4 | 3 | 27 | 26 | 13 | 11 |
| **Q,P** | 5 | 4 | 4 | 3 | 26 | 23 | 12 | 10 |
| **Pex** | 2 | 1 | 1 | 1 | 21 | 17 | 11 | 10 |
| **Q,Pex** | 4 | 2 | 1 | 1 | 17 | 14 | 11 | 10 |

**T**: antiviral Treatment
**P**: home antiviral Prophylaxis
**Pex**: Extended antiviral Prophylaxis
**Q**: home Quarantine

**ASsd**: Adult & Senior social distancing
**CTsd**: Child & Teen social distancing
**S**: School closure

*Averaged over entire adult population

**Infected attack rate < 10%**
**Infected attack rate < 25%**
**4% Antiviral coverage**
**25% Antiviral coverage**

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# Interaction with Neighbor Communities?

1 person/day for 120 day period, superposition on Adult Days Home*

**Case based**

| | None | ASsd | CTsd | CTs dASsd | S | S ASsd | S CTsd | S CTs dASsd |
|---|---|---|---|---|---|---|---|---|
| **None** | 3 | 3 | 3 | 2 | 22 | 23 | 33 | 33 |
| **T** | 3 | 2 | 3 | 2 | 24 | 26 | 35 | 33 |
| **Q** | 6 | 5 | 5 | 5 | 27 | 28 | 35 | 34 |
| **P** | 3 | 2 | 2 | 2 | 29 | 30 | 34 | 32 |
| **Q,T** | 6 | 5 | 5 | 4 | 30 | 31 | 34 | 33 |
| **Q,P** | 6 | 5 | 5 | 4 | 32 | 32 | 34 | 33 |
| **Pex** | 2 | 2 | 2 | 1 | 35 | 35 | 33 | 32 |
| **Q,Pex** | 5 | 3 | 3 | 2 | 36 | 35 | 34 | 32 |

**T**: antiviral Treatment
**P**: home antiviral Prophylaxis
**Pex**: Extended antiviral Prophylaxis
**Q**: home Quarantine

**ASsd**: Adult & Senior social distancing
**CTsd**: Child & Teen social distancing
**S**: School closure

*Averaged over entire adult population

**Infected attack rate < 10%**

**Infected attack rate < 25%**

**4% Antiviral coverage**

**25% Antiviral coverage**

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# Sensitivity to Implementation Threshold?

Increase from 10 to 40 diagnosed people, superposition on Adult Days Home*

**Case based**

| | None | ASsd | CTsd | CTs dASsd | S | S ASsd | S CTsd | S CTs dASsd |
|---|---|---|---|---|---|---|---|---|
| **None** | 3 | 2 | 3 | 2 | 15 | 15 | 20 | 16 |
| **T** | 3 | 2 | 3 | 2 | 17 | 17 | 17 | 13 |
| **Q** | 6 | 5 | 5 | 4 | 19 | 19 | 20 | 17 |
| **P** | 3 | 2 | 2 | 2 | 20 | 19 | 15 | 12 |
| **Q,T** | 6 | 5 | 5 | 4 | 21 | 20 | 16 | 14 |
| **Q,P** | 6 | 5 | 5 | 4 | 22 | 21 | 14 | 12 |
| **Pex** | 2 | 2 | 1 | 1 | 21 | 17 | 13 | 12 |
| **Q,Pex** | 4 | 3 | 2 | 2 | 18 | 16 | 13 | 12 |

**T**: antiviral Treatment
**P**: home antiviral Prophylaxis
**Pex**: Extended antiviral Prophylaxis
**Q**: home Quarantine

**ASsd**: Adult & Senior social distancing
**CTsd**: Child & Teen social distancing
**S**: School closure

*Averaged over entire adult population

**Infected attack rate < 10%**

**Infected attack rate < 25%**

**4% Antiviral coverage**

**25% Antiviral coverage**

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# Sensitivity to Compliance?

Decrease from 90% to 60% compliance, superposition on Adult Days Home*

**Case based**

| | None | ASsd | CTsd | CTs dASsd | S | S ASsd | S CTsd | S CTs dASsd |
|---|---|---|---|---|---|---|---|---|
| **None** | 3 | 3 | 3 | 3 | 16 | 17 | 20 | 22 |
| **T** | 3 | 3 | 3 | 3 | 18 | 19 | 26 | 29 |
| **Q** | 7 | 6 | 7 | 6 | 20 | 20 | 23 | 24 |
| **P** | 3 | 3 | 3 | 3 | 21 | 22 | 28 | 25 |
| **Q,T** | 6 | 6 | 6 | 6 | 23 | 23 | 29 | 30 |
| **Q,P** | 6 | 6 | 6 | 6 | 24 | 25 | 30 | 25 |
| **Pex** | 2 | 2 | 2 | 2 | 31 | 29 | 21 | 18 |
| **Q,Pex** | 5 | 5 | 5 | 5 | 32 | 26 | 19 | 17 |

!

**T**: antiviral Treatment
**P**: home antiviral Prophylaxis
**Pex**: Extended antiviral Prophylaxis
**Q**: home Quarantine

**ASsd**: Adult & Senior social distancing
**CTsd**: Child & Teen social distancing
**S**: School closure

*Averaged over entire adult population

**Infected attack rate < 10%**
**Infected attack rate < 25%**
**4% Antiviral coverage**
**25% Antiviral coverage**

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# Sensitivity to Disease Manifestation?

Longini-like influenza manifestation, superposition on Adult Days Home*

**Case based**

| | None | ASsd | CTsd | CTs dASsd | S | S ASsd | S CTsd | S CTs dASsd |
|---|---|---|---|---|---|---|---|---|
| **None** | 5 | 4 | 5 | 4 | 25 | 26 | 46 | 24 |
| **T** | 4 | 3 | 4 | 3 | 30 | 32 | 23 | 15 |
| **Q** | 8 | 6 | 7 | 6 | 33 | 34 | 34 | 23 |
| **P** | 4 | 3 | 3 | 3 | 39 | 38 | 18 | 14 |
| **Q,T** | 7 | 6 | 5 | 4 | 42 | 37 | 18 | 15 |
| **Q,P** | 7 | 6 | 5 | 4 | 42 | 35 | 18 | 13 |
| **Pex** | 3 | 2 | 2 | 1 | 32 | 25 | 15 | 13 |
| **Q,Pex** | 5 | 3 | 2 | 1 | 25 | 20 | 15 | 13 |

**T**: antiviral Treatment
**P**: home antiviral Prophylaxis
**Pex**: Extended antiviral Prophylaxis
**Q**: home Quarantine

**ASsd**: Adult & Senior social distancing
**CTsd**: Child & Teen social distancing
**S**: School closure

*Averaged over entire adult population

**Infected attack rate < 10%**
**Infected attack rate < 25%**
**4% Antiviral coverage**
**25% Antiviral coverage**

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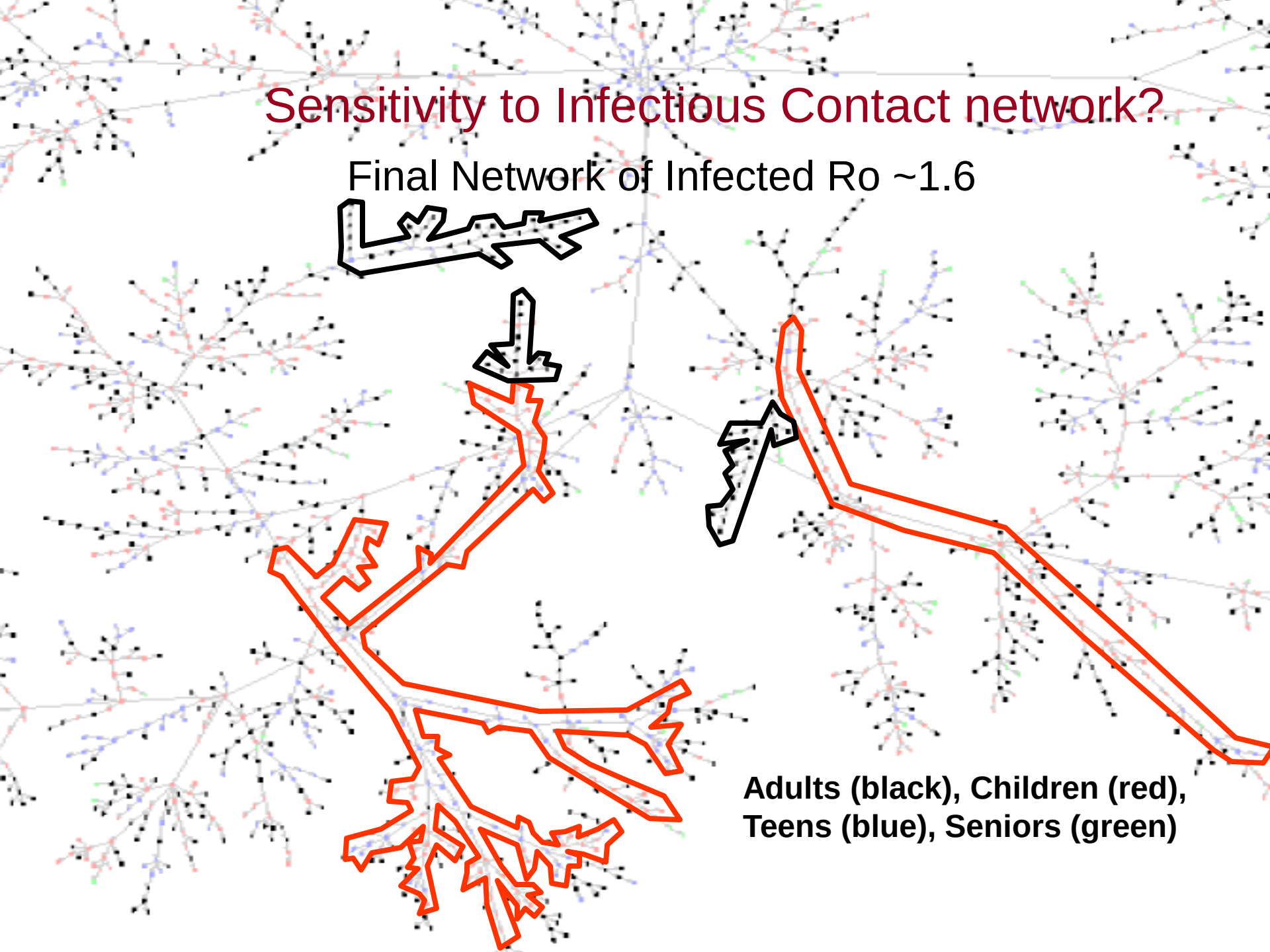
# Sensitivity to Infectious Contact network?

Final Network of Infected Ro ~1.6



**Adults (black), Children (red), Teens (blue), Seniors (green)**

# Adults, Children & Teens on Par?

Identical Infectivity/susceptibility and contacts/day, on Adult Days Home*

**Case based**

| | None | ASsd | CTsd | CTs dASsd | S | S ASsd | S CTsd | S CTs dASsd |
|---|---|---|---|---|---|---|---|---|
| **None** | 4 | 3 | 3 | 2 | 18 | 23 | 23 | 20 |
| **T** | 3 | 2 | 3 | 2 | 21 | 30 | 29 | 13 |
| **Q** | 6 | 4 | 6 | 3 | 25 | 30 | 29 | 17 |
| **P** | 3 | 2 | 3 | 1 | 26 | 22 | 29 | 12 |
| **Q,T** | 6 | 3 | 6 | 2 | 28 | 22 | 28 | 12 |
| **Q,P** | 6 | 3 | 6 | 2 | 29 | 19 | 25 | 11 |
| **Pex** | 2 | 1 | 2 | 0 | 26 | 14 | 17 | 11 |
| **Q,Pex** | 4 | 1 | 3 | 1 | 22 | 13 | 15 | 11 |

**T**: antiviral Treatment
**P**: home antiviral Prophylaxis
**Pex**: Extended antiviral Prophylaxis
**Q**: home Quarantine

**ASsd**: Adult & Senior social distancing
**CTsd**: Child & Teen social distancing
**S**: School closure

*Averaged over entire adult population

**Infected attack rate < 10%**

**Infected attack rate < 25%**

**4% Antiviral coverage**

**25% Antiviral coverage**

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# Summary Points & Policy Implications

**From Current Model Results:**

- **Social distancing forms a foundation** for effective community containment
  - Alone it may be able to hold a pandemic at bay
  - In combination with case based strategies (all of which are less effective alone) lost work days can be decreased
  - But strategies must be implemented **quickly** and with **high compliance**

  **Policy Implication:** Planning, education, and training must be designed for the effective implementation of social distancing measures ***first*** and case based strategies ***second***.

- **Pre-pandemic vaccination** at current levels (7% coverage and 50% efficacy) does not significantly influence the spread.

  **Policy Implication:** Pre-pandemic vaccine at such low levels should be used to keep critical people on the job. *Caveat: Targeted vaccination scenarios in progress

- **Influx from neighboring communities** reduces effectiveness of community containment strategies and increases the time strategies must be vigilantly applied.

  **Policy Implication:** A uniform national policy could reduce this time for all.

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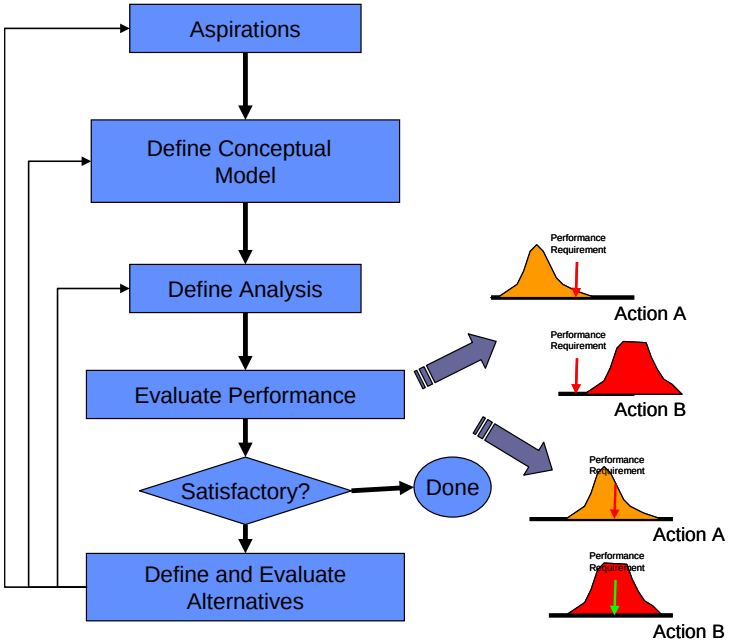
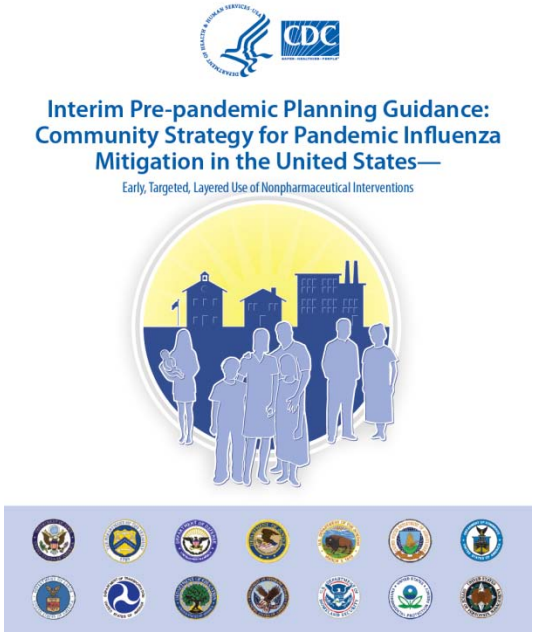
# Uncertainty Evaluation & Reduction

- Disease manifestation
  - Infectivity relation, visible vs invisible infected
  - Aerosol? Surfaces? (influences contact network definition too)
- Social contact network
  - Sub group network: structured to fully mixed
  - Groups: augmented and relative importance (households, neighborhoods/extended families, schools, work, clubs, church, public transportation, etc)
  - Consider situations of critical interest (College campuses, military reservations, high rises…)
  - Collect & incorporate contact network data
  - Instantiation from community data (refined Ferguson & Longini)
- Incorporate Reactive Agent Behavior (social modeling)
- Refine analysis in response to evolving constraints and changes in uncertainty

# Leading to…




**10's of millions of runs later we had the answers to**:

- What is the best mitigation strategy combination? (***choice***)
- How robust is the combination to model assumptions and uncertainty? (***robustness of choice***)
- What is required for the choice to be most effective? (***evolving towards resilience***)

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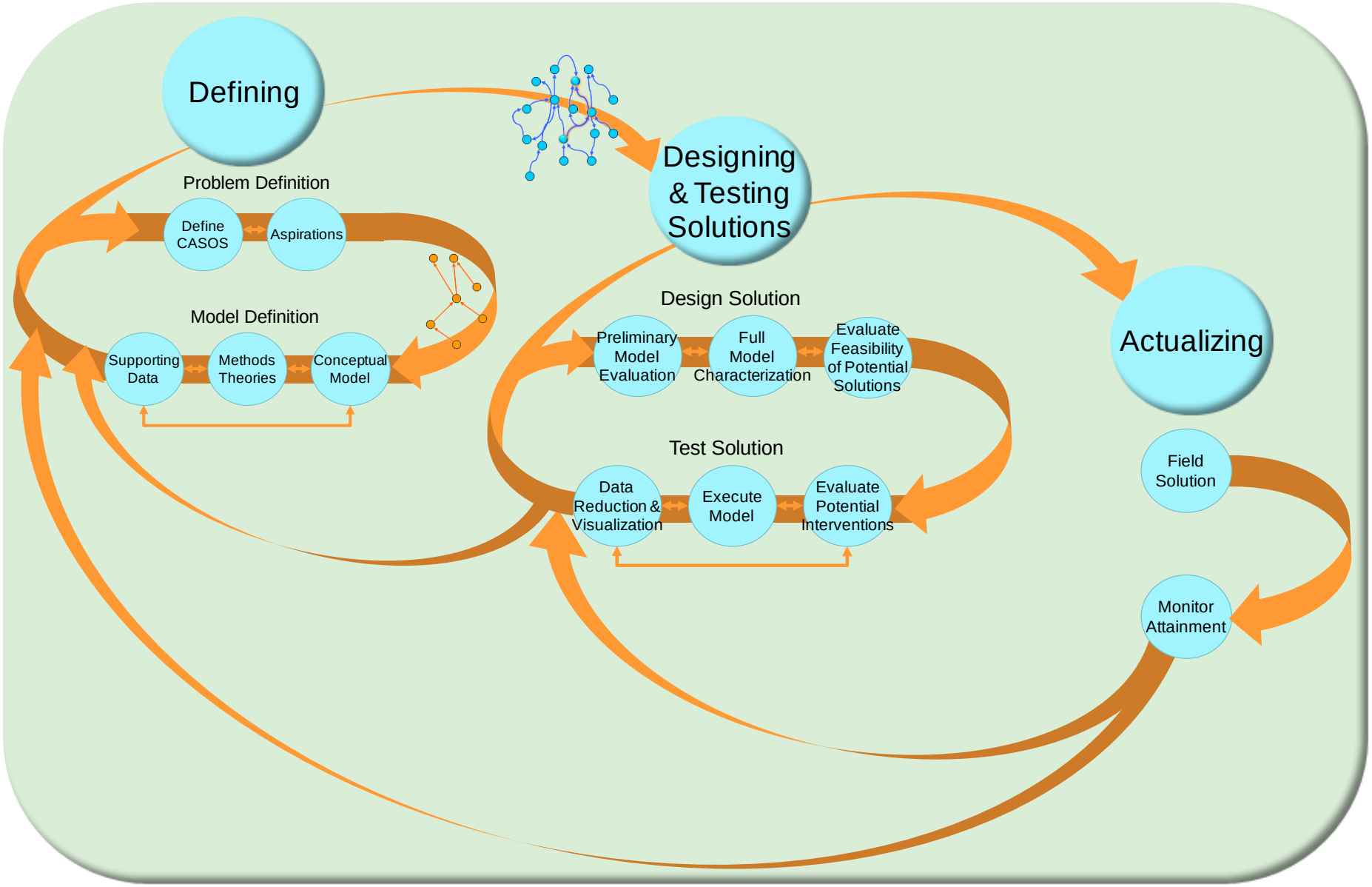
# CASoS Engineering Framework Components

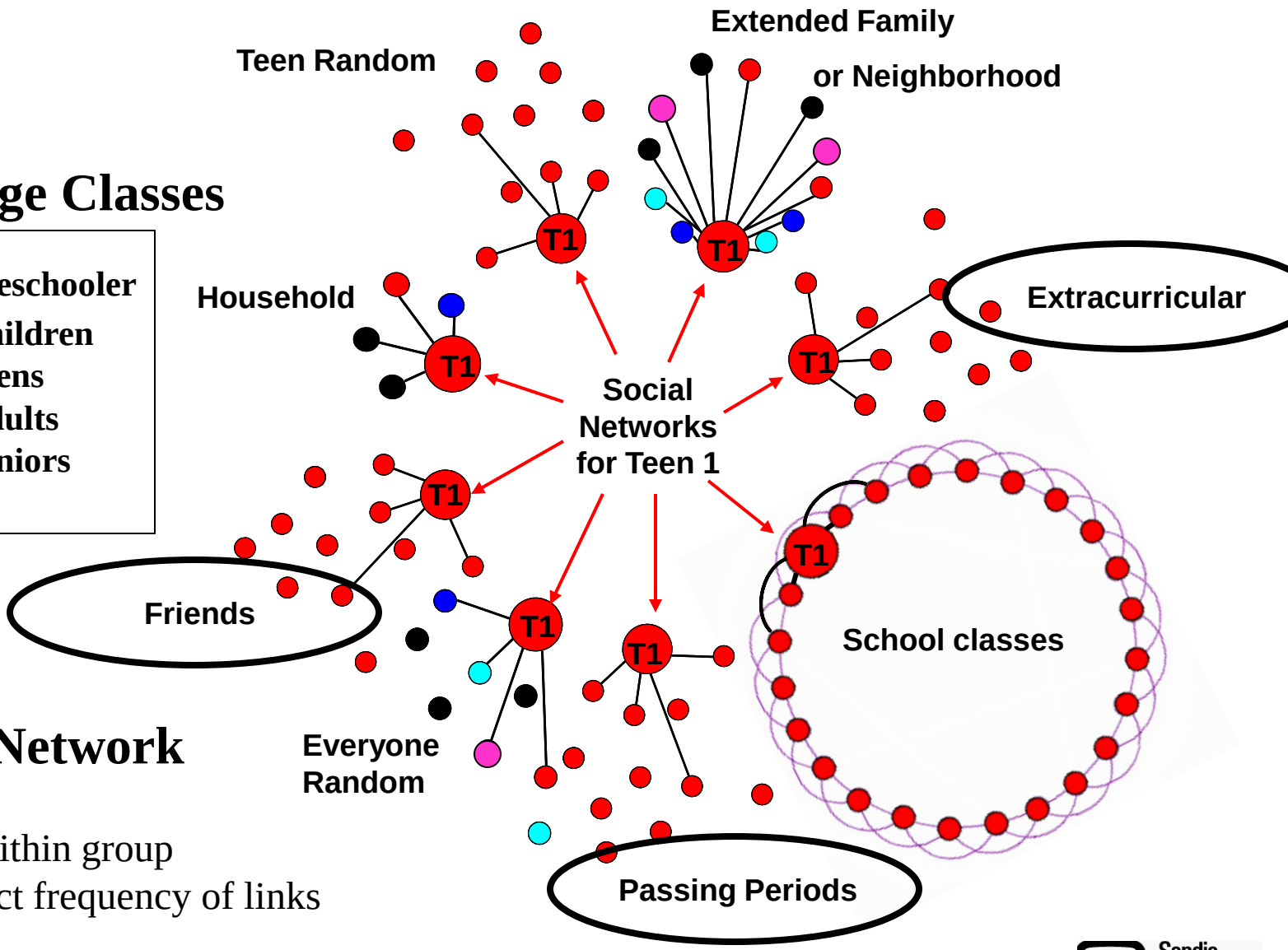


# Back-up
# Extra & Old slides

# Example Teen

## Agent Age Classes

- Preschooler
- Children
- Teens
- Adults
- Seniors




## Social Network

Groups

Links within group

Contact frequency of links

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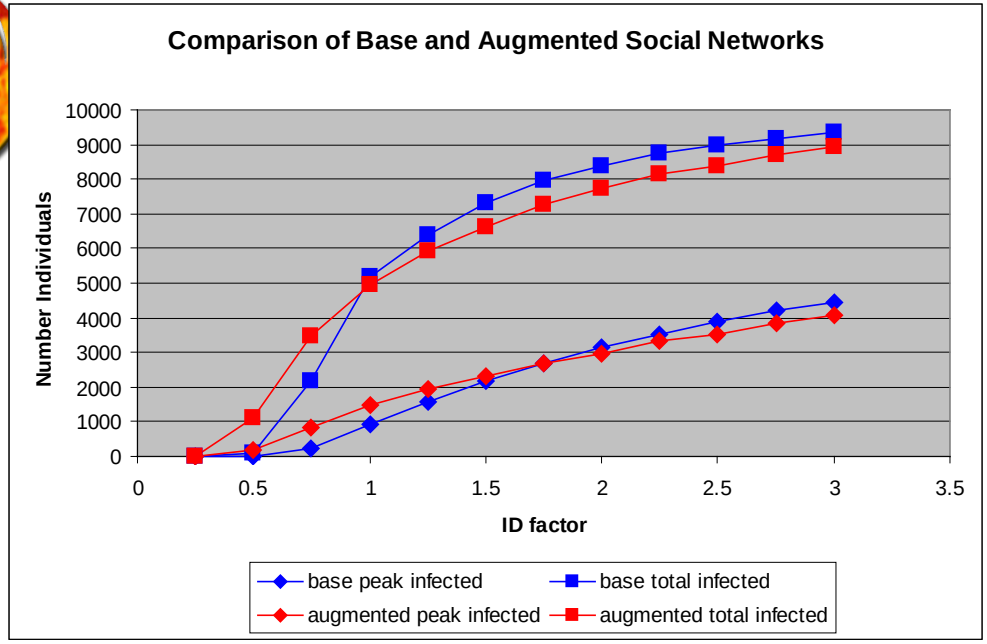
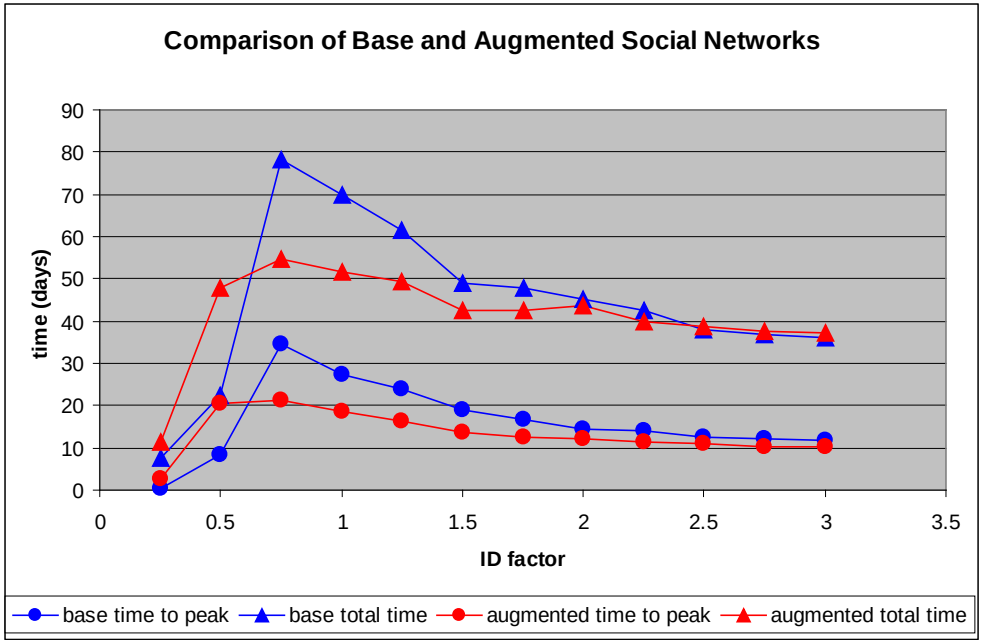
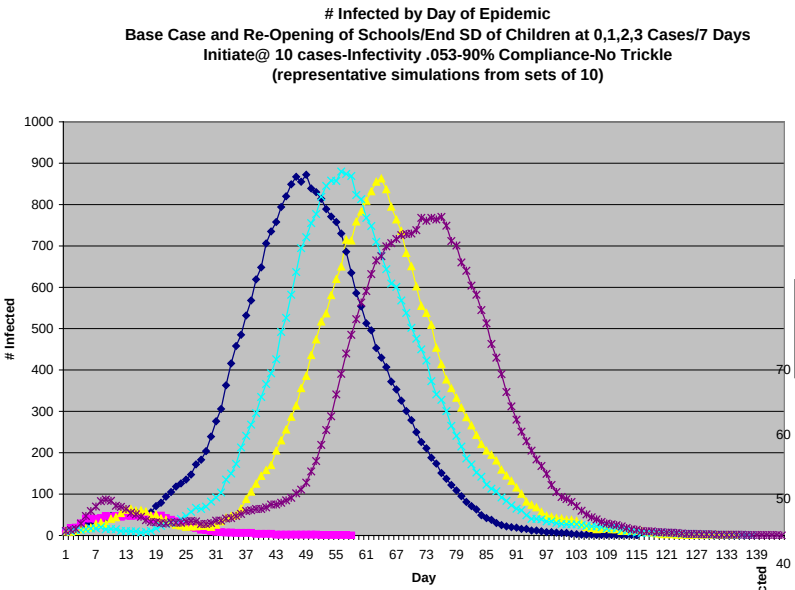

Comparison of Base and Augmented Social Networks
Number Individuals
10000
9000
8000
7000
6000
5000
4000
3000
2000
1000
0
0
0.5
1
1.5
2
2.5
3
3.5
ID factor
base peak infected
base total infected
augmented peak infected
augmented total infected

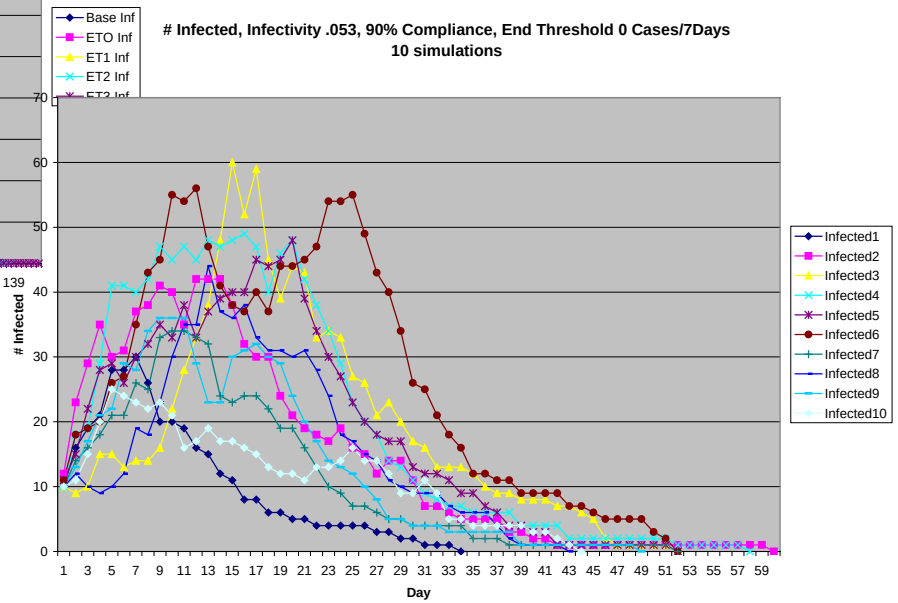

Comparison of Base and Augmented Social Networks
time (days)
90
80
70
60
50
40
30
20
10
0
0
0.5
1
1.5
2
2.5
3
3.5
ID factor
base time to peak
base total time
augmented time to peak
augmented total time

# What if we re-open the schools?

With Victoria Davey, VA

0, 1, 2, 3 new infections in 7 day period

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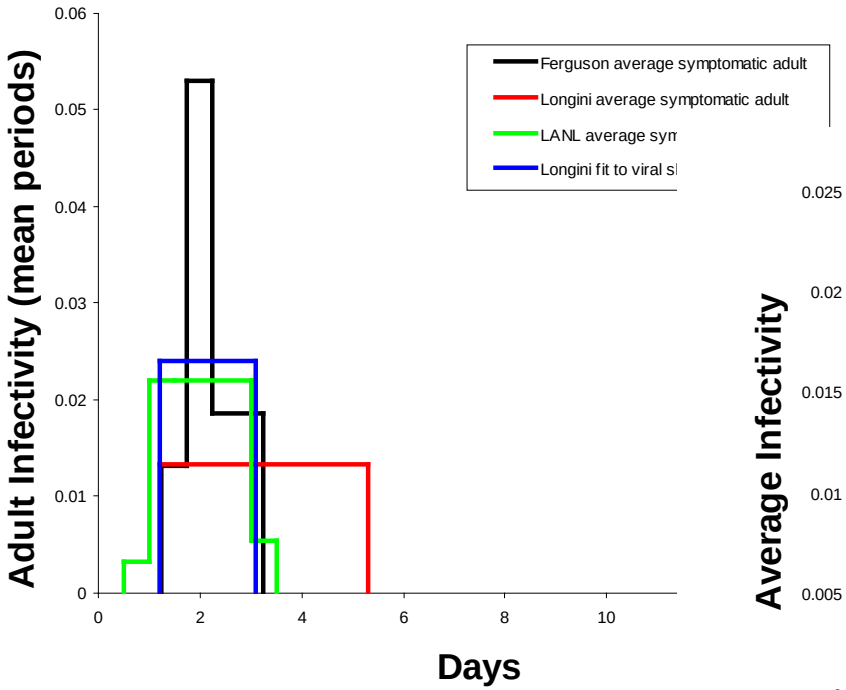
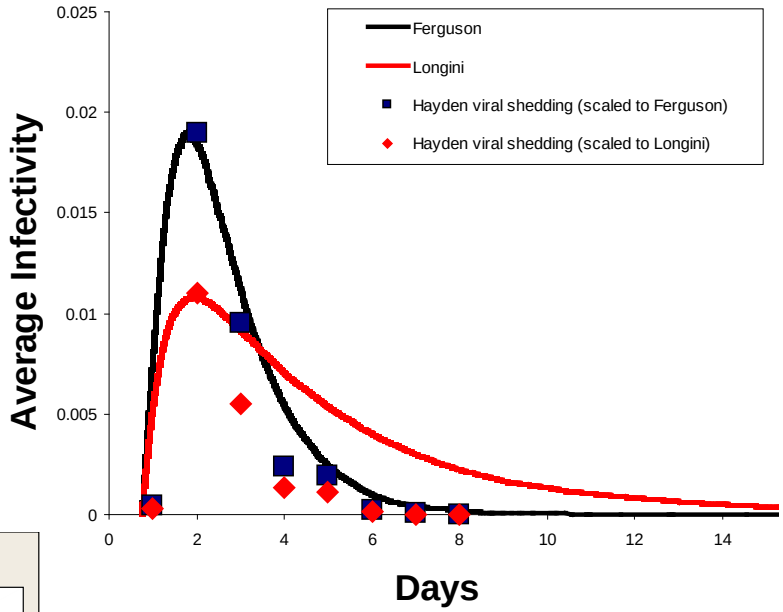
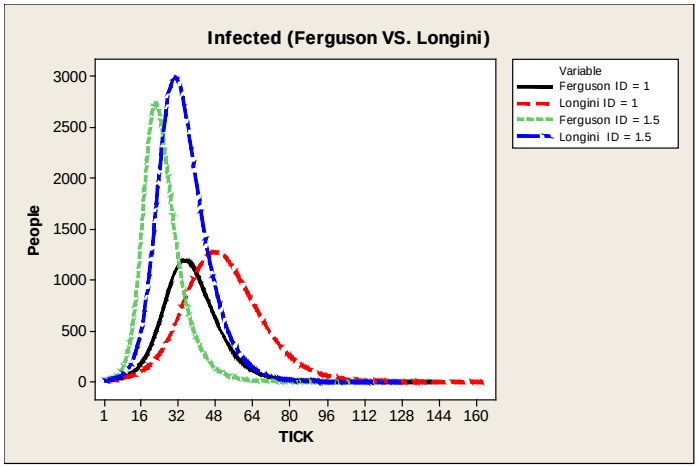
# Longini-like Vs Ferguson-like

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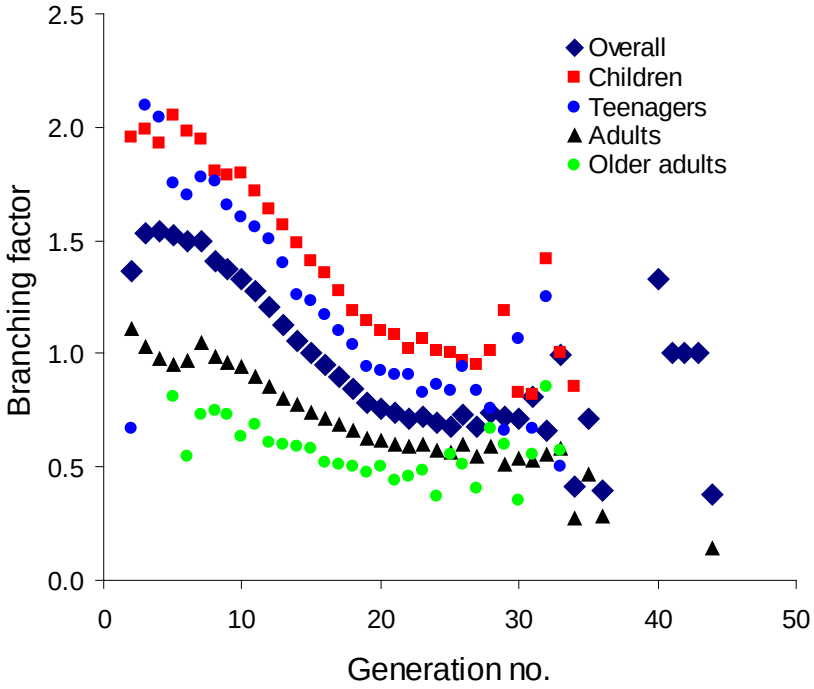
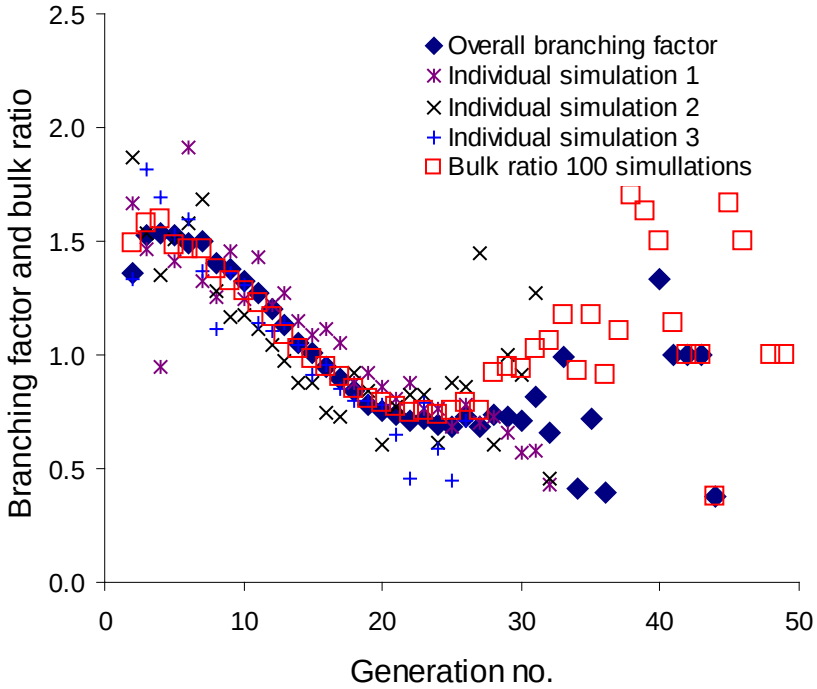
# Branching Factors




Ro ~ bulk ratio ~ 1.6

Ro ~ 1.5- 1.7 ~ 1957-58 pandemic

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# Infectious Contact Fractions

| | To Children | To Teenagers | To Adults | To Seniors | Total From |
|---|---|---|---|---|---|
| **From Children** | 18.6 | 2.9 | 16.1 | 1.2 | 38.8 |
| **From Teenagers** | 2.4 | 9.1 | 8.0 | 0.6 | 20.1 |
| **From Adults** | 6.0 | 3.8 | **26.0** | 2.1 | 38.0 |
| **From Seniors** | 0.2 | 0.2 | 0.9 | 1.8 | 3.1 |
| **Total To** | 27.3 | 16.0 | 50.9 | 5.8 | |

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# Building Strategies

| | | | Averages for simulations with epidemics | | | |
|---|---|---|---|---|---|---|
| | Number Sims | # of Epidemics | Total Infected | Total Time (days) | Peak Infected | Time to Peak (days) |
| **Case 1: Base Case Pandemic Influenza** | | | | | | |
| Average | **1000** | 978 | 5018 | 82 | 703 | 36 |
| **TARGETED SOCIAL DISTANCING STRATEGIES** | | | | | | |
| **Case 2: Schools closed after 10 symptomatic detected, Compliance 90%** | | | | | | |
| Average | 100 | 99 | 3916 | 114 | 329 | 48 |
| **% reduction from base case** | | | 22% | -39% | 53% | -34% |
| **Case 3: Schools closed after 10 symptomatic detected, non-school contacts doubled, Compliance 90%** | | | | | | |
| Average | 100 | 95 | 5898 | 79 | 894 | 35 |
| **% reduction from base case** | | | -18% | 4% | -27% | 2% |
| **Case 4: Schools closed after 10 symptomatic, children/teens kept home, household contacts doubled, Compliance 90%** | | | | | | |
| Average | 100 | 93 | 361 | 62 | 45 | 17 |
| **% reduction from base case** | | | 93% | 25% | 94% | 52% |
| **Case 5: Schools closed after 10 symptomatic, children/teens kept home, household contacts doubled, Compliance 50%** | | | | | | |
| Average | 100 | 95 | 1630 | 141 | 94 | 49 |
| **% reduction from base case** | | | 68% | -72% | 87% | -36% |
| **Case 6: Children's schools closed after 10 symptomatic, children kept home, household contacts doubled, Compliance 90%** | | | | | | |
| Average | 100 | 96 | 2642 | 120 | 206 | 51 |
| **% reduction from base case** | | | 47% | -46% | 71% | -40% |
| **Case 7: All symptomatic stay at home, Compliance 90%** | | | | | | |
| Average | 100 | 94 | 3926 | 95 | 433 | 43 |
| **% reduction from base case** | | | 22% | -16% | 38% | -20% |

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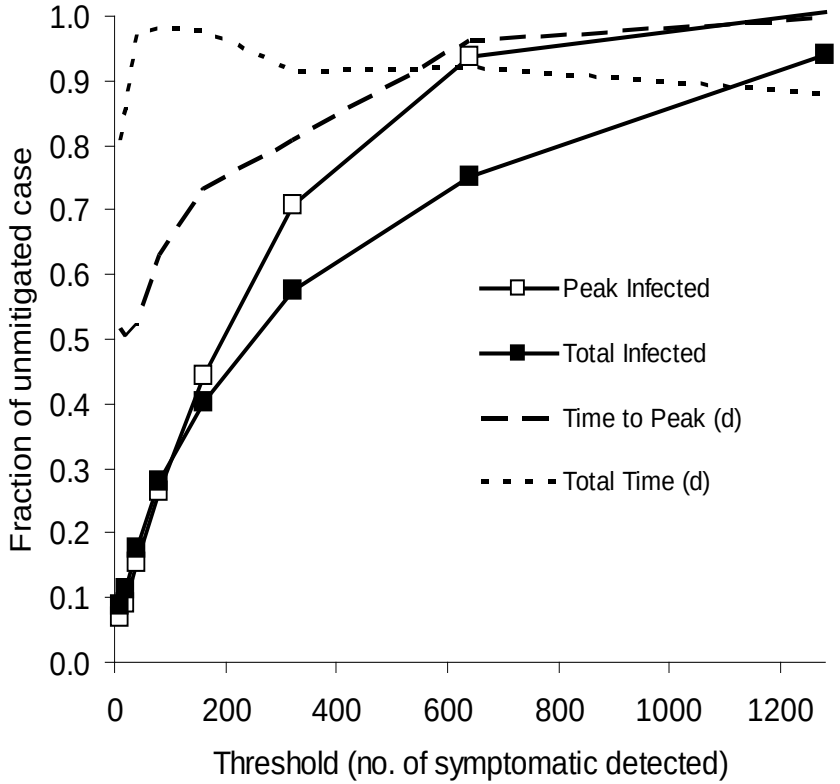
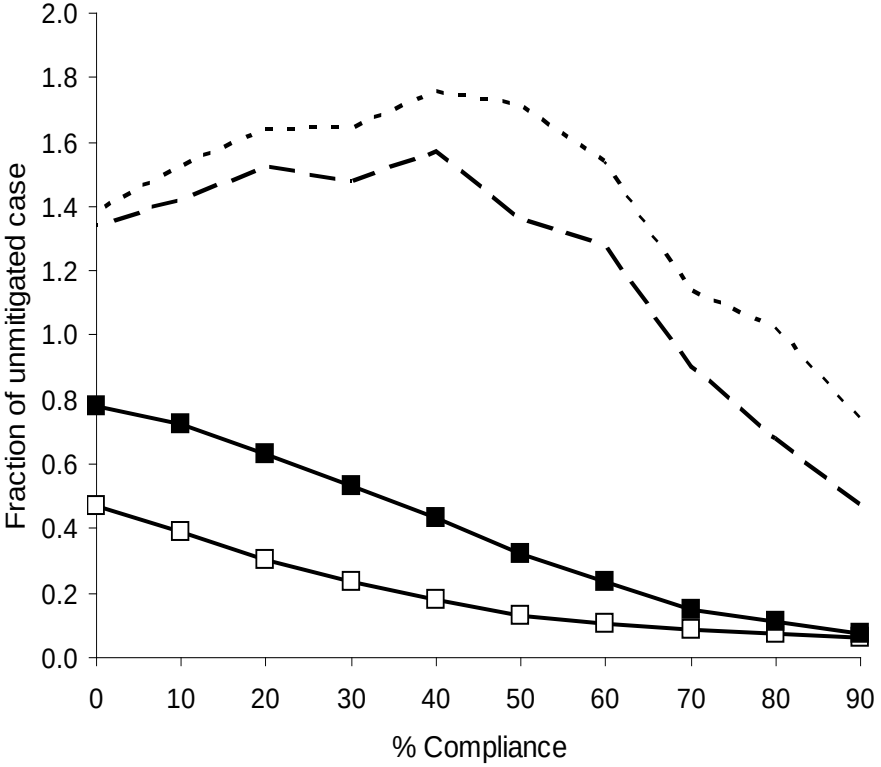
# Threshold and Compliance

Threshold




Compliance




Only Schools closed

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# 5 Social Distancing Strategies

| | |
|---|---|
| ***S*** | School closure, contact frequency within schools reduced by 90%, household contacts doubled |
| ***CTsd*** | Children and Teenagers social distancing, contact frequencies of all non-household and non-school groups reduced by 90%, household contacts doubled |
| ***ASsd*** | Adult and Senior social distancing, contact frequencies of all non-household and non-work groups reduced by at 90%, household contacts doubled |
| ***LL*** | Liberal Leave, all children and teens and 90% of adults withdraw to the home when symptomatic |
| ***Wsd*** | Work social distancing, contact frequency within work groups reduced by 50%. |

# Strategy Matrix Results

**Base Case**

| # | Strategy combination S | KTsd | ASsd | LL | Wsd | *Infectivity Factor* 1 | 1.25 | 1.5 | 2 |
|---|---|---|---|---|---|---|---|---|---|
| 1 | | | | | | 51 | 66 | 75 | 86 |
| 2 | | | | | Wsd | 48 | 63 | 72 | 84 |
| 3 | | | | LL | | 41 | 57 | 67 | 79 |
| 4 | | | | LL | Wsd | 39 | 55 | 65 | 78 |
| 5 | | | ASsd | | | 38 | 51 | 59 | 70 |
| 6 | | | ASsd | | Wsd | 35 | 48 | 56 | 66 |
| 7 | | | ASsd | LL | | 32 | 46 | 55 | 66 |
| 8 | | | ASsd | LL | Wsd | 30 | 43 | 52 | 63 |
| 9 | | KTsd | | | | 41 | 58 | 69 | 82 |
| 10 | | KTsd | | | Wsd | 37 | 55 | 66 | 79 |
| 11 | | KTsd | | LL | | 29 | 48 | 60 | 75 |
| 12 | | KTsd | | LL | Wsd | 27 | 45 | 57 | 72 |
| 13 | | KTsd | ASsd | | | 29 | 46 | 56 | 68 |
| 14 | | KTsd | ASsd | | Wsd | 26 | 42 | 52 | 64 |
| 15 | | KTsd | ASsd | LL | | 22 | 39 | 51 | 64 |
| 16 | | KTsd | ASsd | LL | Wsd | 20 | 37 | 48 | 61 |
| 17 | S | | | | | 41 | 61 | 73 | 85 |
| 18 | S | | | | Wsd | 36 | 57 | 70 | 83 |
| 19 | S | | | LL | | 23 | 47 | 62 | 78 |
| 20 | S | | | LL | Wsd | 19 | 44 | 59 | 76 |
| 21 | S | | ASsd | | | 26 | 47 | 59 | 74 |
| 22 | S | | ASsd | | Wsd | 20 | 41 | 55 | 70 |
| 23 | S | | ASsd | LL | | 11 | 35 | 51 | 68 |
| 24 | S | | ASsd | LL | Wsd | 9 | 32 | 47 | 65 |
| 25 | S | KTsd | | | | 4 | 26 | 50 | 73 |
| 26 | S | KTsd | | | Wsd | 3 | 15 | 40 | 68 |
| 27 | S | KTsd | | LL | | 2 | 7 | 29 | 60 |
| 28 | S | KTsd | | LL | Wsd | 2 | 6 | 20 | 54 |
| 29 | S | KTsd | ASsd | | | 2 | 4 | 13 | 44 |
| 30 | S | KTsd | ASsd | | Wsd | 2 | 3 | 7 | 30 |
| 31 | S | KTsd | ASsd | LL | | 2 | 3 | 9 | 34 |
| 32 | S | KTsd | ASsd | LL | Wsd | 2 | 3 | 6 | 25 |

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# Preliminary Results

Highly Infectious Influenza, a bit worse than 1918, Ro ~ 2.4

Low Compliance (50-60%)

High Compliance (90%)

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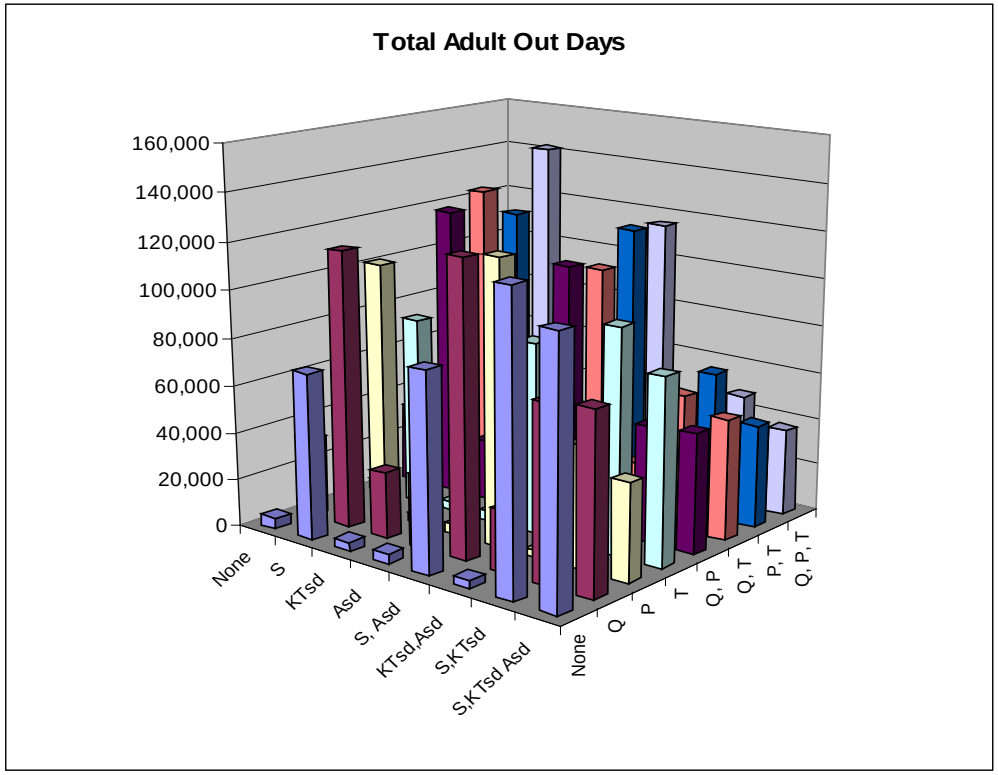
# Preliminary Results

Highly Infectious Influenza, a bit worse than 1918, Ro ~ 2.4




Low Compliance (50-60%)

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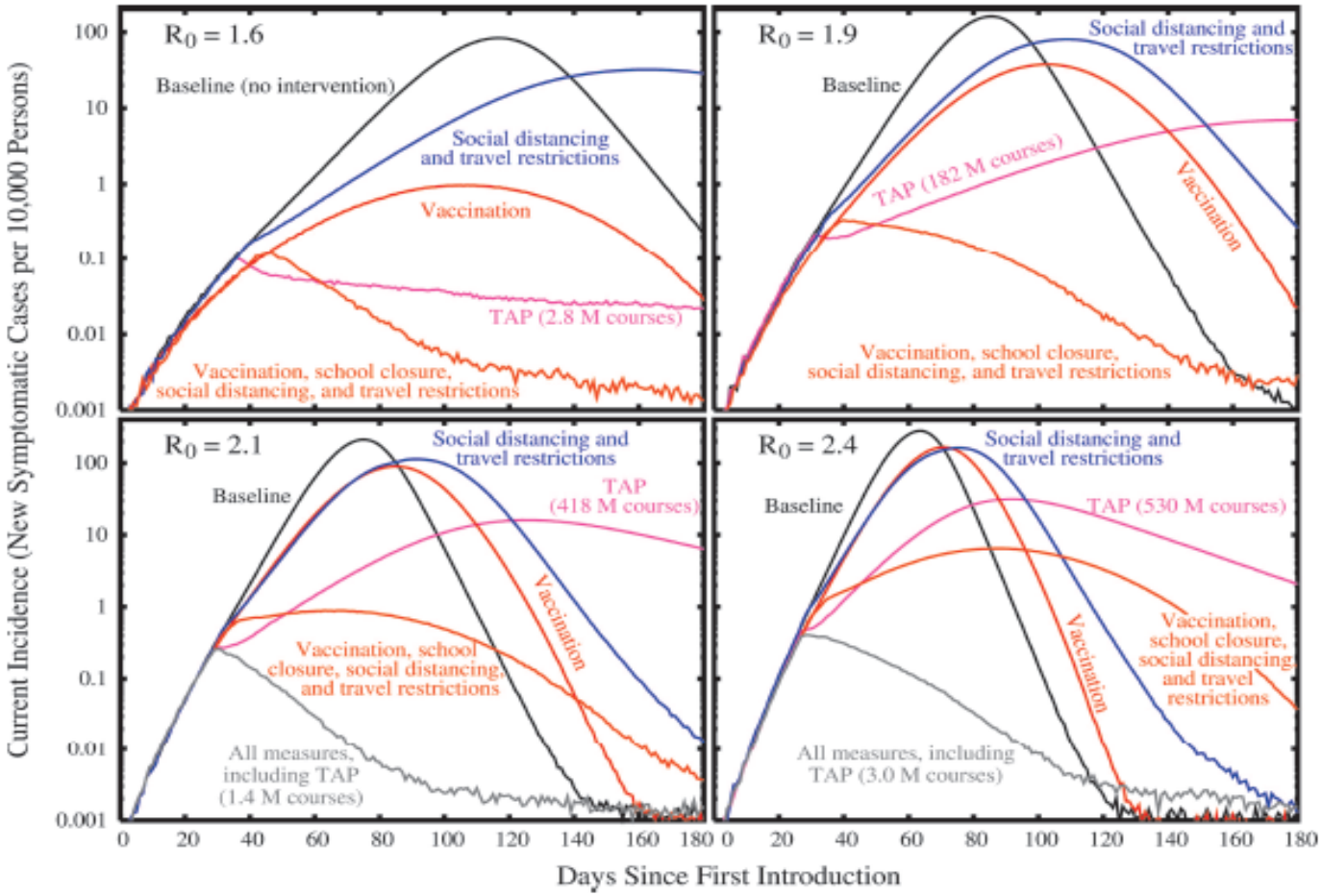
# Germann et al. PNAS

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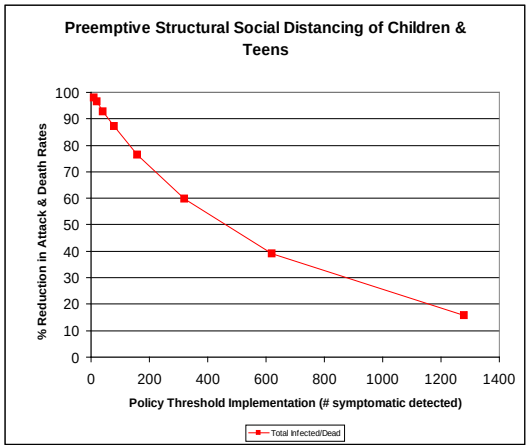
# Local Mitigation Strategies for Pandemic Influenza

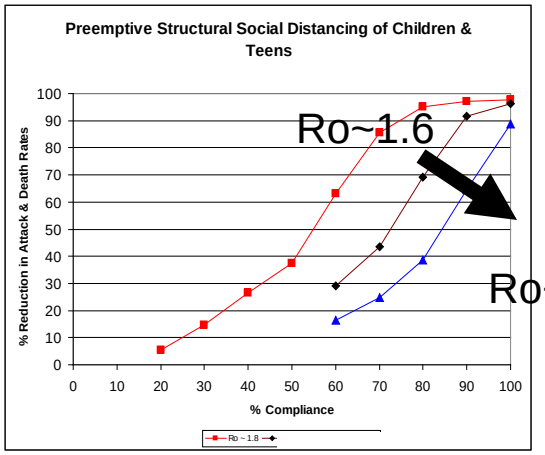
***Target zones of high infectious contact: Children & Teens***

*Best Social Distancing Strategy:* Close the schools, send Children & Teens home and keep them there

Threshold




Compliance




Increasing Infectivity Somewhat Erodes Effectiveness (black arrow)

All points represent an average of 100 simulations

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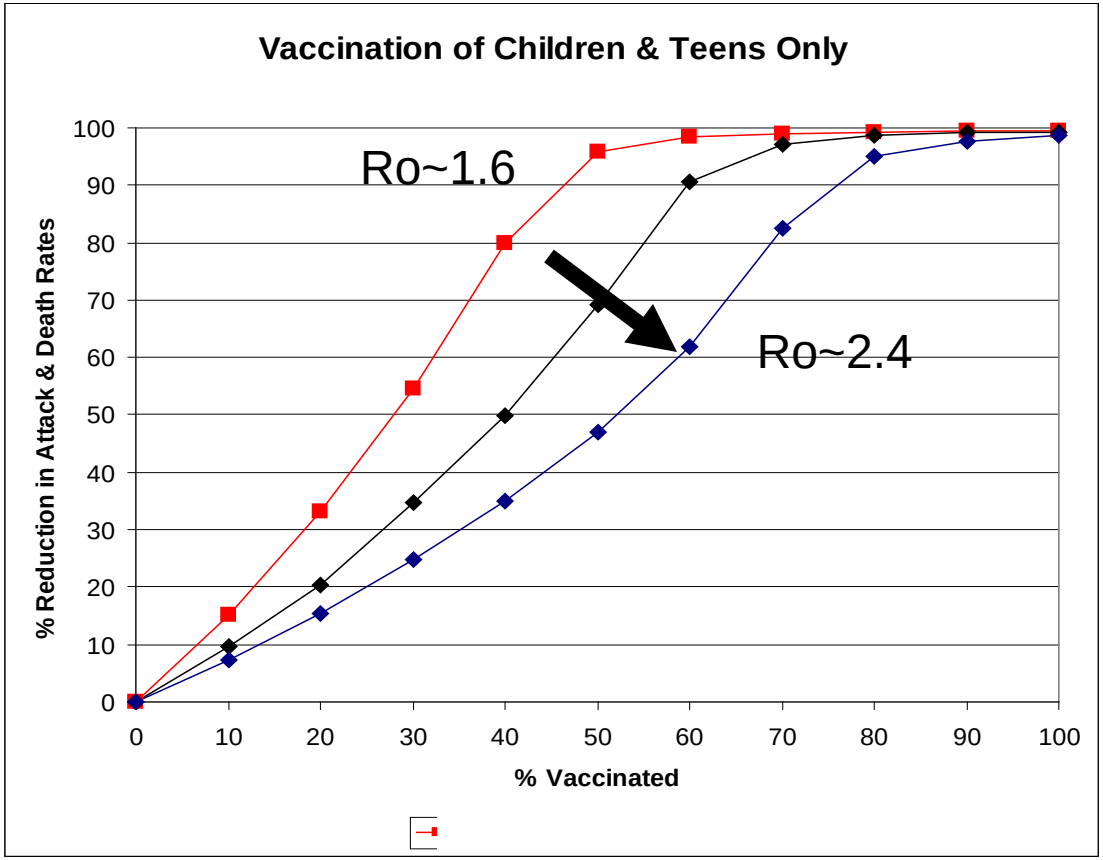
# Vaccination when Vaccine Available

*Best Vaccination Strategy:* Children and Teens first




Increasing Infectivity Somewhat Erodes Effectiveness (black arrow)

All points represent an average of 100 simulations

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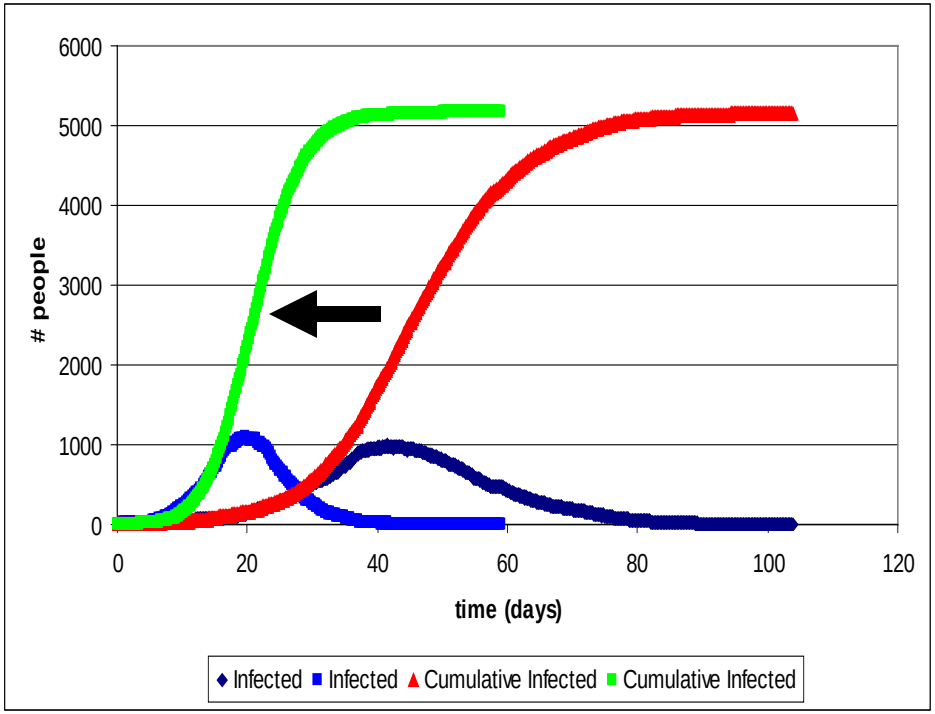
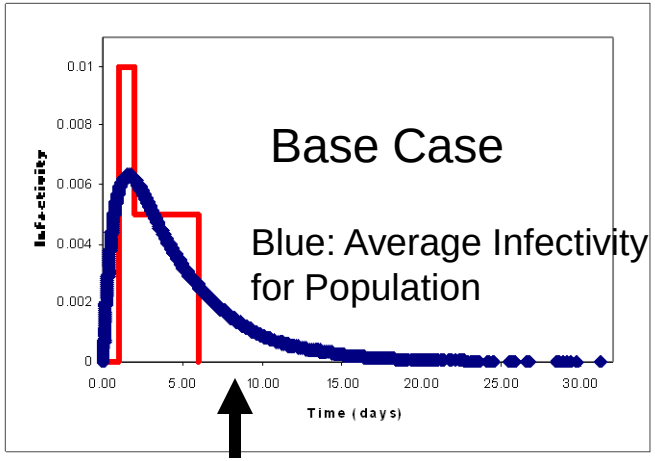
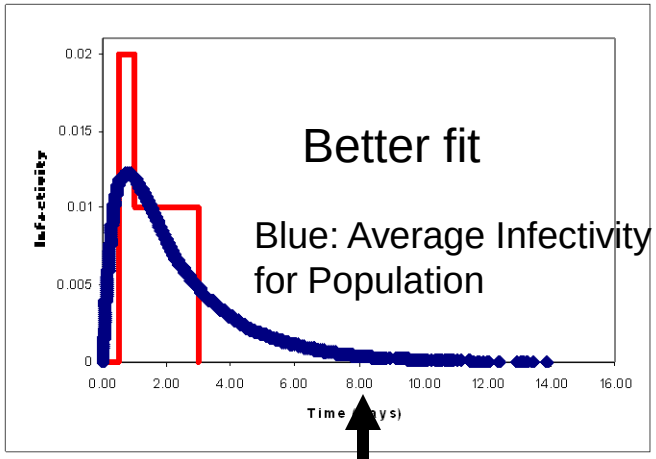
# Better representation of viral shedding Data?

We won't know until virus erupts but if it was exactly like normal flu:




8 days




8 days

To fit we must 1) Reduce disease state time periods by half and 2) Increase $I_D$ by 2

-Yields identical attack rates but with time scale halved (black arrow above)

*No influence on effectiveness of mitigation strategies*

Refer to previous slide with data from Tamiflu site

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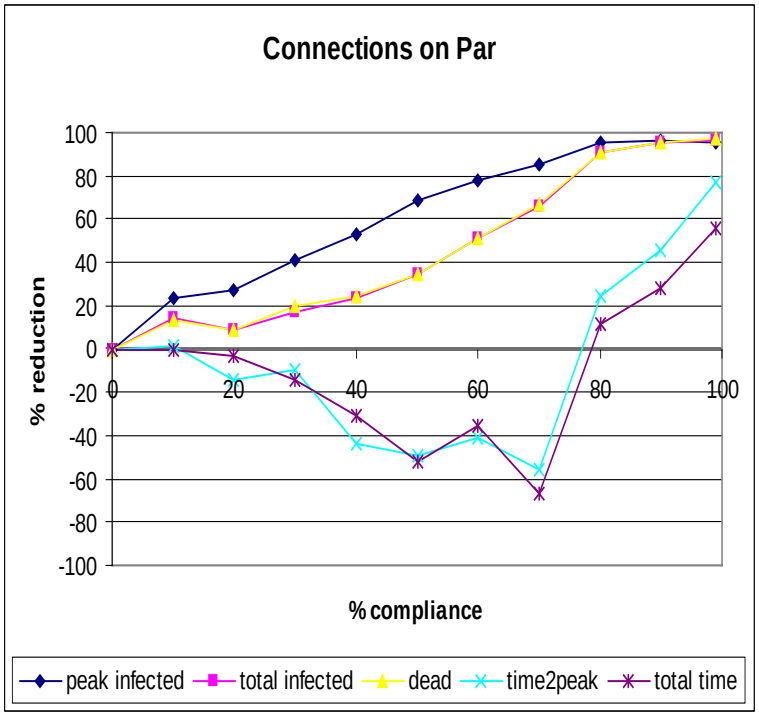
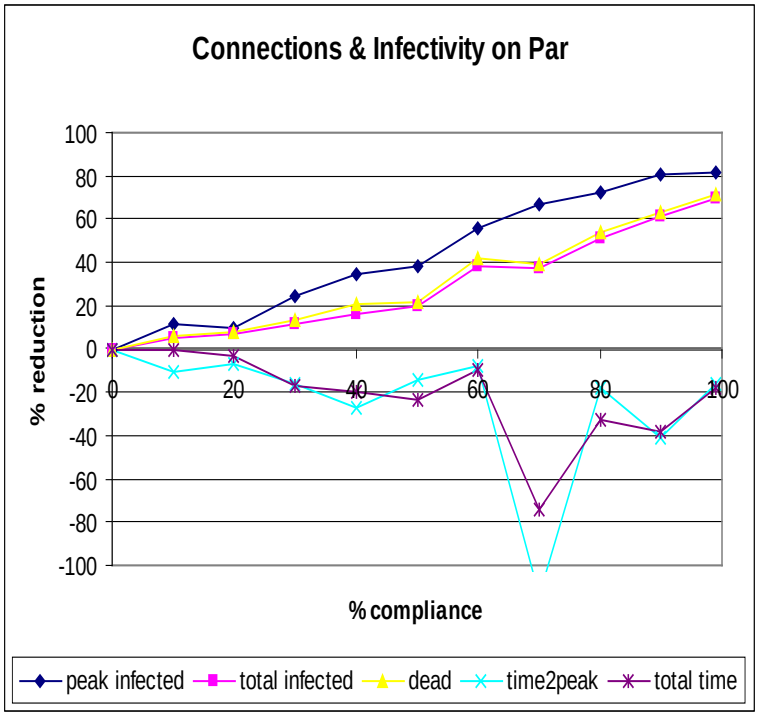
# Putting Adults, Children and Teens on Par

While our baseline social contact network and age class relative infectivity seems reasonable, they emphasize children & teens. What if we remove this emphasis?




Increase Adult work connections by factor of 4 to put on par:
Slight erosion of Effectiveness

All relative infectivity removed:
~30% erosion in Effectiveness

**Note, all points are an average of 10 simulations, hence they are a bit noisy**

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# Past and Ongoing

- Initial development of Loki-Infection December 2004.
- High school science project Winter 2005, 4th place in INTEL International Science and Engineering Fair.
- Participation in FAST Avian Influenza Analysis for Jon MacLaren DHS, November-December 2005.
- Glass, R.J., L.M. Glass, W.E. Beyeler, Local Mitigation Strategies for Pandemic Influenza, submitted for publication December 2005.
- Further application/development pending Funding from Pandemic Influenza Initiative at DHS

# Outline

- **Brief Overview** of model assumptions, base case unmitigated results (see Glass et al (2005, 2006) for details), and strategy implementation.

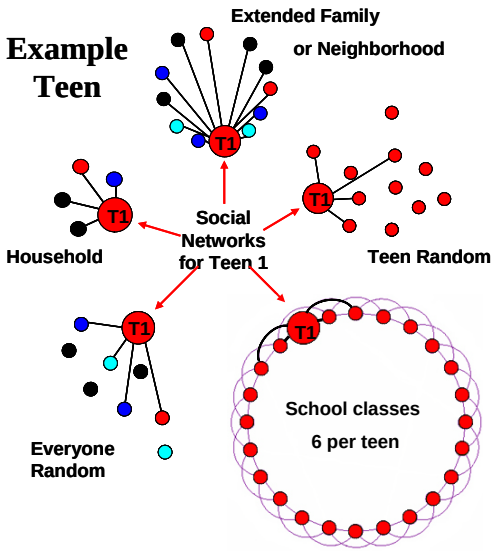
- **Pull from current results to address**:
  - What community containment strategy combinations are effective?
  - How do constraints limit options?
  - What about Pre-pandemic vaccine?
  - Interaction with neighboring communities?
  - How sensitive are results to implementation threshold? Compliance? Disease manifestation (Ferguson vs Longini)?
  - Sensitivity of results to the infectious contact network?

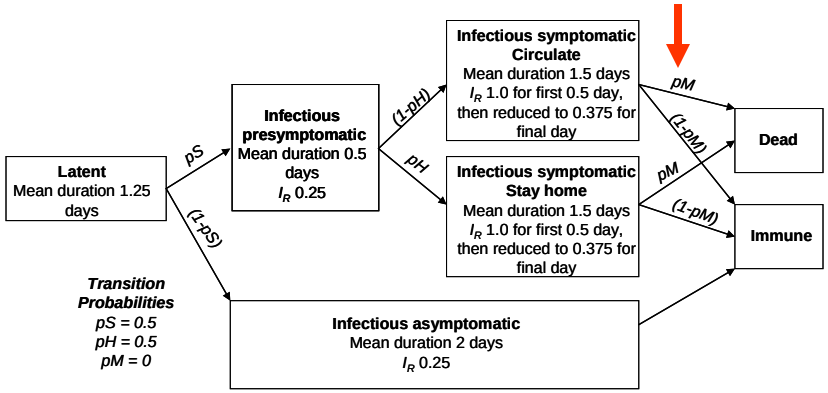
- **Summary Points & Policy Implications**

- **Ongoing: Uncertainty Evaluation and Reduction**

# Networked Agent-Based Model

- **Explicit social contact network, current:**
  - Stylized US community of 10000 (Census, 2000)
  - Agents: Child18%, Teen11%, Adult 59%, Senior 12%
  - Groups with explicit sub networks: Households, school classes, businesses, neighborhoods/extended families, clubs, senior gatherings, random
  - Household adult stays home to tend sick or sent home from school children in the family
- **Influenza disease manifestation, current:**
  - scaled normal flu, (Ferguson-like, ~viral shedding)
  - *pSymptomatic* = 0.5, *pHome* = *pDiagnosis* = 0.8
  - Children 1.5 and Teens 1.25 times more infectious & susceptible than adults & seniors
  - Added 7 day recovery period for symptomatic (ill)




**For Details see:**
***Local Mitigation Strategies for Pandemic Influenza***, Robert J. Glass, Laura M. Glass, and Walter E. Beyeler, SAND-2005-7955J (December 21, 2005).
***Targeted Social Distancing Design for Pandemic Influenza***, Robert J. Glass, Laura M. Glass, Walter E. Beyeler, and H. Jason Min, *Emerging Infectious Diseases* November, 2006).

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