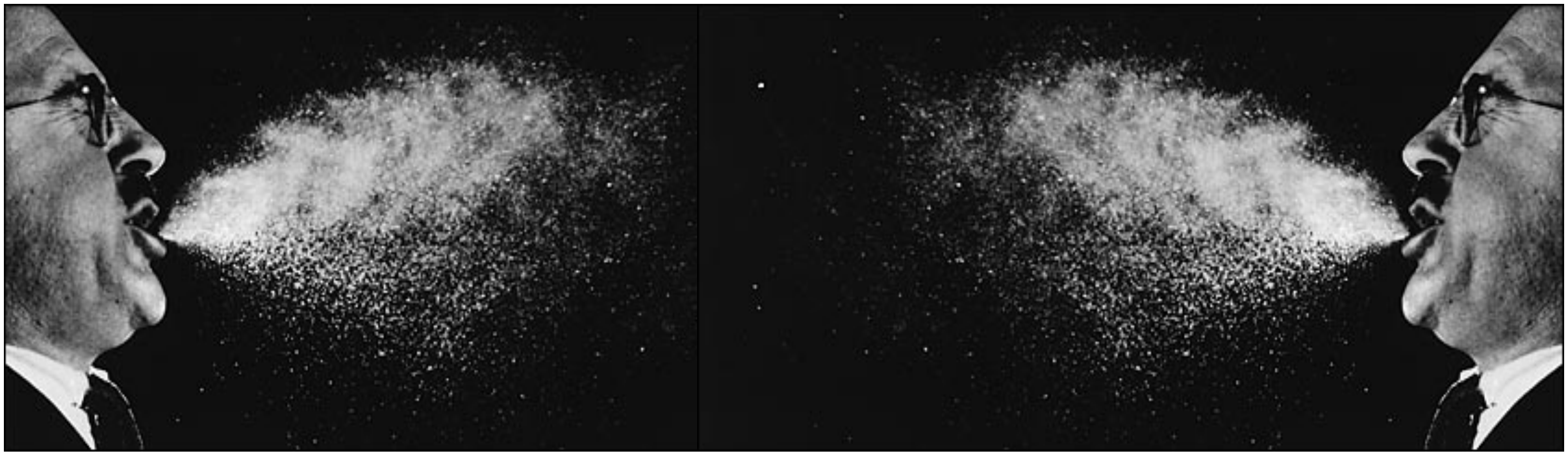
Presentation to the AMORS IX

Planning and Response Resources for Infectious Disease



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Infectious Disease Worldwide

- **Infectious disease/outbreaks are common and deadly, because of:**
  - Increased worldwide population density, travel and transfer of goods.
- **Infectious disease/outbreaks are a source of major instability in developing and undeveloped countries, because:**
  - Relative decline in healthcare in many countries.
- **Developed countries are at great risk from new bio-threats, natural or engineered,because:**
  - Developed countries operate more optimally and are therefore less robust.
  - Responses to new biothreats, unlike nuclear threats, are complicated by background of common threats and by advances in *dual-use* medical research.

Leading Infectious Causes of Death Worldwide

Cause	Rank	1993 rank	~Number of Deaths
Respiratory infections	1	1	3,871,000
HIV/AIDS	2	7	2,866,000
Diarrheal diseases	3	2	2,001,000
Tuberculosis	4	3	1,644,000
Malaria	5	4	1,124,000
Measles	6	5	745,000
Pertussis	7	7	285,000
Tetanus	8	**12**	282,000
Meningitis	9	8	173,000
Syphilis	10	**11**	167,000

Source: WHO, 2002

Infrastructure Impact and Dependency

Dependency matrix - Critical Infrastructure Protection Task Force of Canada

Sector	Element	Electrical Power (Greatest Impact)	Water Purification	Sewage Treatment	Natural Gas	Oil Industry	Customs and Immigration	Hospital & Health Care Services	Food Industry
		Energy & Utilities					Services		
Energy & Utilities	Electrical Power		L			M			
	Water Purification	H				M			
	Sewage Treatment	M	H			H			
	Natural Gas	L				L			
	Oil Industry	H	L						
Services	Customs & Immigration	H	L	L	L	L		L	
	Hospital & Health Care Services (Greatest Dependency)	H	H	L	H	H	M		H
	Food Industry	H	H	H	L	M	M	L	

KEY: H High, M Medium, L Low

- Because workers are required to support all systems, high dependency of health care is a problem.
- Not evaluated is workforce impact - as might be drastically reduced by a failure of the health care system.

See Grenier, Jacques. "The Challenge of CIP Interdependencies". *Conference on the Future of European Crisis Management* (Uppsala, 19–21 March 2001). http://www.ntia.doc.gov/osmhome/cip/workshop/ciptf_files/frame.htm.

Operational Response to Infectious Disease

Approach:

- Capture primary impact - disease progression
- Capture secondary/tertiary effects - e.g, mission readiness

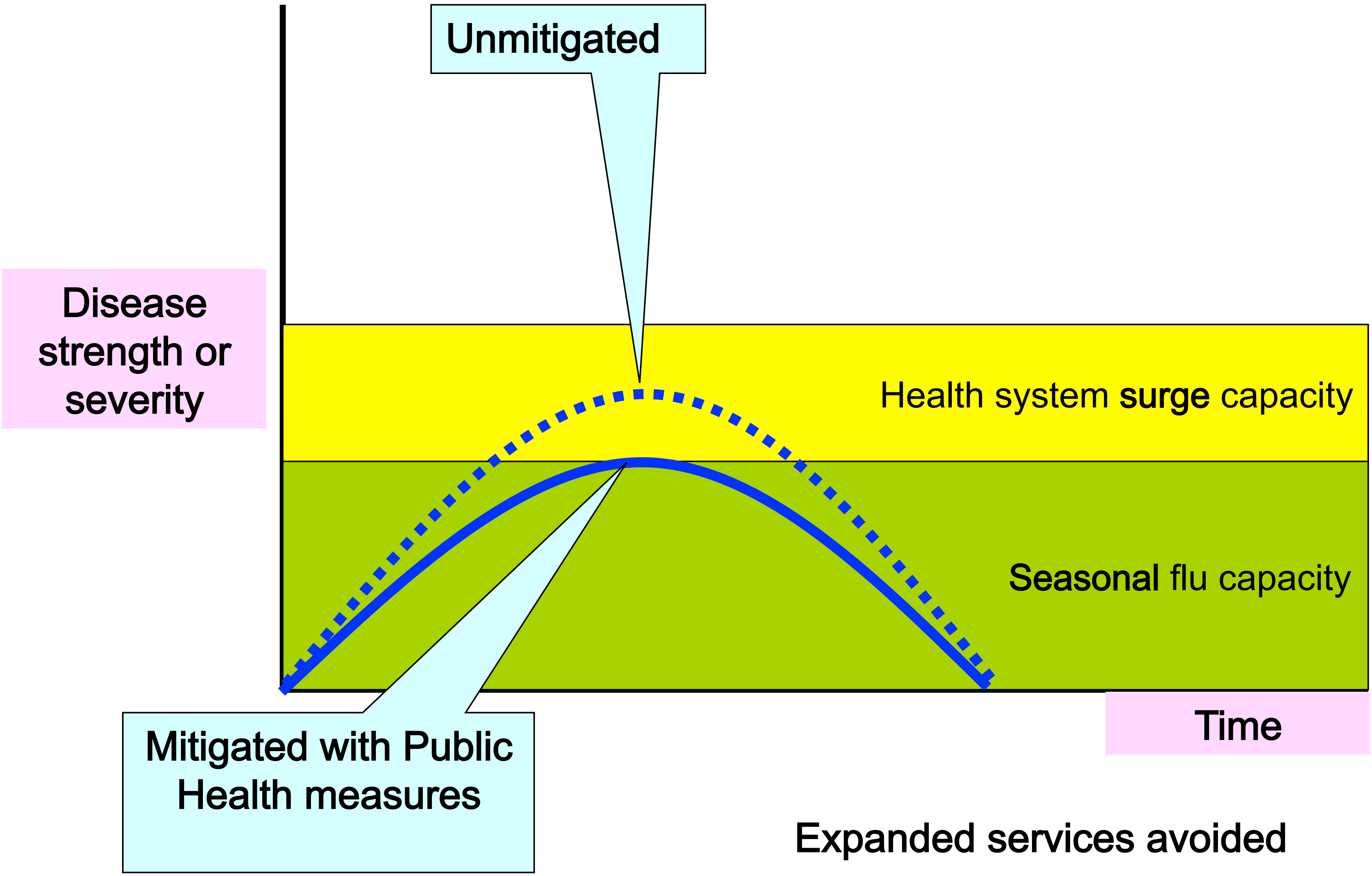
Goal:

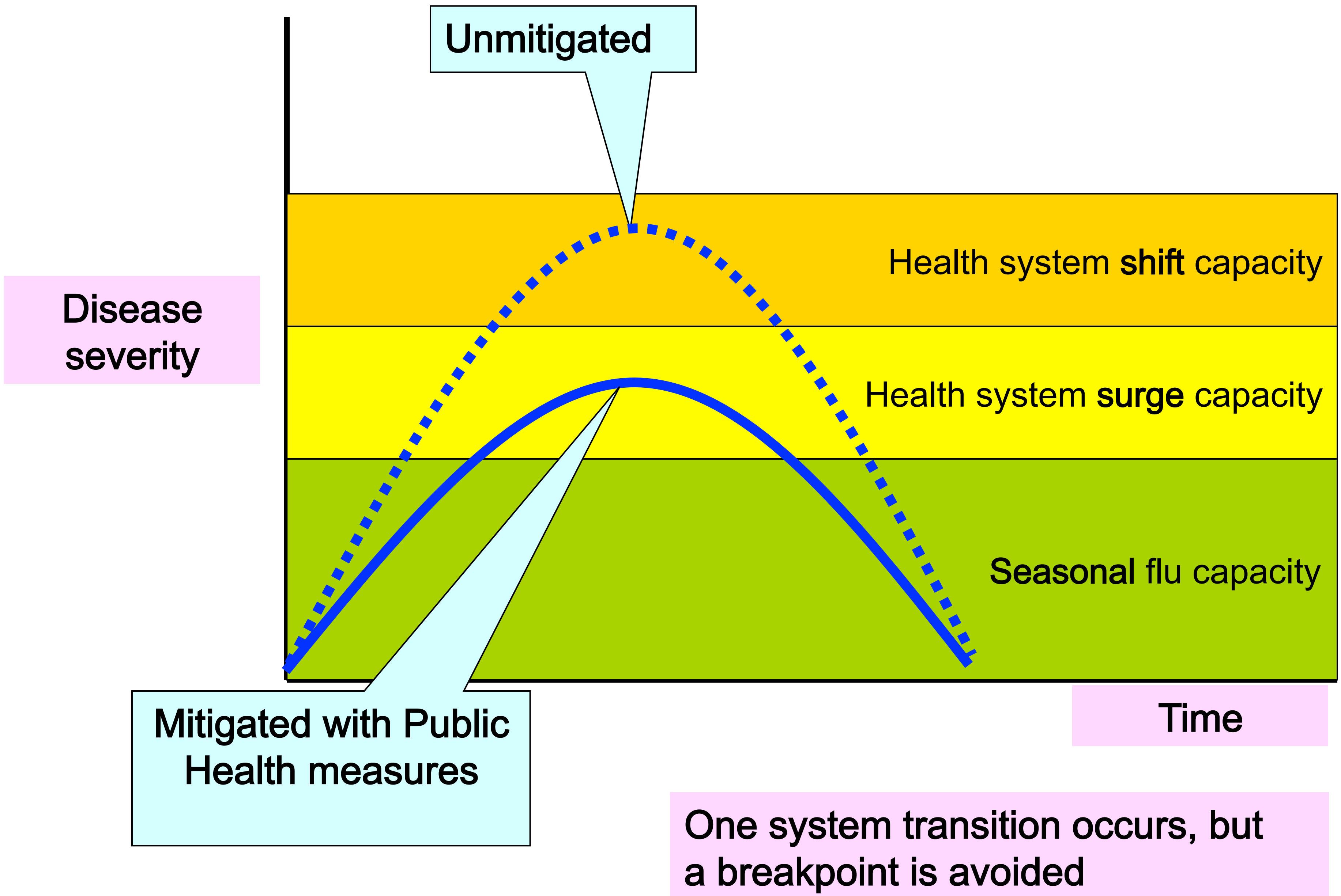
- Avoid breakpoints - significant system transitions from relatively small changes - particularly, in the health system
- Breakpoints in one system can cause breakpoints in other systems.

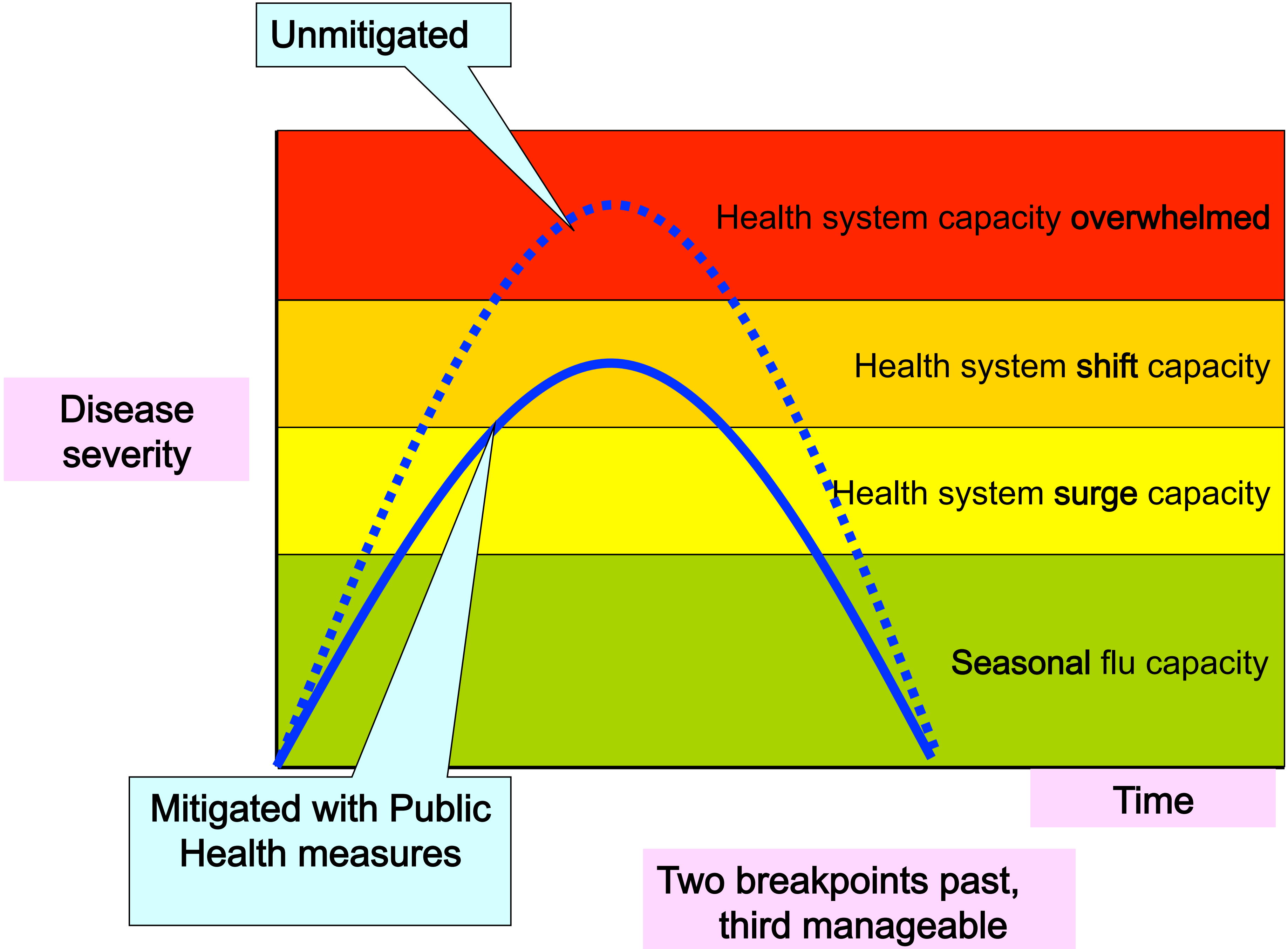
Game Changer: Mitigations (preventative measures) can prevent breakpoints.

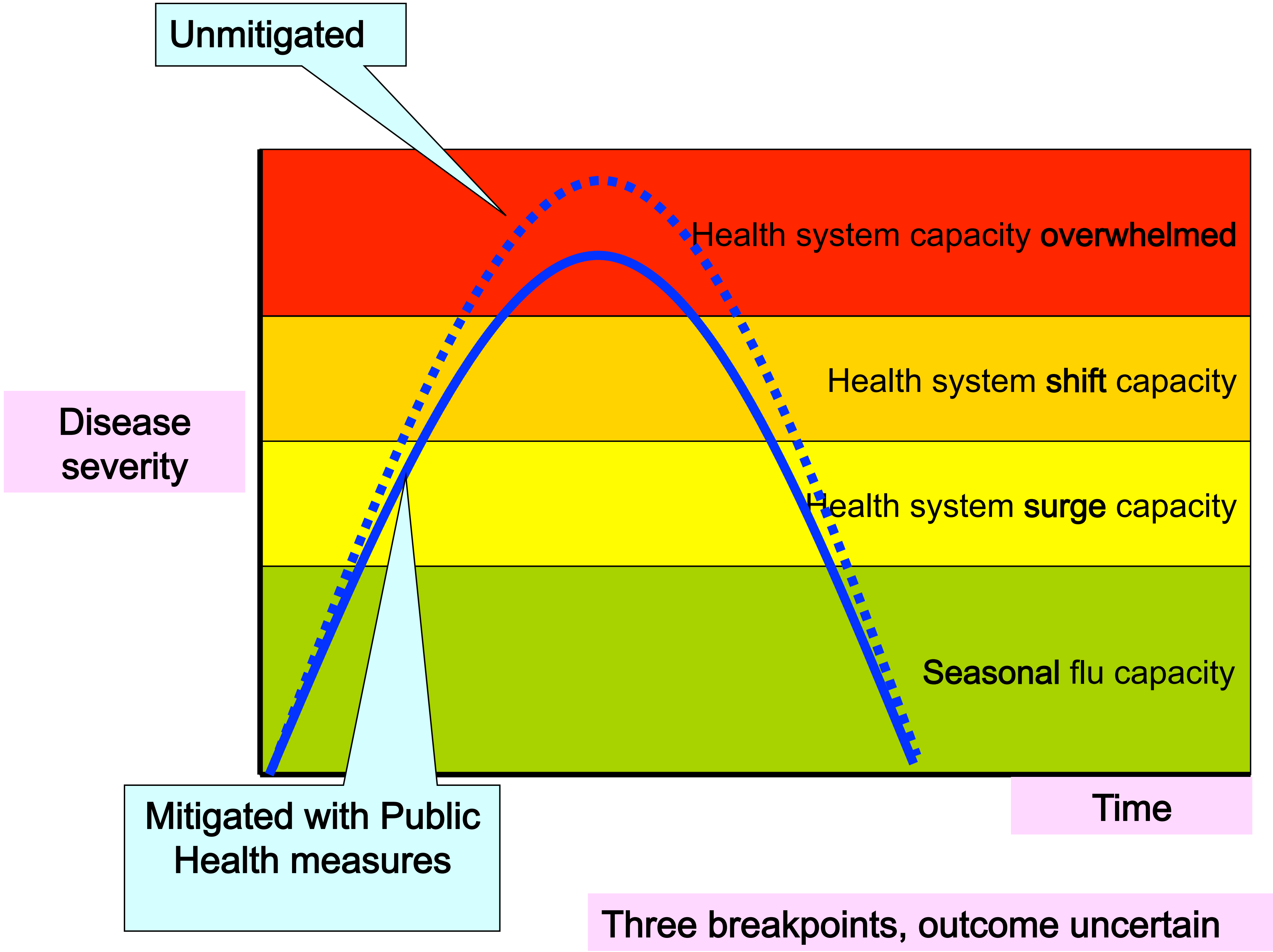
What resources are available?

Breakpoints in the public health systems (from AUS MoH)



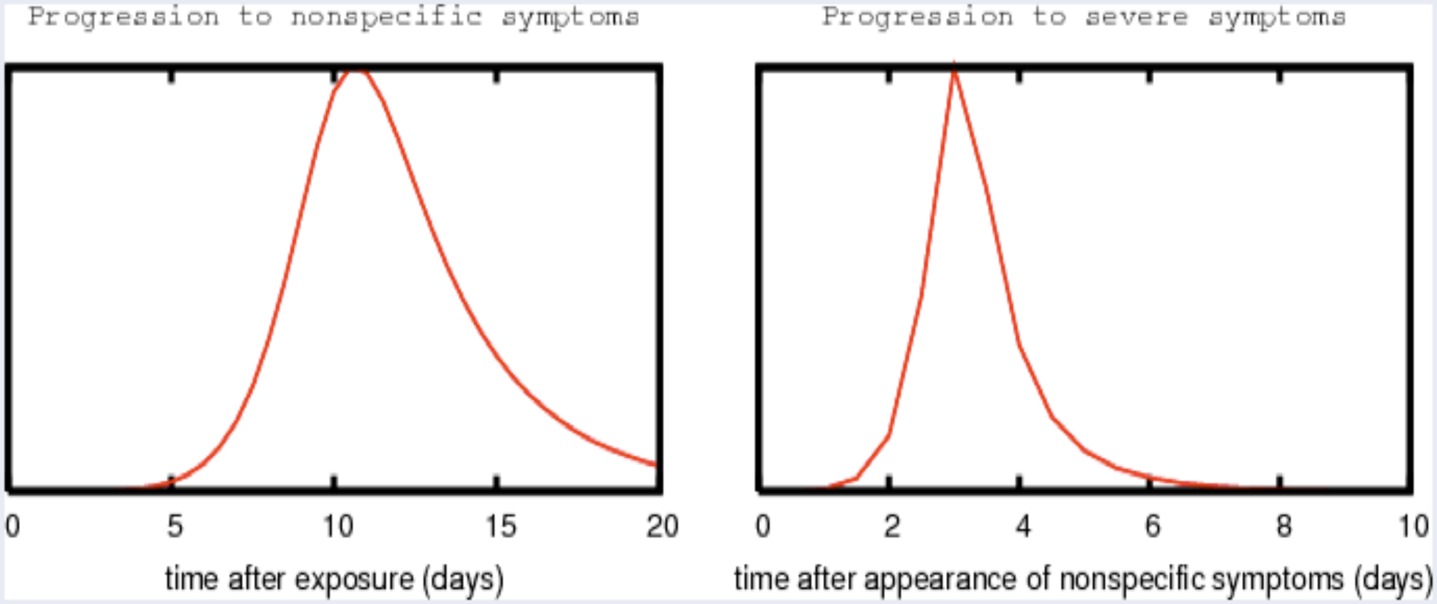

Unmitigated
Disease severity
Health system **shift** capacity
Health system **surge** capacity
Seasonal flu capacity
Mitigated with Public Health measures
Time
One system transition occurs, but a breakpoint is avoided


Unmitigated
Health system capacity overwhelmed
Health system shift capacity
Health system surge capacity
Seasonal flu capacity
Disease severity
Time
Mitigated with Public Health measures
Two breakpoints past, third manageable


Unmitigated
Disease severity
Health system capacity **overwhelmed**
Health system **shift** capacity
Health system **surge** capacity
Seasonal flu capacity
Mitigated with Public Health measures
Time
Three breakpoints, outcome uncertain

Disease Progression in a diverse population

Smallpox Medical data



Death occurs 8 days after appearance of severe symptoms

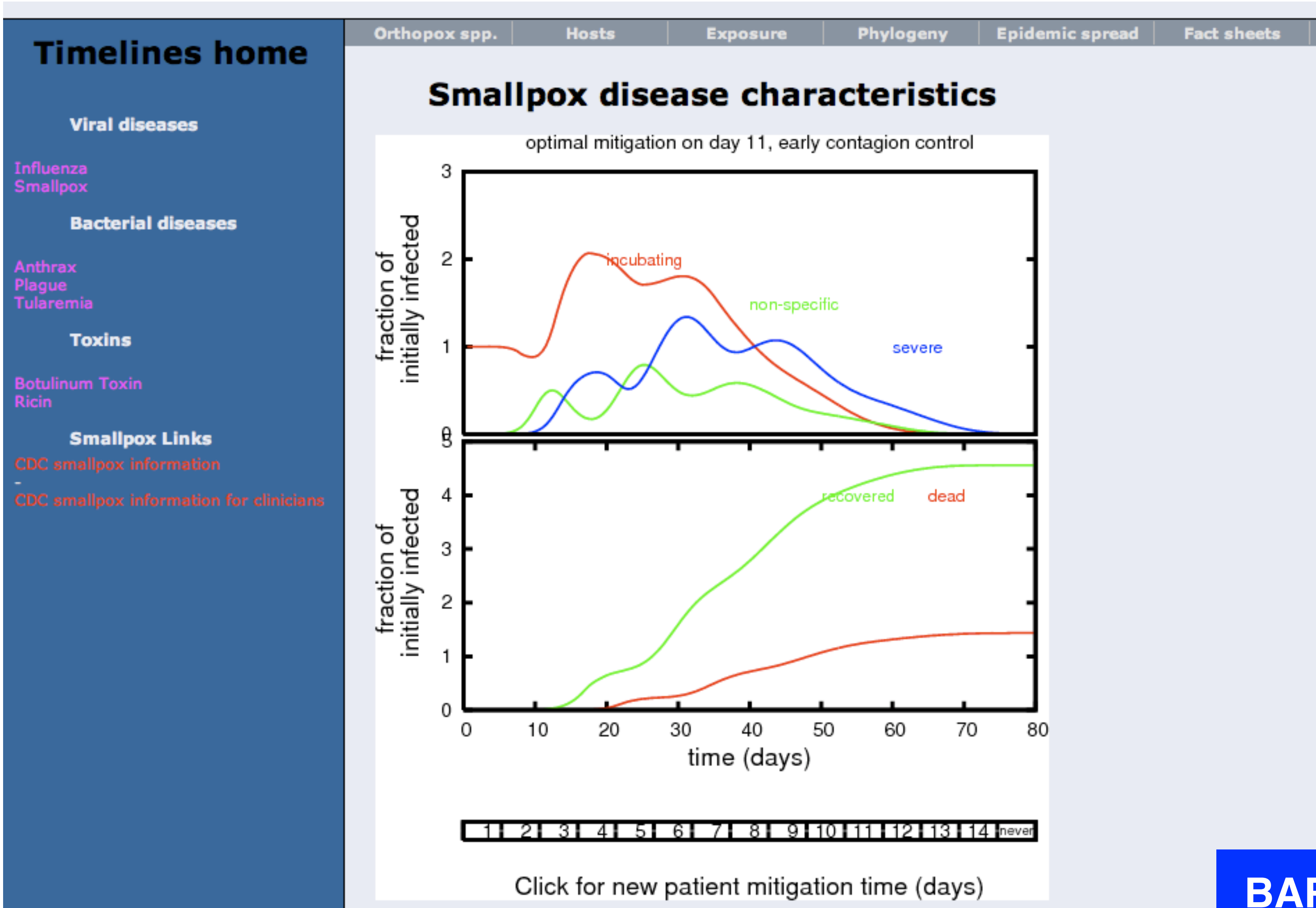
Mitigative Efficacy at Different Times in Disease Progression

	Prophylatic	At Appearance of Non-Specific Symptoms	At Appearance of Severe Symptoms	Never
Non-Specific Symptom Rate	.2	1.0	1.0	1.0
Duration of Severe Symptoms in Survivor Days	1	3	3	3
Severe Symptom Rate	0.05	0.98	1.0	1.0
Fatality Rate	0.02	0.33	0.33	0.33

Required for viruses, bacteria, toxins, etc.

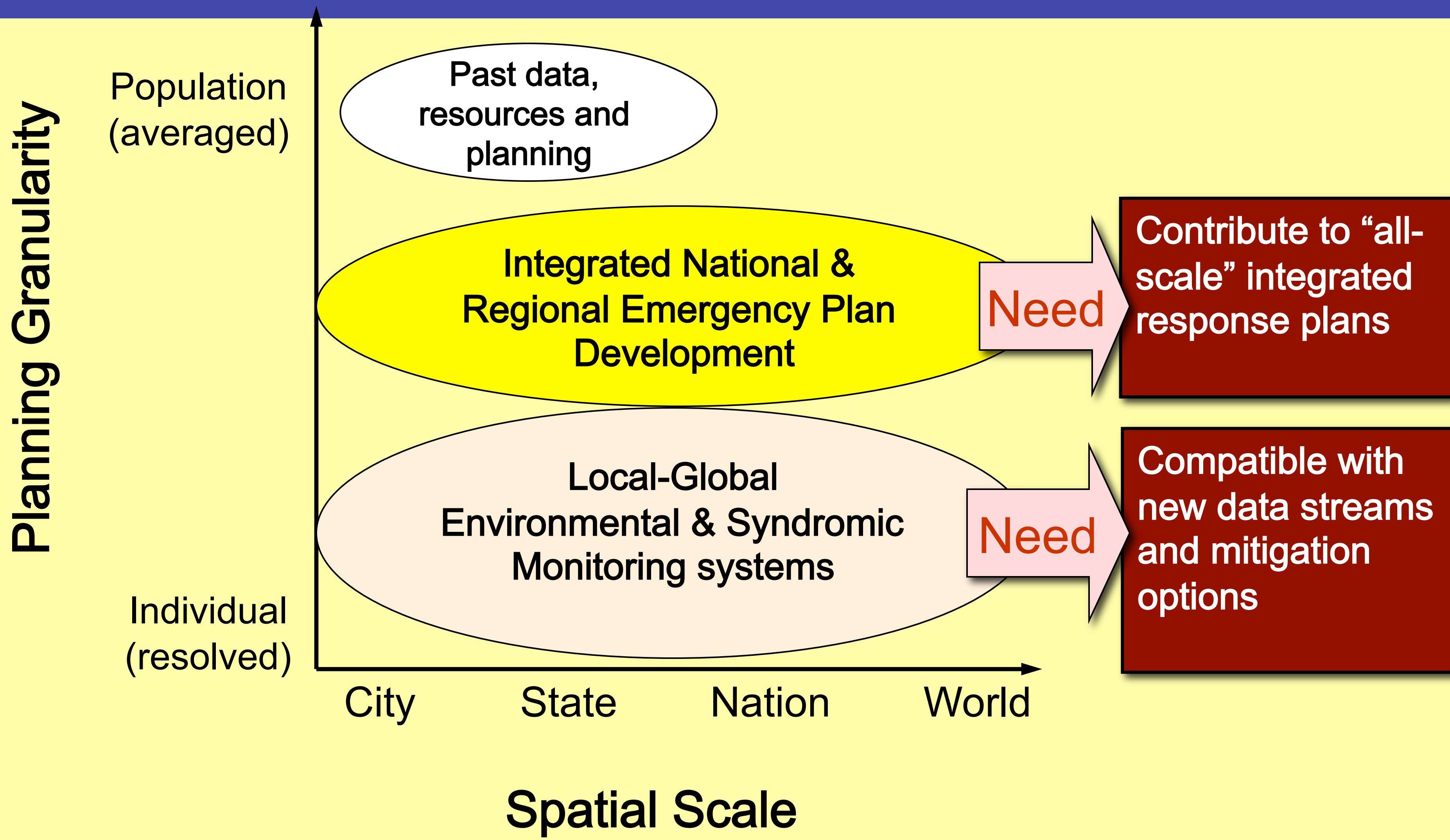
And the different types or strains of each.

Example: **Biological Agent Reference Tool (BART): a Web-based response information tool**



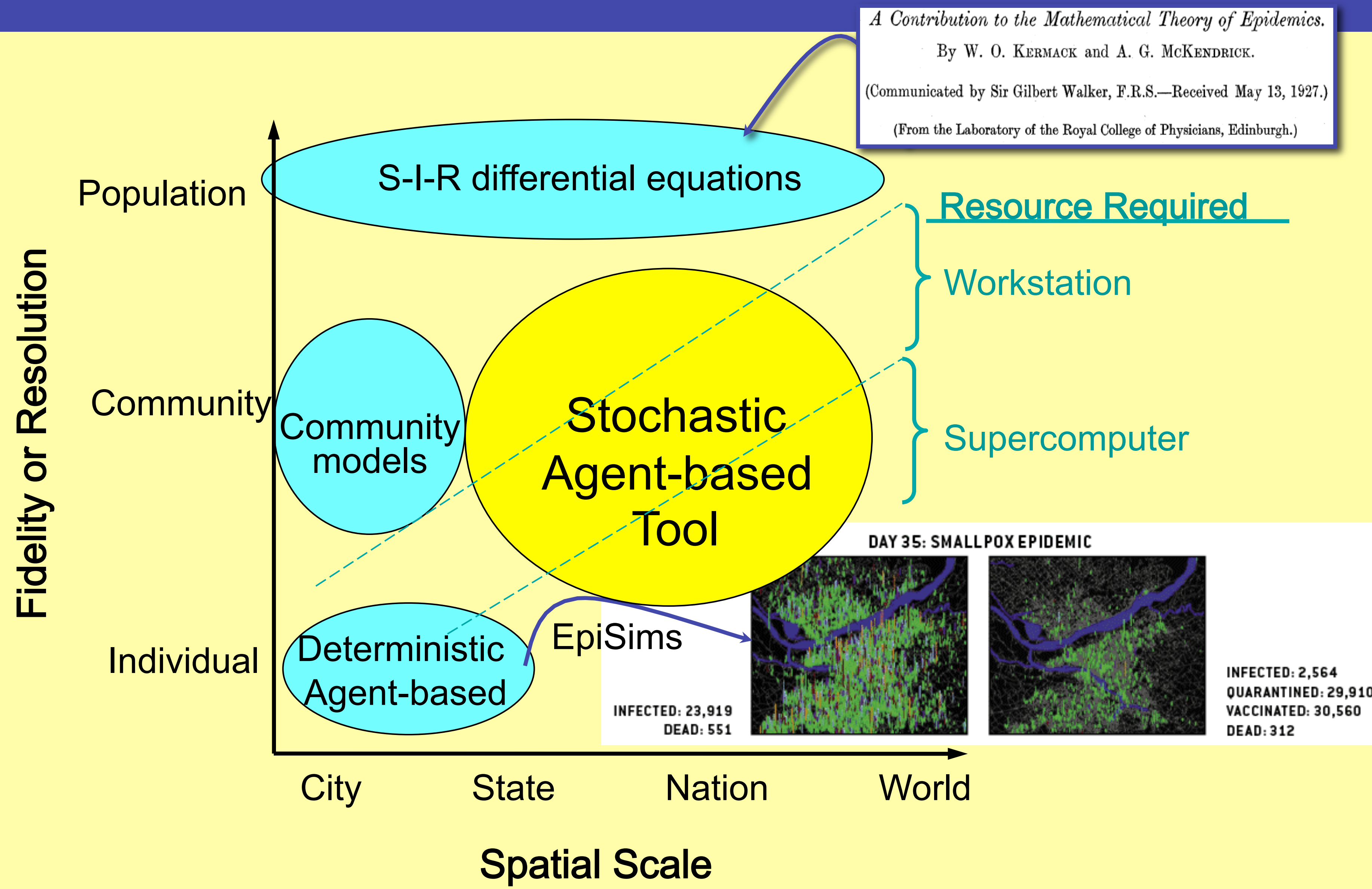
BART

Epidemiological Resources Needed



Resource needs: prediction of disease progression in heterogeneous populations, across large scales, resolved at individual and local level

A Landscape of Epidemiological Options



EpiCast (Epidemiological Forecasting)

- A stochastic agent-based simulation model to predict the global/national/regional spread of infectious diseases and to assess mitigation strategies
- Capable of simulating billions of agents on supercomputers and millions on laptops

Four components:

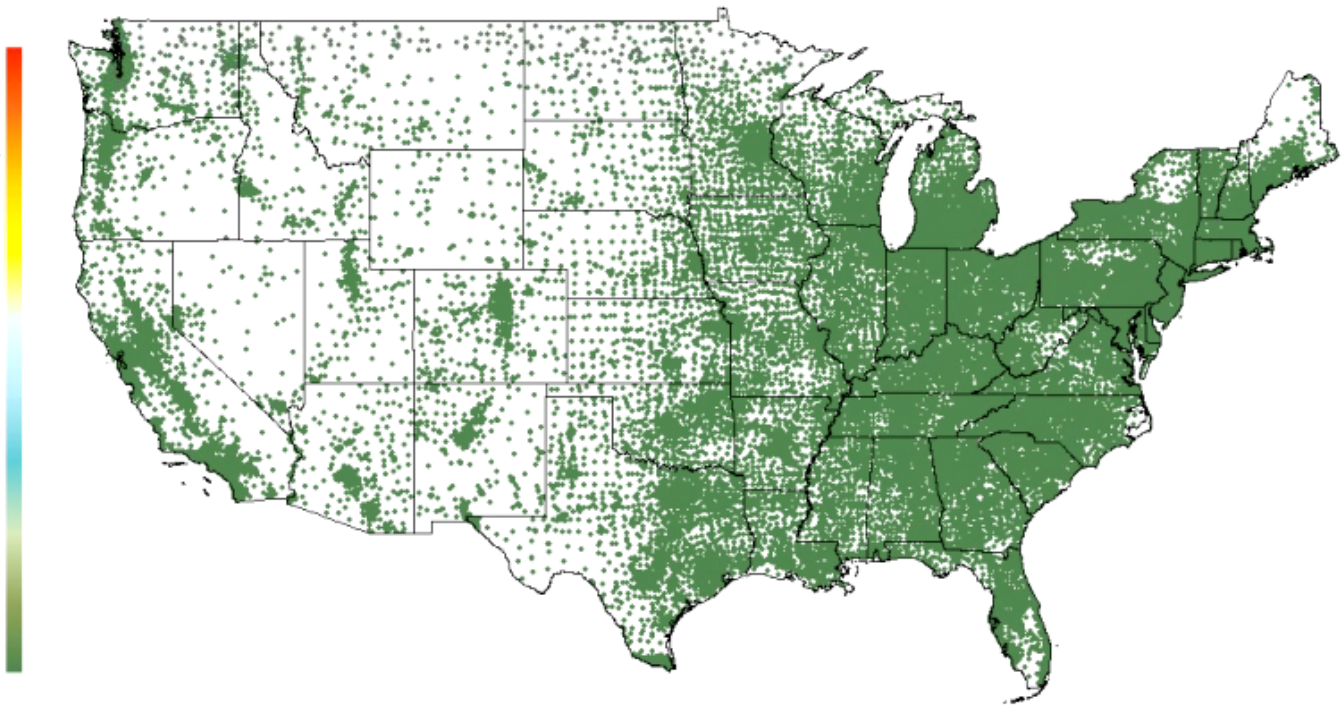
1. An Individual disease progression model - varies by type of person: age, occupation, health status, but not location.
2. Demographics (where people live) and workerflow data (where they work) – at "community" resolution.
3. Community network: Contacts between people based on contact groups (family, work group, school, community…).
4. Irregular travel - travel between Community networks, usually long range.

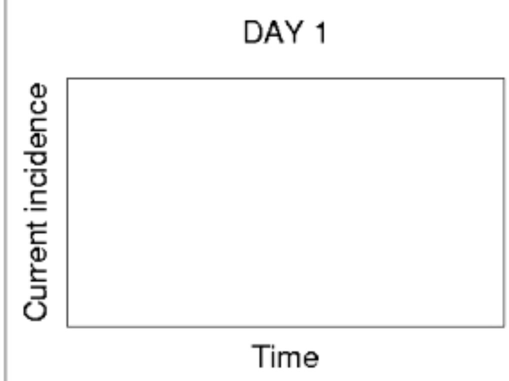
Disease model is general. The rest are determined by data from area of operations

T. C. Germann, K. Kadau, I. M. Longini, and C. A. Macken, "Mitigation Strategies for Pandemic Influenza in the United States," *Proceedings of the National Academy of Sciences* **103**, 5935-40 (2006).

Influenza in the US:
Planning for the next pandemic

Baseline - Moderate Severity





Each Census tract is represented by a dot colored according to its prevalence (number of symptomatic cases at any point in time) on a logarithmic color scale, from 0.3-30 cases per 1,000 residents.

Baseline simulated pandemics

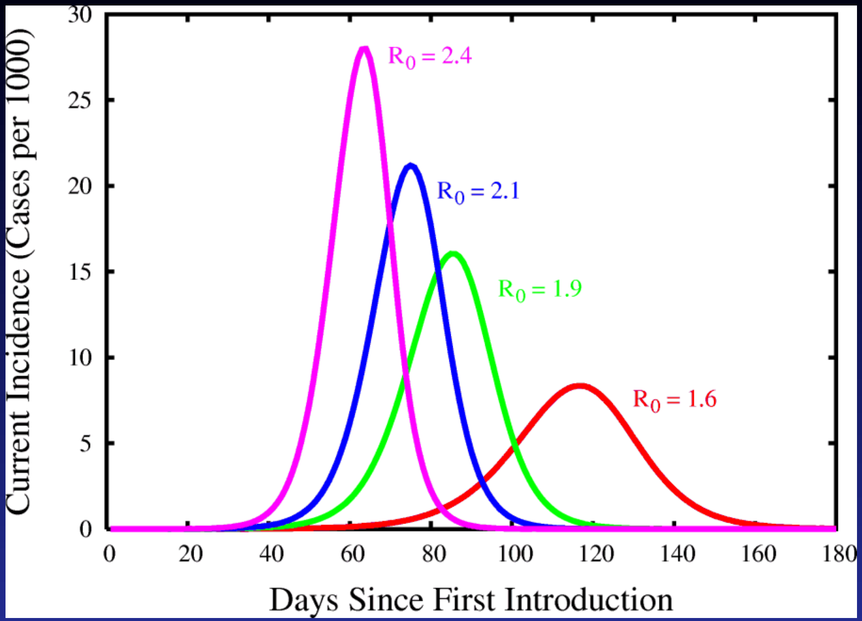


Table 4. Characteristics of nationwide outbreaks of pandemic influenza, as given by baseline simulations without any interventions.

Probability of transmission given contact, P_{trans}	0.12	0.15	0.17	0.20
Basic reproductive number, R_0	1.6	1.9	2.1	2.4
1,000th ill person, days after initial introduction	14	13	12	11
10,000th ill person, days after initial introduction	29	24	22	19
100,000th ill person, days after initial introduction	48	37	34	29
1,000,000th ill person, days after initial introduction	70	52	46	39
Peak of epidemic, days after initial introduction	117	85	75	64
Peak of epidemic, number of new cases	2.3 M	4.5 M	6.0 M	7.9 M
Duration, number of days with >100,000 new cases	86	68	60	52
Cumulative number of ill persons	92 M	122 M	136 M	151 M

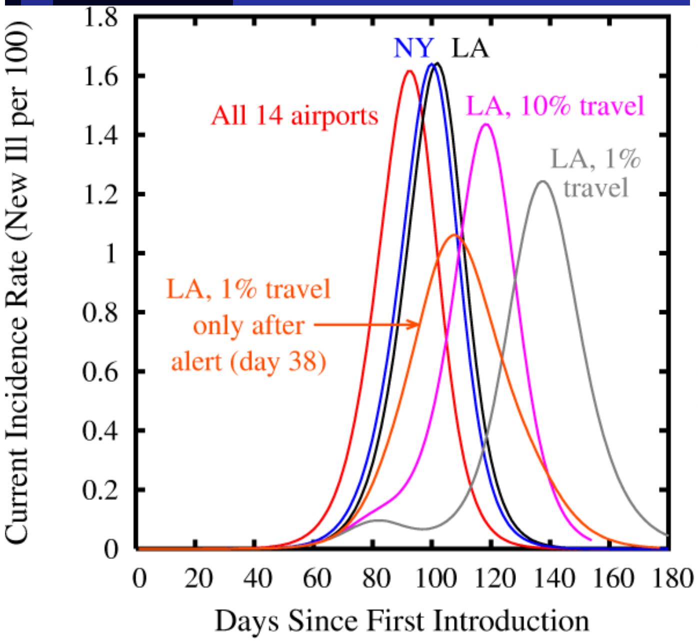
Most of the epidemic activity is in a 2-3 month period, starting 1-2 months after introduction

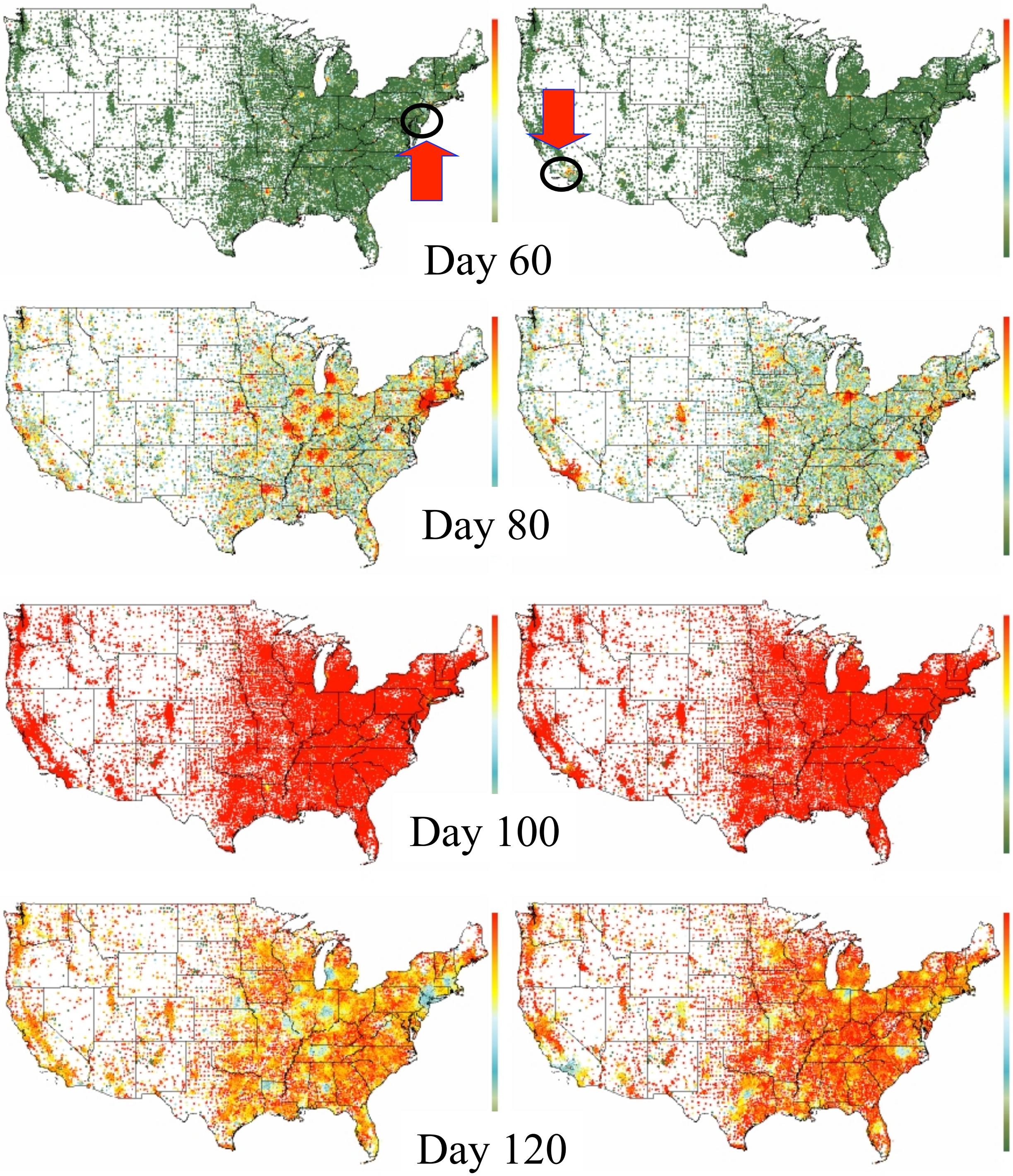
Breakpoint ($R_0 \sim 1$) Behavior

$R_0 \sim 0.9$

$R_0 \sim 1.2$

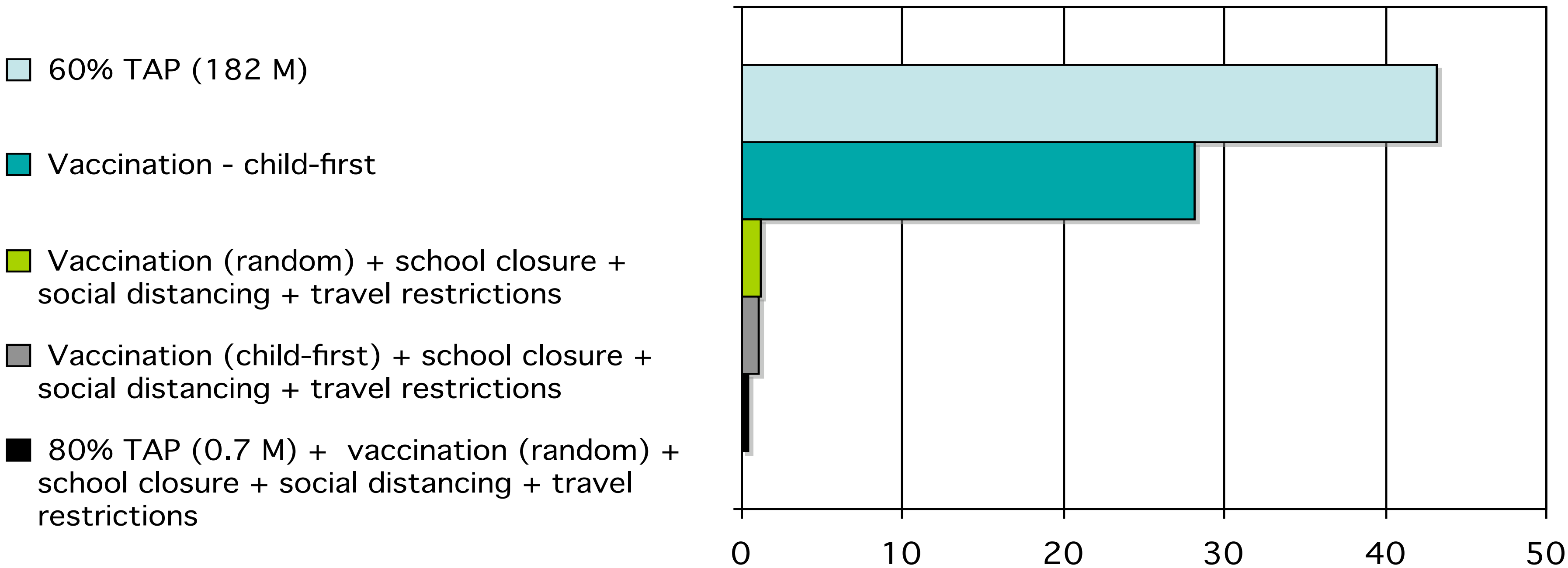
Introduction of 40 infecteds on day 0, either in NY or LA, with and without nationwide travel restrictions





Strategies for Pandemic Influenza Mitigation for R_0 = 1.8 (Simulations of 280 mill people in USA for “moderate” pandemic)

Successful Mitigations



Failed Mitigations - Full Pandemic (>10%)

- Social distancing alone
- Travel restrictions alone
- Social distancing + travel restrictions

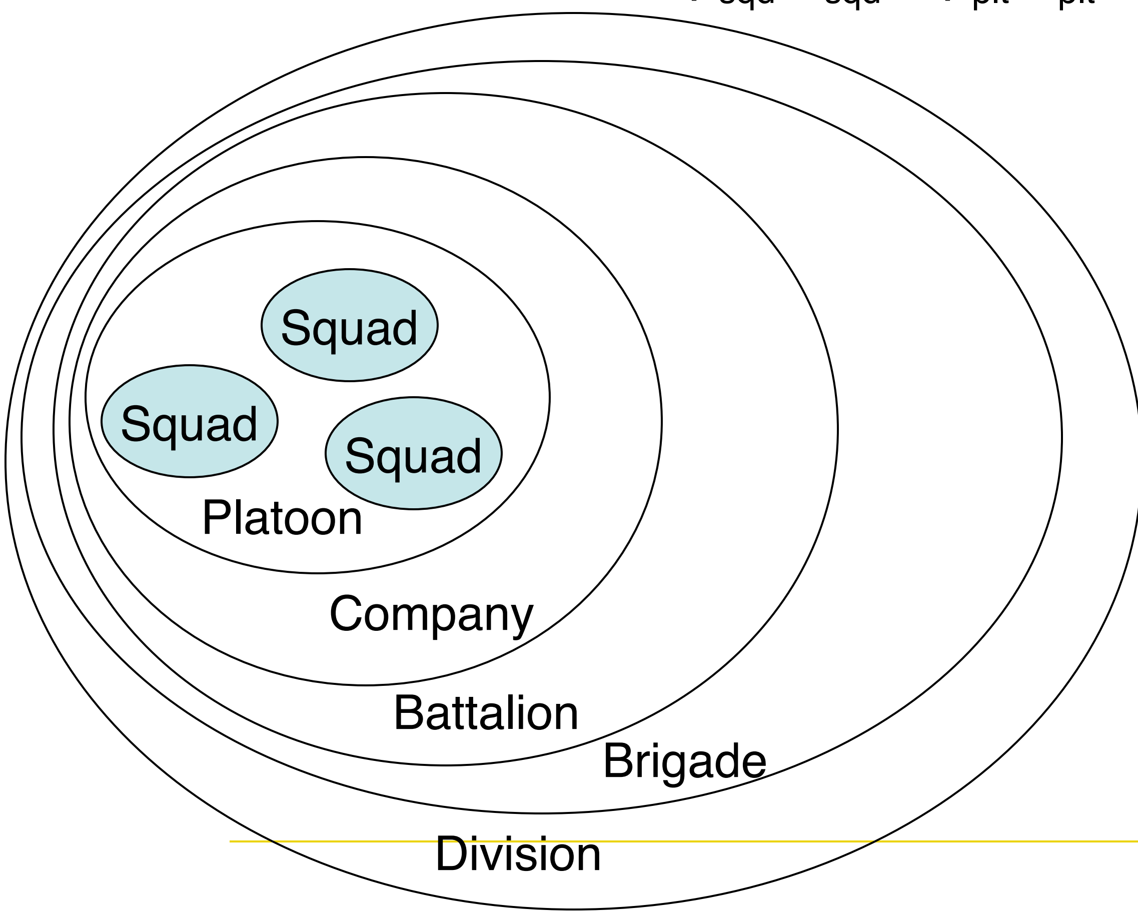
Uncertain Mitigations

- Vaccination - random
- School closure alone

Modeling Military Force Structure & Interactions

How "community network" (#2) is determined:

- Each individual solider belongs to a specific squad, platoon, …, army
- The squad … division levels comprise a hierarchy of "community networks: an individual's likelihood of becoming infected from these interactions is: $p_{sqd} \cdot n_{sqd} + p_{plt} \cdot n_{plt} + \ldots + p_{div} \cdot n_{div}$

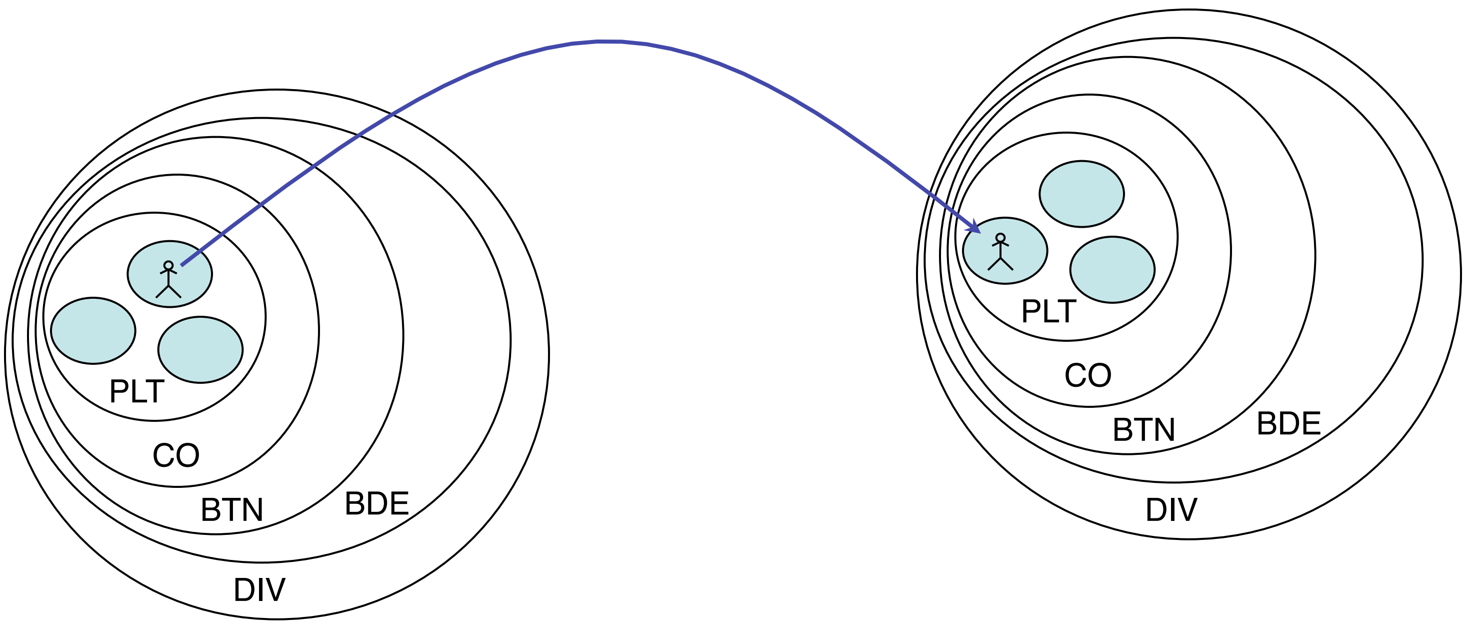


- where the p_X are contact rates from the unit interaction survey, and n_X are the number of infectious soldiers in that unit.
- A survey was done to determine p_X.

Modeling military force structure & interactions

How "irregular travel", typically long-range travel, is modeled:

- Interactions with other divisions are captured in a manner analogous to the long-range travel in the civilian sector:
  - With a specified frequency, soldiers are randomly selected and sent for a period of 1-14 days to a unit outside their own division
  - The outside unit is randomly selected, but biased towards those in the same corps to approximate "upward" interaction rates



Demographics and Workflow (#2) and Irregular travel (#4) for Public-military Model for South Korea

Public (#2 and #4):

- Census for 2000 for the 9 provinces and 6 special cities, ranging from 0.5 to 10 million people each (46 million total) - used in "public" community network.
- Worker-flow data estimated by geographic proximity (no USA census-like data available).
- Random long-range travel by public

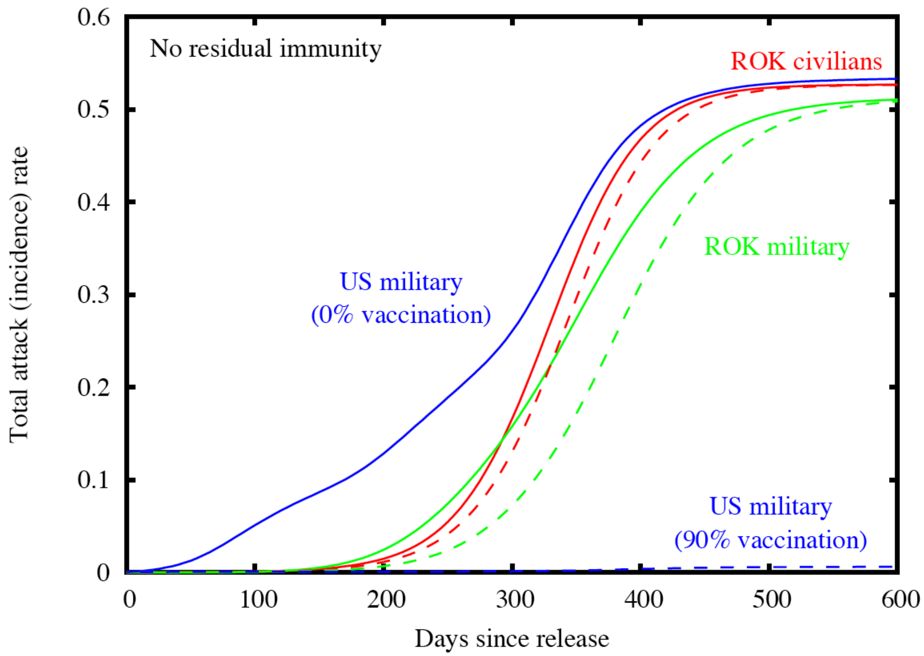
Military demographics (#2):

- Republic of Korea forces down to battalion level
- U.S. forces in South Korea

Military-Civilian interaction (#4):

- Based upon the geographic position of each military unit; soldiers occasionally (very rarely) interact with a random community in the local province/special city.

Effect of US vaccination policy on public (smallpox)



Final attack rates
(averaged over 10 realizations):

US military vaccination level	civilians	ROK forces	US forces
0%	52.7%	51.3%	53.4%
90%	52.7%	51.4%	0.6%

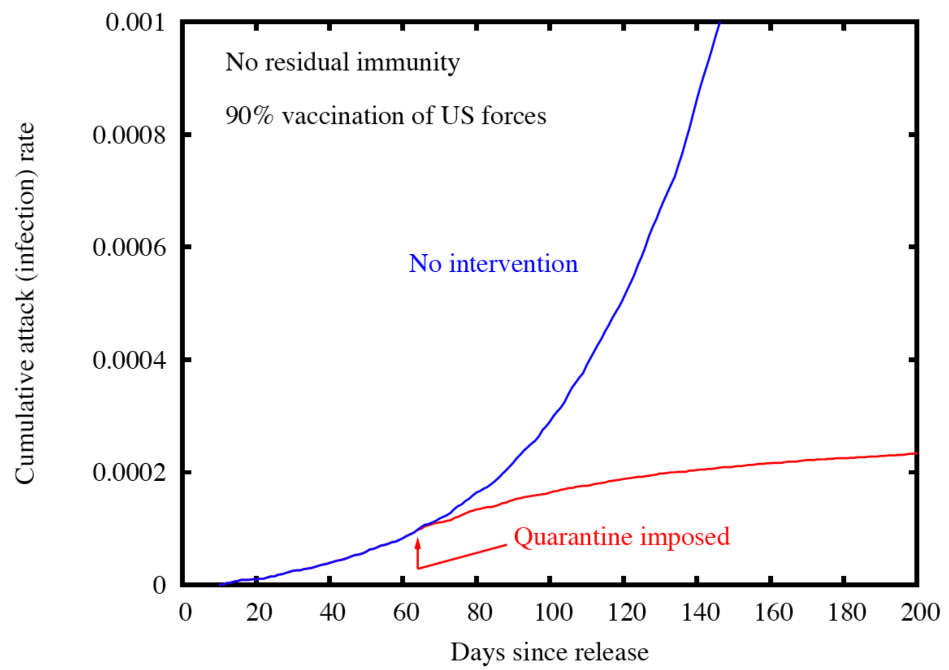
- No protection of public is observed for different rates of vaccination of US forces (as expected - military are not “spreaders”).
- US forces remain at risk due to the widespread epidemic among the surrounding (unvaccinated) population.

Mitigation: Post-detection intervention of quarantine

- Assume 50% leakage from civilian quarantine, but perfect squad-level quarantine of military personnel
- Quarantine benefits non-quarantined civilians

Final attack rates
(averaged over 10 realizations):

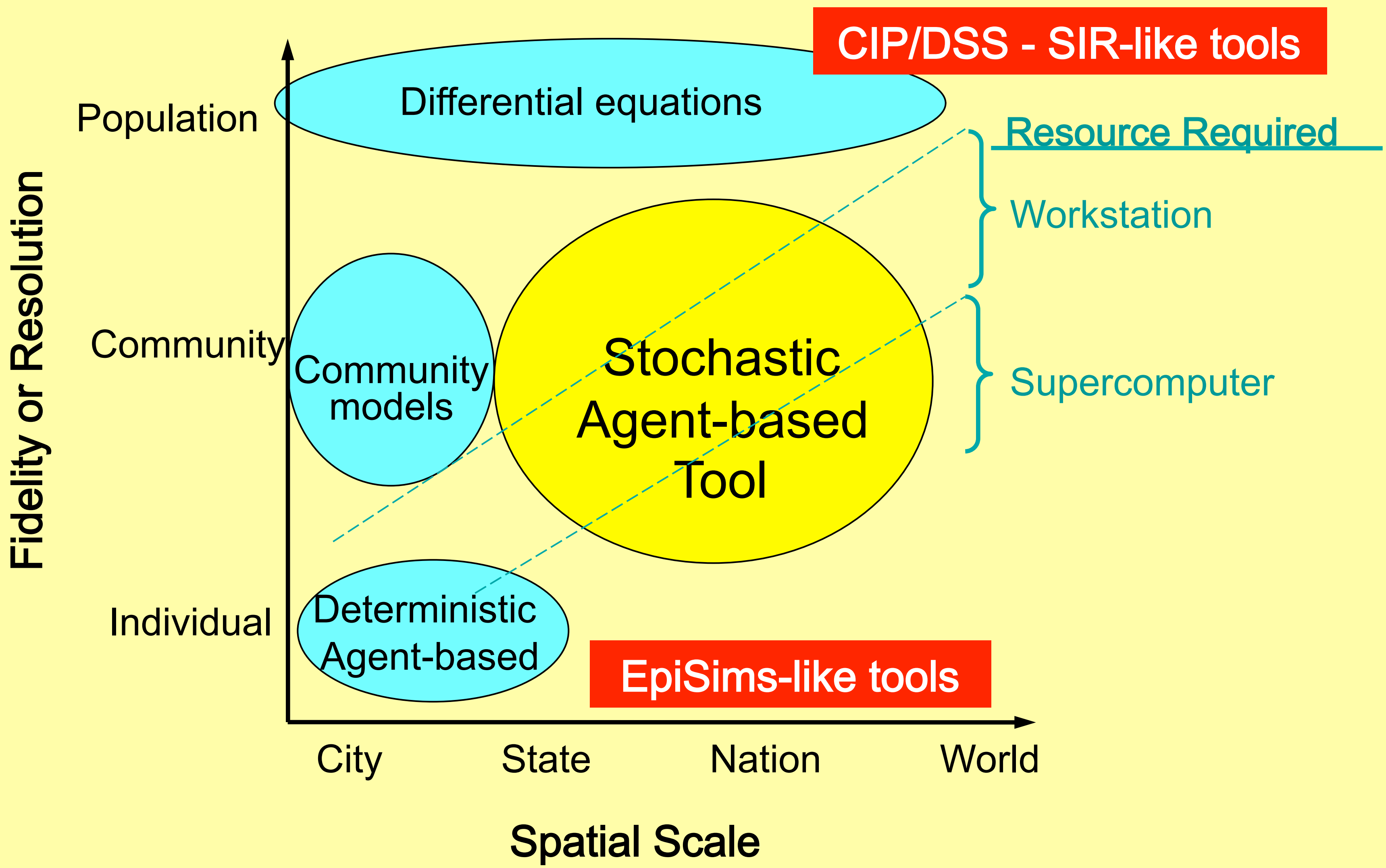
US military vaccination level	civilians	ROK forces	US forces
0%	52.7%	51.3%	53.4%
90%	52.7%	51.4%	0.6%
90% + quarantine	0.04%	0.01%	0.04%



Conclusions: no surprises because of the long time of disease progression of small pox. The same conclusions are NOT true for pandemic influenza!

System-of-System Resources

Critical Infrastructure Protection (CIP) resources



Critical Infrastructure Interdependency Modeling: A Survey of U.S. and International Research (Aug 2006)

30 infrastructure simulations tools reviewed, based on infrastructure included, approach, coupling type, platform, software requirements, user skill, maturity.

- **Tools: AIMS, Athena, CARVER+, CIMS, CIP-DSS, CIPMA, COMM-ASPEN,DEW, EMCAS, FAIT, FINSIM, IIM, MIN, NEMO, Net-Centric GIS, NISAC, NGTools,…**

			Area Model by Infrastructure Sector															Simulation Type		System Model		Hardware Platform Requirements		Software Requirements			User and Maturity Levels	
	Simulation Name	Developer	Electric Power	Natural Gas	Drinking Water	Sewage Water	Storm Water	Human Activity	Financial Networks	SCADA	Telecom	Computer Networks	Oil Pipeline	Rail System	Highway System	Waterway System	Police/ Regulatory Constraints	Continuous	Discrete	Integrated	Coupled	PC	HPC	Windows	Linux	Solaris	Users	Maturity Level
1	AIMS	UNB														X		X		X							IA	RS
2	Athena	On Target Technologies, Inc.	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	A	X	A	X		X			EA	MI
3	CARVER²	National Infrastructure Institute																				X		X			B	MC
4	CI³	ANL	X	X						X	X							X		X							B	MI
5	CIMS	INL	X					X		X									A	X		X	X	X	X	X	B	DV
6	CIP/DSS	LANL, SNL, ANL	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X		X		X		X				MI
7	CIPMA	Australia	X	X					X		X		X					X									B	MI
8	CISIA	University Roma Tre	X							X																		
9	COMM-ASPEN	SNL							X		X									X		X					IA	DV
10	DEW	EDD	X							X																	B	MC
11	EMCAS	ANL	X						X							X			A	X		X					IA	MI
12	FAIT	SNL	X	X												X		I		X				X	X		IA	DV
13	FINSIM	LANL							X		X							X			A			X			IA	DV
14	Fort Future	USACE	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X										B	MC
15	IEISS	LANL	X	X														X			A	X		X	X		IA	MI
16	IIM	UV	X						X		X							I		X							IA	RS
17	Knowledge Management and Visualization	CMU	X											X	X	X											IA	RS
18	MIN	Purdue						X							X													
19	MUNICIPAL	RPI	X								X			X														
20	N-ABLE	SNL	X						X					X					A	X							IA	MI
21	NEMO	SPARTA	X	X	X									X			X	X		X		X						DV
22	Net-Centric GIS	York University												X	X	X											IA	RS
23	NEXUS Fusion Framework	IntePoint, LLC.	X					X			X			X	X												B	MC
24	NGtools	ANL	X	X																							B	MI
25	NSRAM	JMU	X								X								X									RS
26	PFNAM	ANL		X									X															
27	TRAGIS	ORNL												X	X	X	X											MI
28	TRANSIMS	LANL						X											A		A		X		X		B	MC
29	UIS	LANL			X	X	X	X			X				X	X		X	A		A		X		X		IA	MI
30	WISE	LANL			X	X	X											X			A			X			IA	DV

Simulation Type:
I — Input-Output Model
A — Agent-based

Users:
IA — Internal Analyst
EA — External Analyst
B — Both

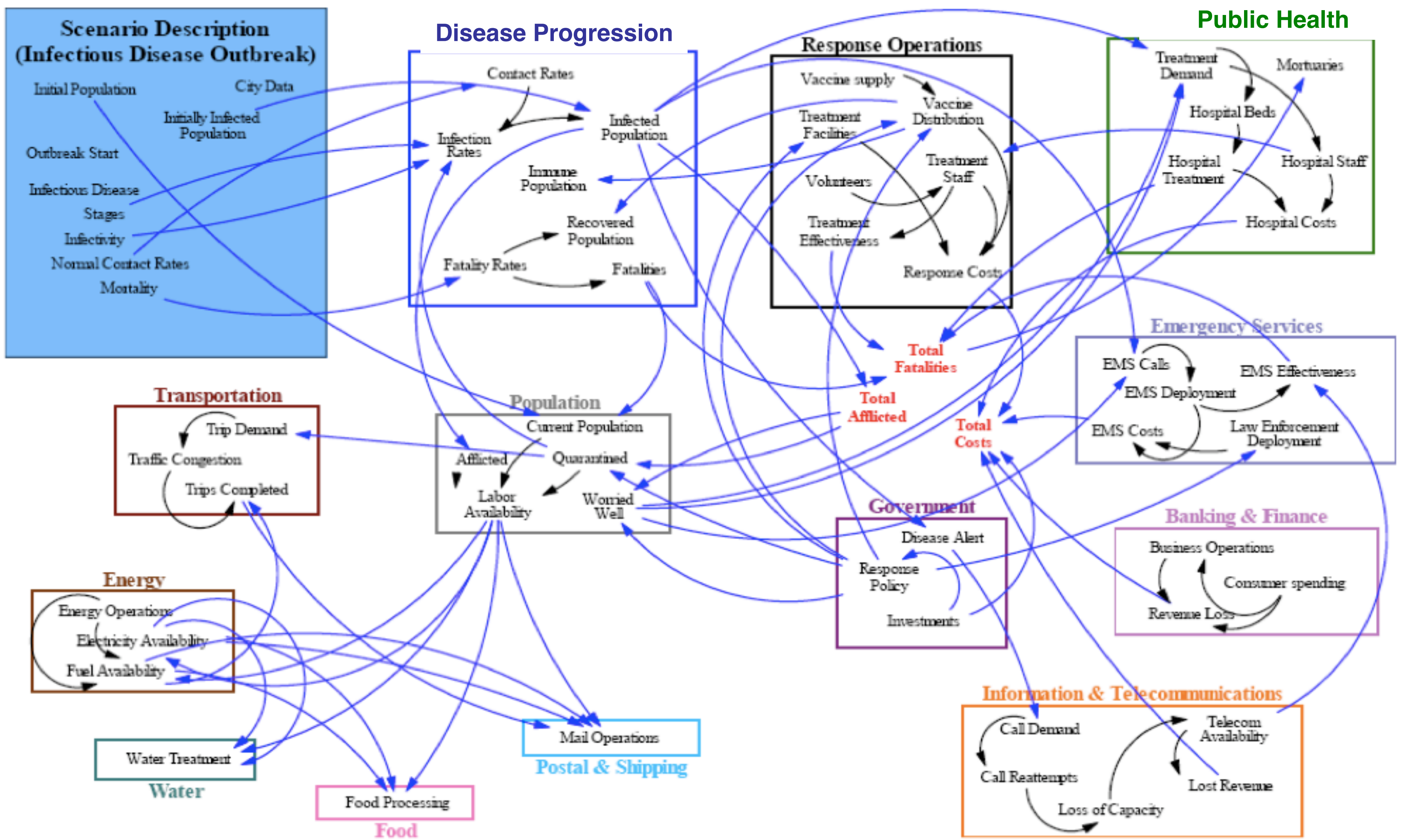
Maturity:
RS — Research
DV — Development
MI — Mature Internal
MC — Mature Commercial

CIP/DSS Resource: Coupled Infrastructures

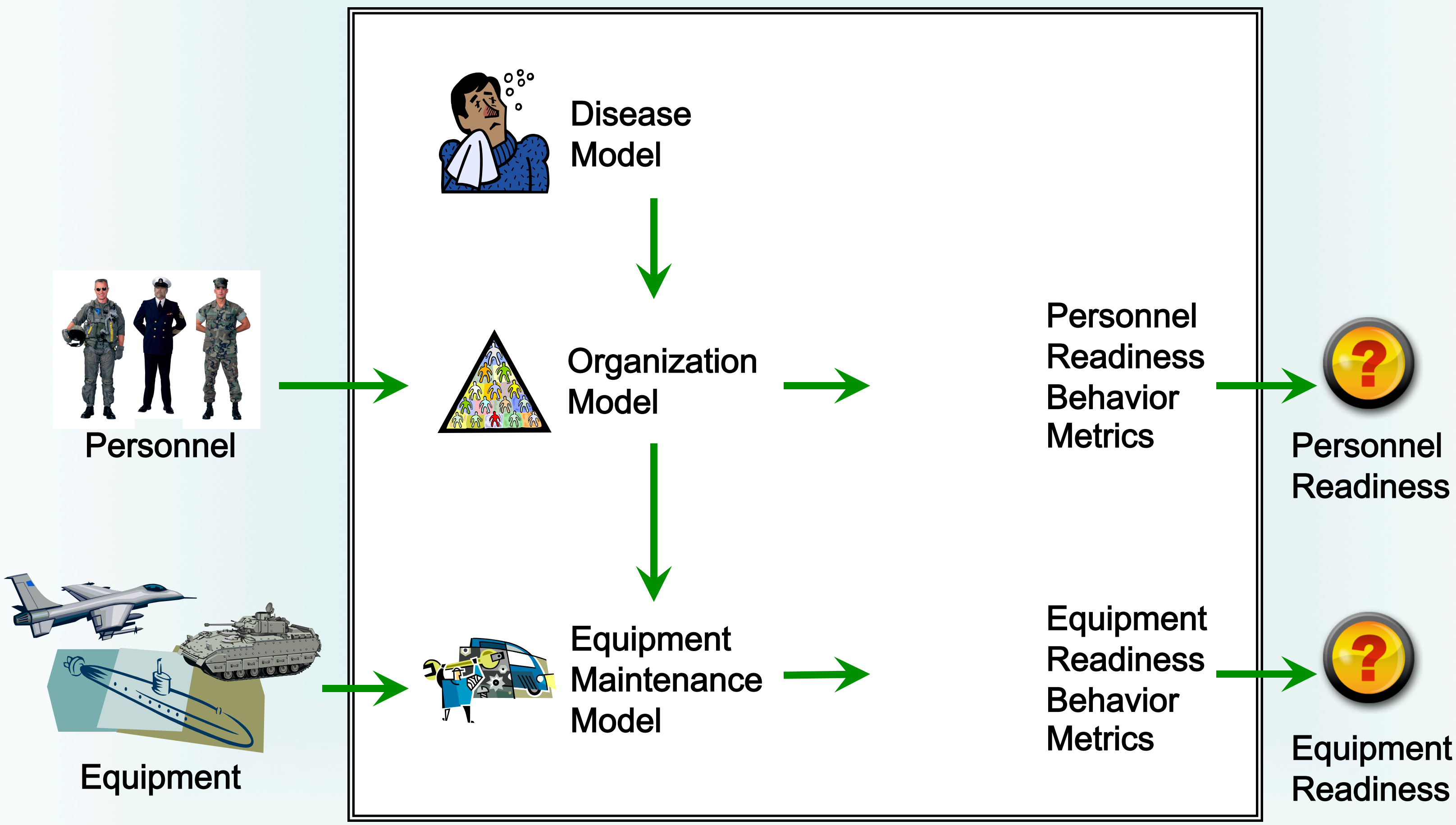
- **Critical Infrastructure Protection / Decision Support System (CIP/DSS) Toolset:**
  - Includes 14-17 infrastructures
  - Calibrated to detailed National Infrastructure Simulation and Analysis Center (NISAC) resources
  - Open-source approach - Implemented in a system simulation resource: VENSIM

- **Public Health component combines:**
  - A multi-binned SIRx infectious spread model (modifiable) capable of treating regional, public/military, age populations
  - Includes hospitals, staff, beds, etc.
  - Includes many medical mitigation options including use of therapeutic stockpiles and time required to distribute these

CIP-DSS Combined Epi and Public Health



Toolkit for Operational Medical Modeling (TOMM)



Determines impact on operational readiness and optimal course of action from automated scenario exploration

Summary of Disease Progression Resources and Their Uses

Resource	Method	Scope	Resolution	Typical Uses
BART Sponsor: DHS/S&T	Novel: distributions and disease stages	Diverse populations but well mixed	Spatial: none; Individuals: distributions; Time: minutes	Population impact Tool: • How quickly do I have to act? • What is the basic knowledge I need to address the threat?
CIP-DSS Source: DHS/NISAC	Couple differential equations (SIRx type)	Regional-Multisector	Spatial: regional; Individual: none; Time: minues	Multisector Consequence Analysis: • Sector impact? • Multiple breakpoints?
EpiCast Sponsor: DHS/S&T	Community based agent model, census data driven	World, nation, regional and local	Spatial: 2000 people tracks; Individual: yes; Time: 1/2 day	Epidemic Forecasting Tool: • National impact? • Individual-national options
EpiSimS Source: DHS/NISAC	Individual activity based agent model	Regional and local (to building and car level)	Spatial: buildings; Individual: detailed activity; Time: minutes	High-fidelity geospatial epidemic progression: • Validation of coarse models • Individual mitigation options
TOMM Sponsor: DoD/ONR	Use any epidemiolog-ical model, adds readiness evaluation	Theater of operations; public optional	Depends on epi model uses.	Operational readiness: • Personnel? • Mission/equipment? • Best coarse-of-action

Selection of Resource by Application

Application	BART	CIP-DSS	EpiCast	EpiSimS
Approach used	Distribution functions	Differential SIRx models	Stochastic agent-based	Deterministic agent-based
Predict disease progression in diverse populations for planning	Data driven for populations (green)	Requires aggregate disease progression parameters (yellow)	State of the art for national-regional epidemics (green)	State of the art for regional epidemics (green)
Utility of different medical mitigation options at local level	Single mitigation for each biothreat (red)	Limited local and individual mitigations (yellow)	Full spectrum, realistically implemented (green)	Full spectrum, realistically implemented (green)
Impact on civilian workforce	Inferred only (red)	Explicitly captured in model (green)	Limited workforce impact (yellow)	Predictive workforce impact (green)
Use in Operations Response	Coarse response resource only (yellow)	Ideal option for CIP impact - but limited epi (green)	Good for regional impact and detailed mitigations (green)	Computer intensive, limited adaptability (yellow)

green: go, yellow: caution - limited utility, red: not feasible

References

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- **EpiCast** (National and regional): Tim Germann tcg@lanl.gov (also <norman@SantaFe.edu>). See T. C. Germann, K. Kadau, I. M. Longini, and C. A. Macken, "Mitigation Strategies for Pandemic Influenza in the United States," *Proceedings of the National Academy of Sciences* **103**, 5935-40 (2006).
- **EpiSims**: http://ndssl.vbi.vt.edu/episims.php
- **CIP-DSS**: http://www.sandia.gov/mission/homeland/programs/critical/nisac.html
- **TOMM**: Darren Kwock <dkwock@alionscience.com> (also njohnson@referentia.com)
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