Designing Response Supply Chain Against Bioattacks

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Recipients of the 2020 Koopman Prize

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WELCOME!

Thursday, 3 December 2020
12:00 – 1:00 pm EST

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To all MAS members, potential MAS members, MORS members, friends, and guests—a hearty WELCOME!

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Military and Security Society

2019-2020 MAS President

Dr. Natalie Scala

https://connect.informs.org/militaryandsecurity/home

- MAS seeks to foster the development, dissemination, and implementation of knowledge, basic and applied research, and science and technologies that improve the understanding and execution of military and security operations.
- The society is planning its next major forums wherein analysts may participate, learn, and develop, either as attendees, presenters, or session coordinators.
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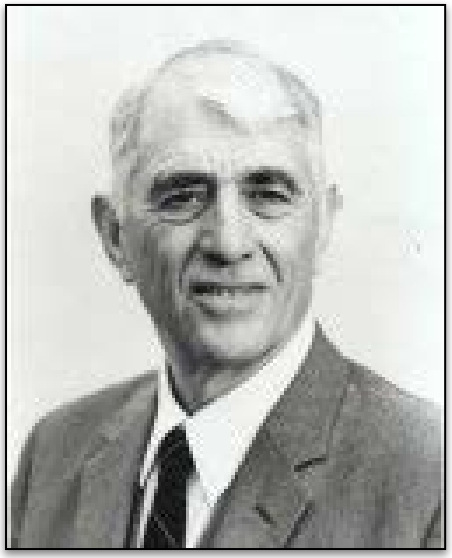
Benefits of joining and participating in MAS

- ✓ Develop professional skills
- ✓ Grow your professional network
  - ❖ Meet practitioners with interesting problems
  - ❖ Meet researchers with advanced technical knowledge
  - ❖ Learn about others' approaches to related challenges and applications
- ✓ Increase your domain knowledge
- ✓ Earn recognition

Koopman Prize



This is a $500 award for the best published paper or report on military operations research topics directly related to the goals of MAS. The award honors the memory of Bernard Koopman (1900-1981), who was a pioneer in the field of operations research. He was active in the founding of the Operations Research Society of America (ORSA), later merged with TIMS to form INFORMS, and served as its president in 1956. Dr. Koopman served as an operations research liaison between the U.S. Department of Defense and United Kingdom military establishments and NATO, and played a critical role in making operations research a permanent NATO activity.

Koopman Prize Winner

Designing Response Supply Chain Against Bioattacks

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Designing Response Supply Chain Against Bio-attacks

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Koopman Prize Presentation, MAS Webinar
Dec 3, 2020

In collaboration with Profs. David Simchi-Levi and Nikos Trichakis

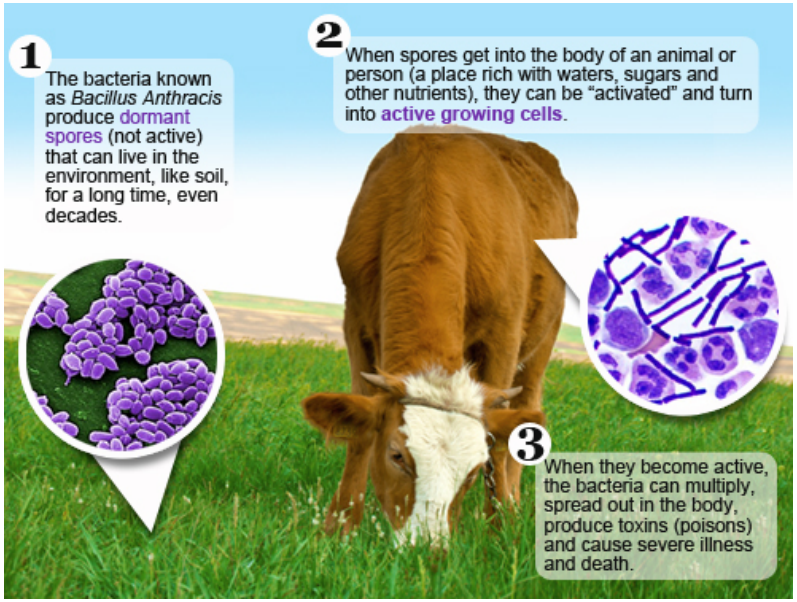
What is Bio-attack?

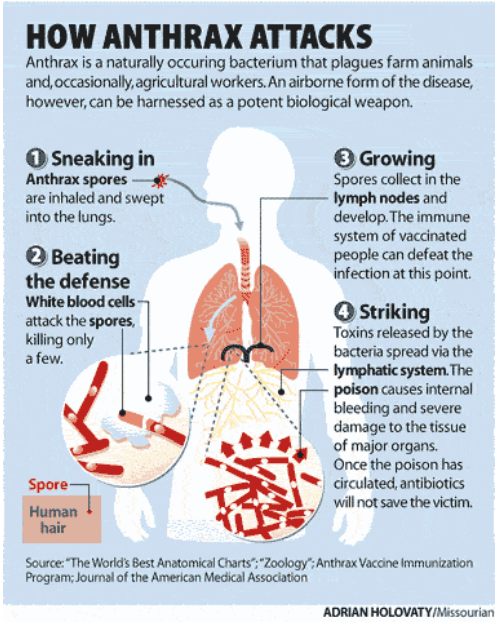
Intentional release of pathogens against humans to cause illness/death

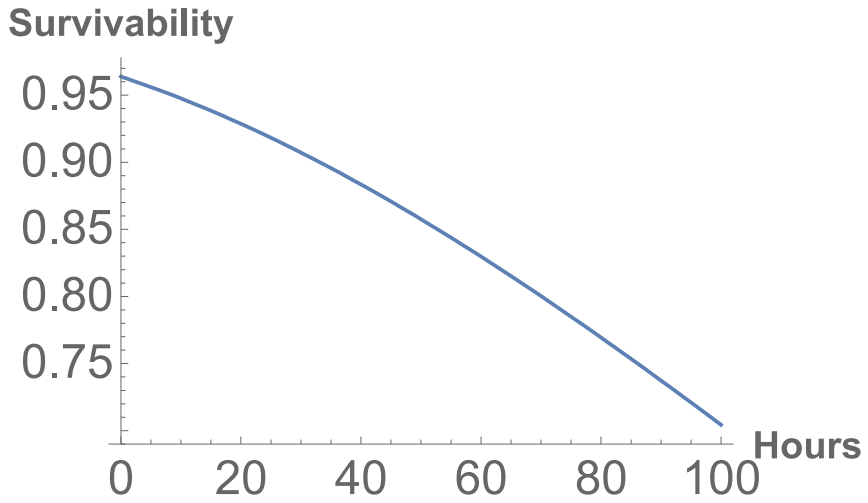
- Small quantity affects large population

What is Bio-attack?

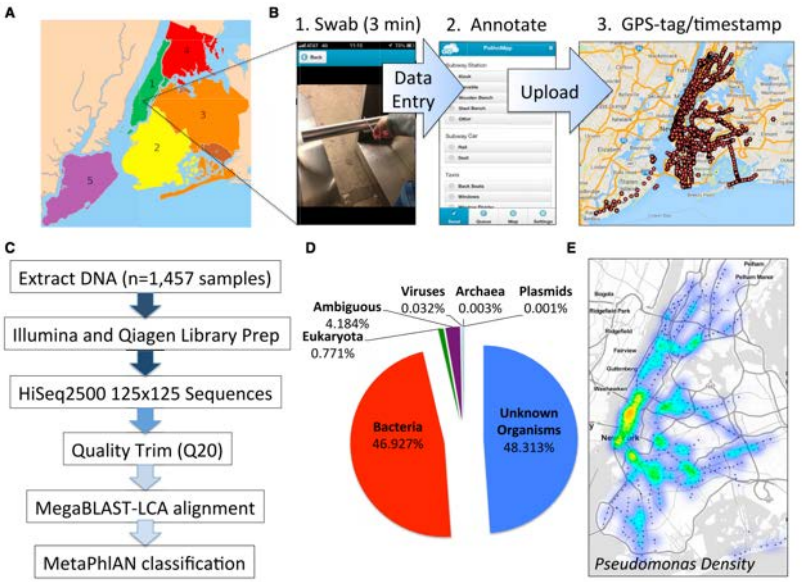
- Short treatment window
- E.g., anthrax







Bio-defense Strategies



(CDC 2012): Modeling activities should be increased substantially . . . An end-to-end model capturing the flow . . . as well as costs . . . and health measures, should begin at the . . . inventory site and go all the way to the point of dispensing . . . to the public.

Supply Chain Decisions

MCM = medical countermeasure

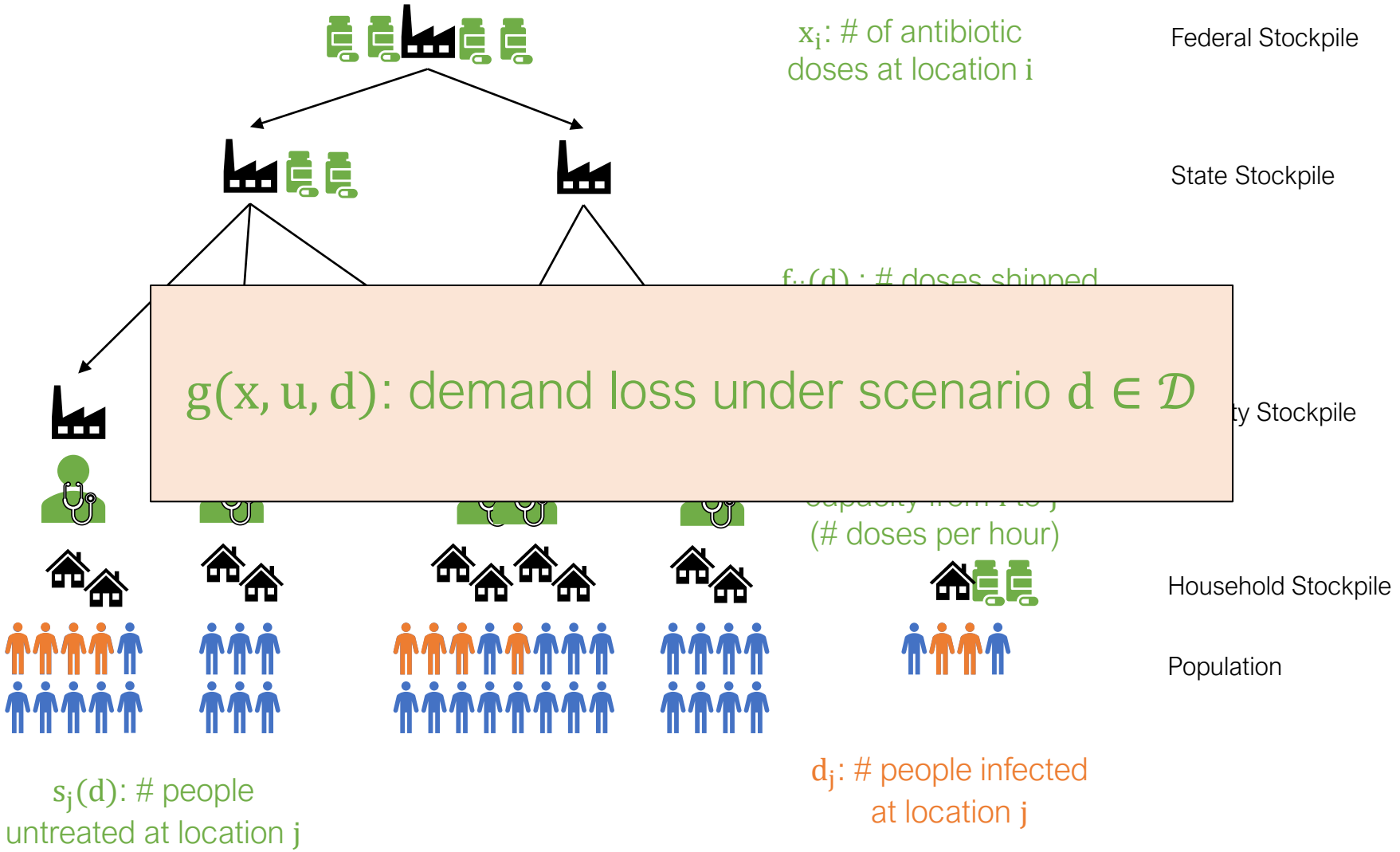
	Pre-Attack (Stage 1)	Attack	Post-Attack (Stage 2)
Federal Stockpiles	MCM Quantity		
Regional Stockpiles	MCM Quantity		
Shipment			Routing[2]
Points of Dispense	Capacity, layout[1]		Operations[1,2,3]
USPS Dispense	Capacity		Deployment[3]
Households	Home medical kits	Demand[4]	Antibiotic efficacy[2,3]

[1] Hupert et al. (2009), Lee et al. (2006, 2006, 2009, 2009)
[2] King and Muckstadt (2009, 2012), Bravata et al. (2006)
[3] Craft et al. (2005), Wein et al. (2003)
[4] Berman and Gavious (2007)

Our Contributions

Quantitative design of responsive supply chain, to minimize impact from demand shock

Model	Integrative model with tractable solution heuristic
Theory	Optimality of solution approach
Case Study	Prepositioning antibiotics against anthrax attacks


x_i: # of antibiotic doses at location i
Federal Stockpile
State Stockpile
$f_{ij}(d)$: # doses shipped
$g(x, u, d)$: demand loss under scenario $d \in \mathcal{D}$
(# doses per hour)
Household Stockpile
Population
$s_j(d)$: # people untreated at location j
d_j: # people infected at location j

Demand Loss Function $g(d)$

$$g(d) = \left\{ \begin{array}{cl} \min\limits_{f(d),s(d)\geq 0} \sum_j s_j(d) & \text{Total demand loss} \\ \text{s.t. } s_j(d) \geq d_j - \sum_i f_{ij}(d) & \text{Flow balance} \\ x_i \geq \sum_j f_{ij}(d) & \end{array} \right\}$$

$g(d)$ is a nonlinear function of d

For exposition: we suppress dependence on x,u and flow-related cost such as treatment delays.

Demand Scenario Set $\mathcal{D}$

- Prop
  - La
  - Attacker ≠ nature
  - Policymakers: "attacker has limited resources"
  - Often seeking

Division of Strategic National Stockpile (DSNS) Program Review

A Report from the Board of Scientific Counselors (BSC)

along with the requirement of having to respond to simultaneous events in three cities, how much material

CDC (2012)

Overall Two-Stage Model

Defender decision	Attacker decision	Loss
$(x, u) \in X$	$d \in \mathcal{D}$	$g(d)$

$$\min_{(x,u)\in X} \max_{d\in\mathcal{D}} g(d)$$

- Robust optimization literature: two-stage robust optimization or adjustable robust optimization
- Military and security literature: defender-attacker-defender framework

Existing Solution Approaches

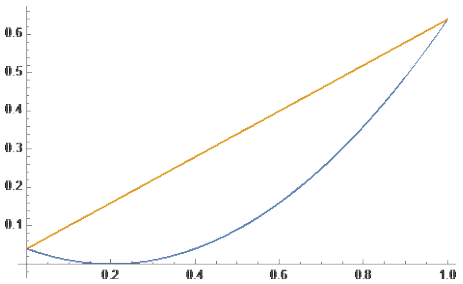
$$\min_{(x,u)\in X} \max_{d\in\mathcal{D}} g(d)$$

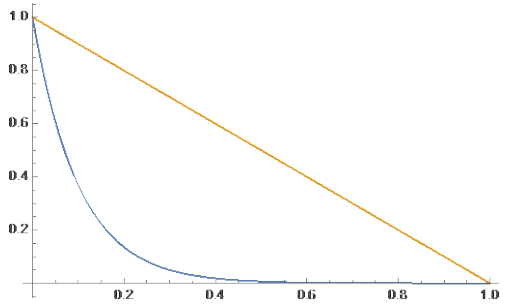
- Overall decision problem: intractable
  - Atamturk and Zhang (2007)
- Exact methods: 100 to 1,000-node network
  - Atkinson (2009), Alderson et al. (2015), Lazzaro (2016)
- National bio-defense: >100,000-node network

Our Solution Approach

$$\min_{(x,u)\in X} \max_{d\in\mathcal{D}} g(d)$$

- Treat it as single-stage nonlinear robust optimization
- Approximate $g(d)$ affine $f(d)$ and $s(d)$ to reformulate it as linear robust optimization
  - Affinely adjustable robust counterpart is tractable, Ben-tal et al. (2004)

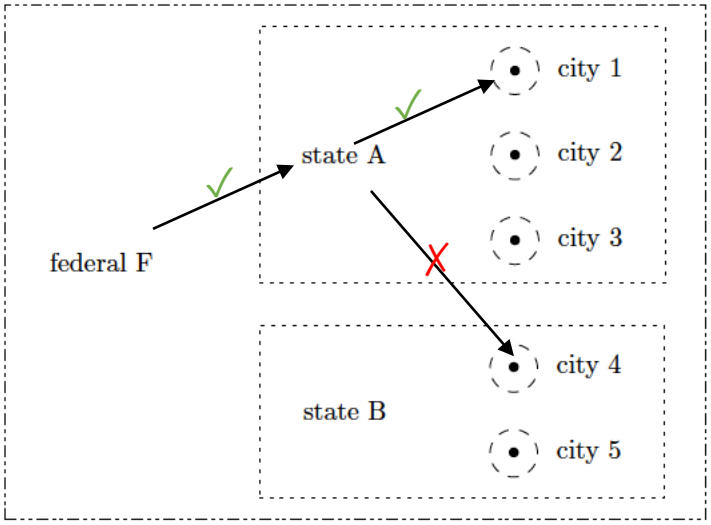




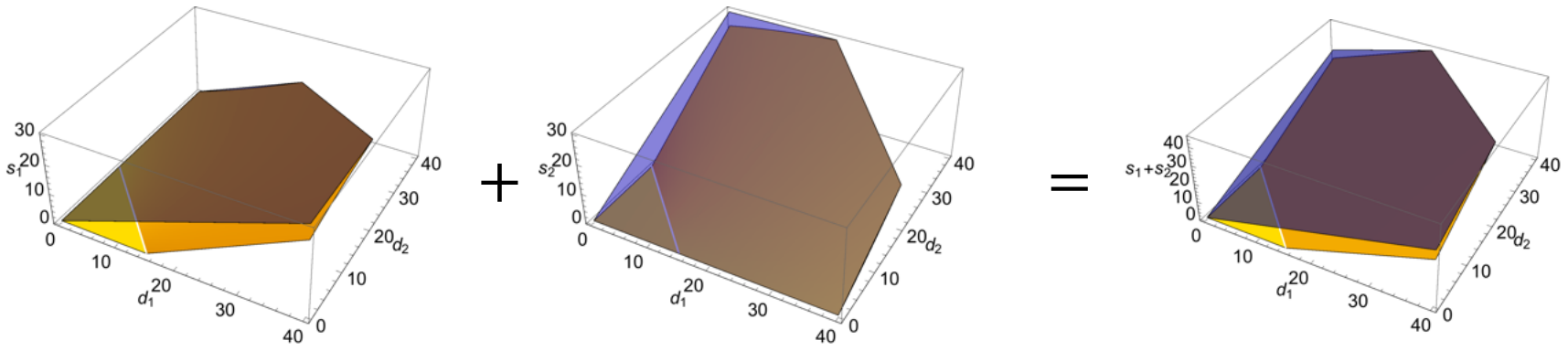
Optimality of Our Approach

Theorem

If the network is a tree, then affine approximation is precise, and tractable.



Key Element in Proof



sum of envelopes = envelope of sum

$\overline{s_1}(d)$ $\overline{s_2}(d)$ —sum→ $\overline{g}(d)$

envelope ↑ ↑ envelope

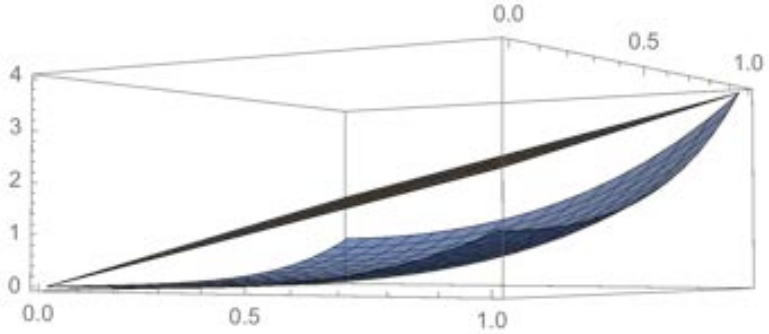
$s_1^\star(d)$ $s_2^\star(d)$ —sum→ $g(d)$

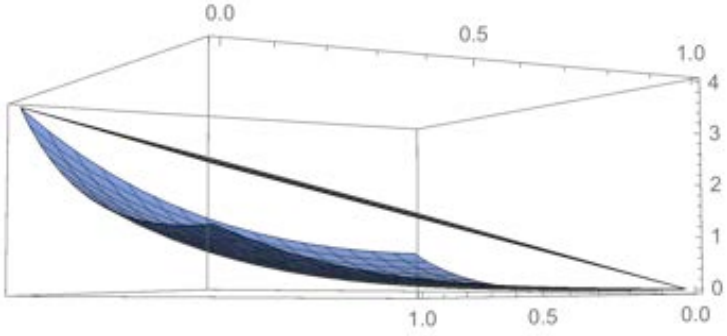
univariate convex

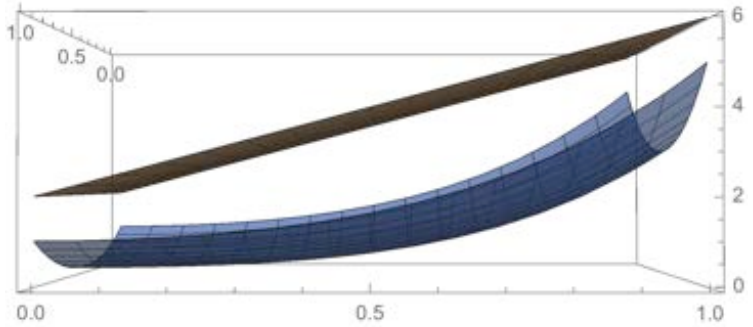
Counter Example

- In general

  Sum of envelopes != Envelope of sum





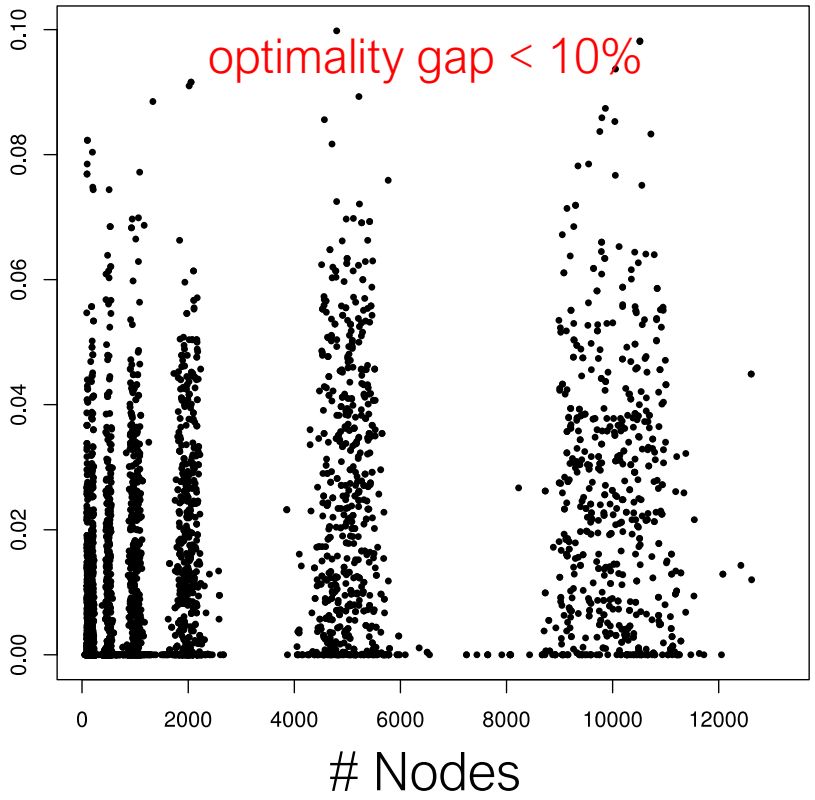


Performance on General Networks

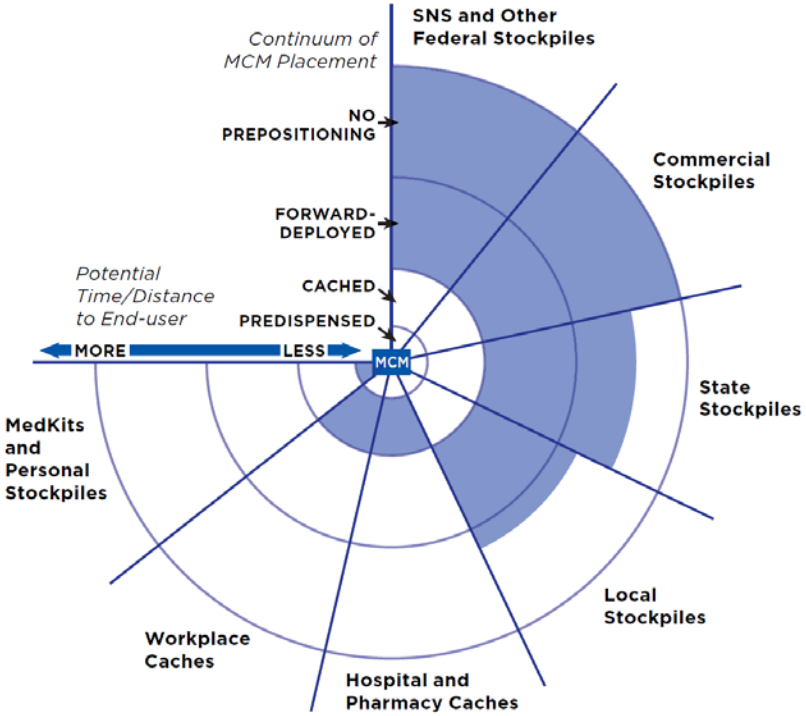
5000 random instances

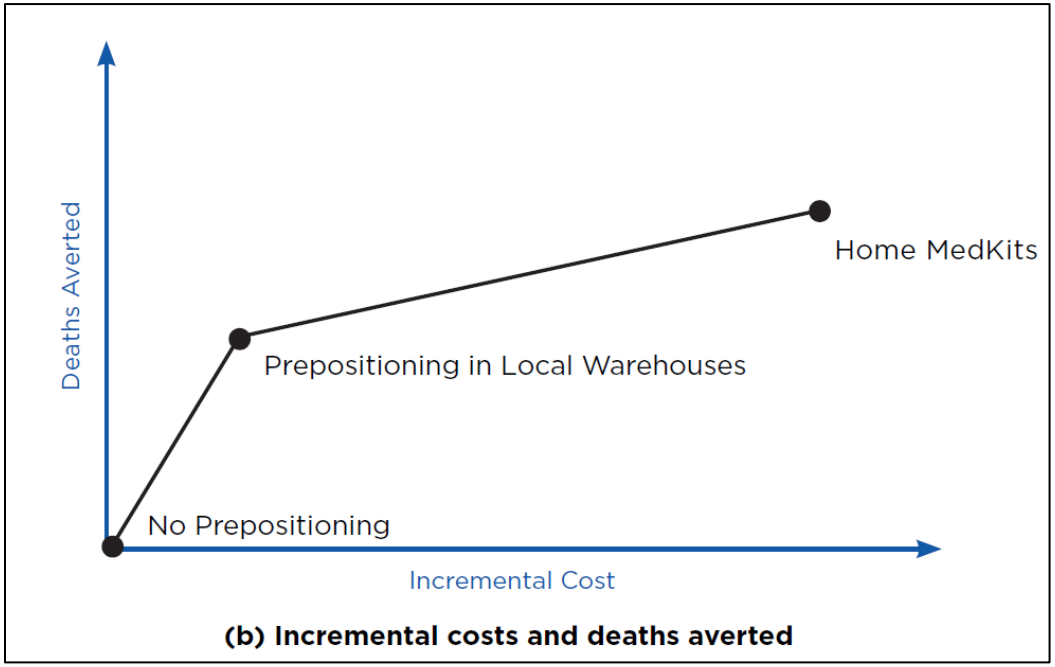
Solution method	Solved (4-hour limit)	Generated Lower Bound	Average Run Time
Affine	100%	-	6 seconds
Exact	2%	91%	3.9 hours

Gap Between Affine and Lower Bound



Case Study: Prepositioning Against Anthrax Attacks

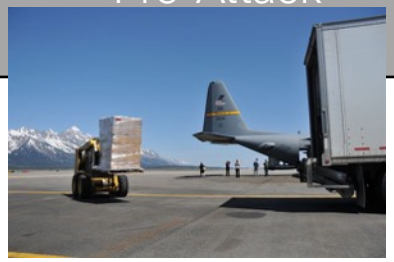
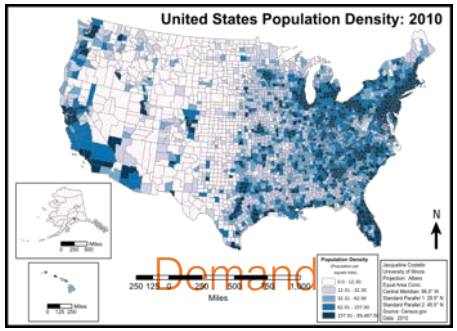
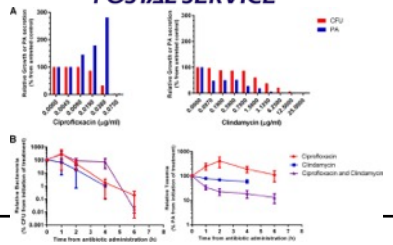




Source: *Prepositioning Antibiotics for Anthrax*, Stroud et al, National Academies Press (2012)

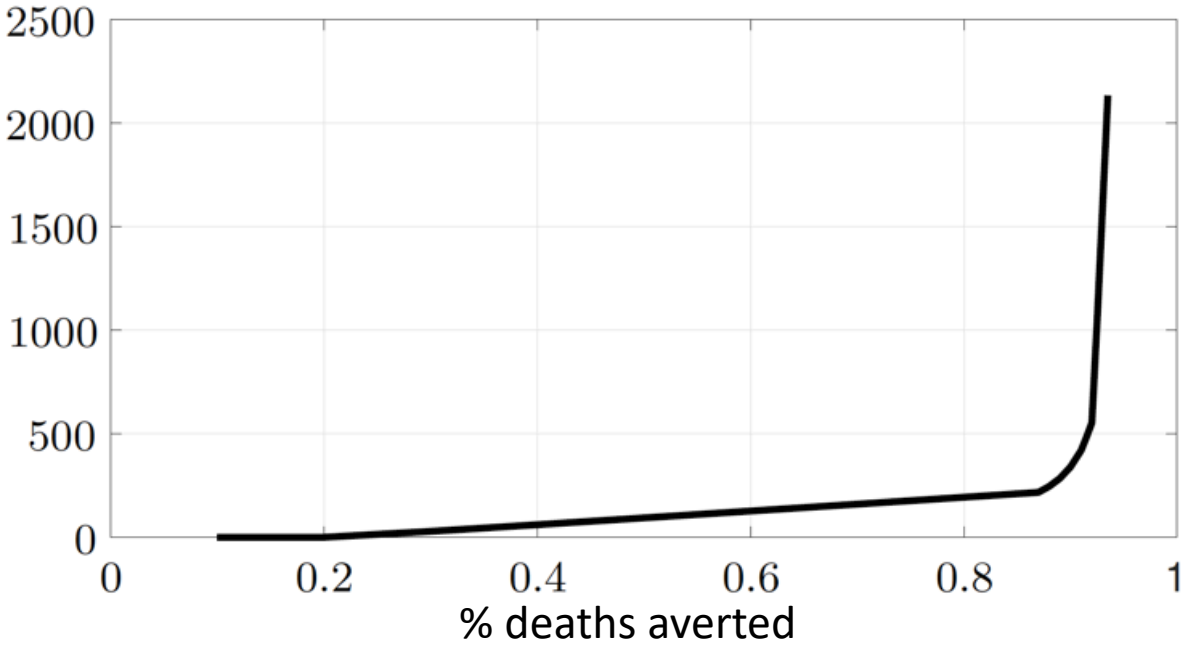
Data Calibration

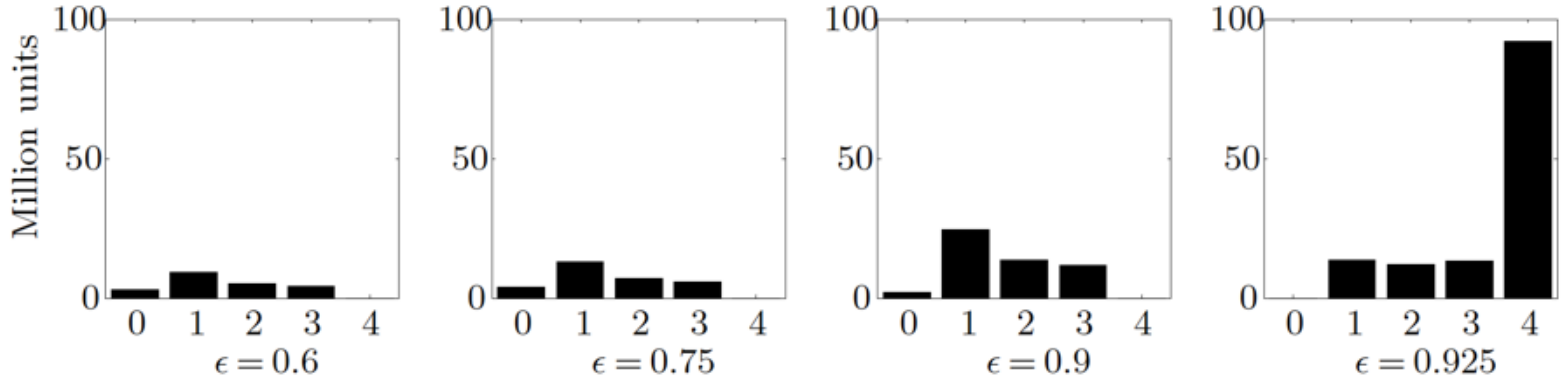
MCM = medical countermeasure

	Pre-Attack	Attack	Post-Attack (Stage 2)
Federal Stockpiles			
Regional Stockpiles			
Shipment			
Points of Dispense			
USPS Dispense	Capacity		
Population	H  its	Demand	

Increasing Marginal Cost

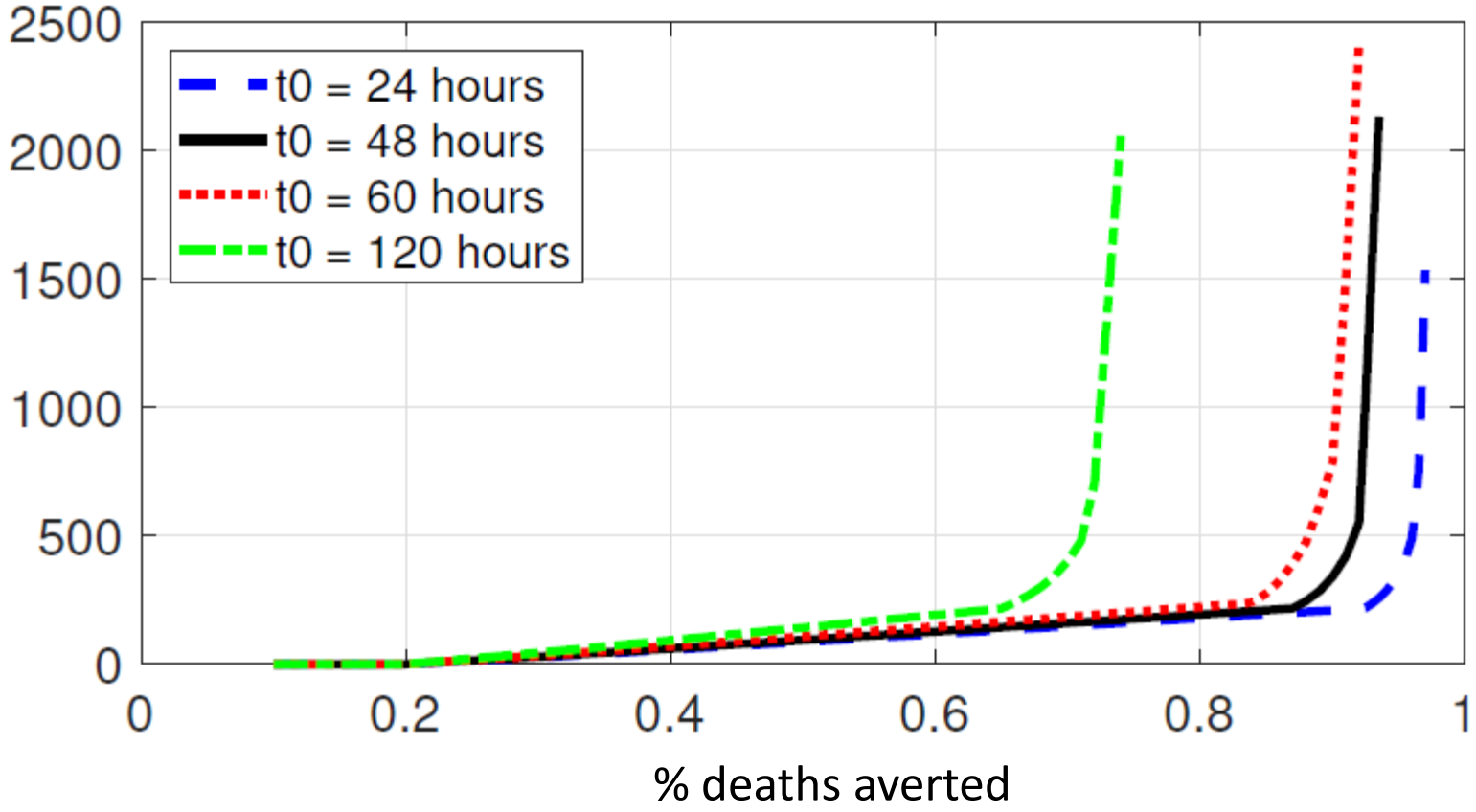
Cost
Million $ / Year



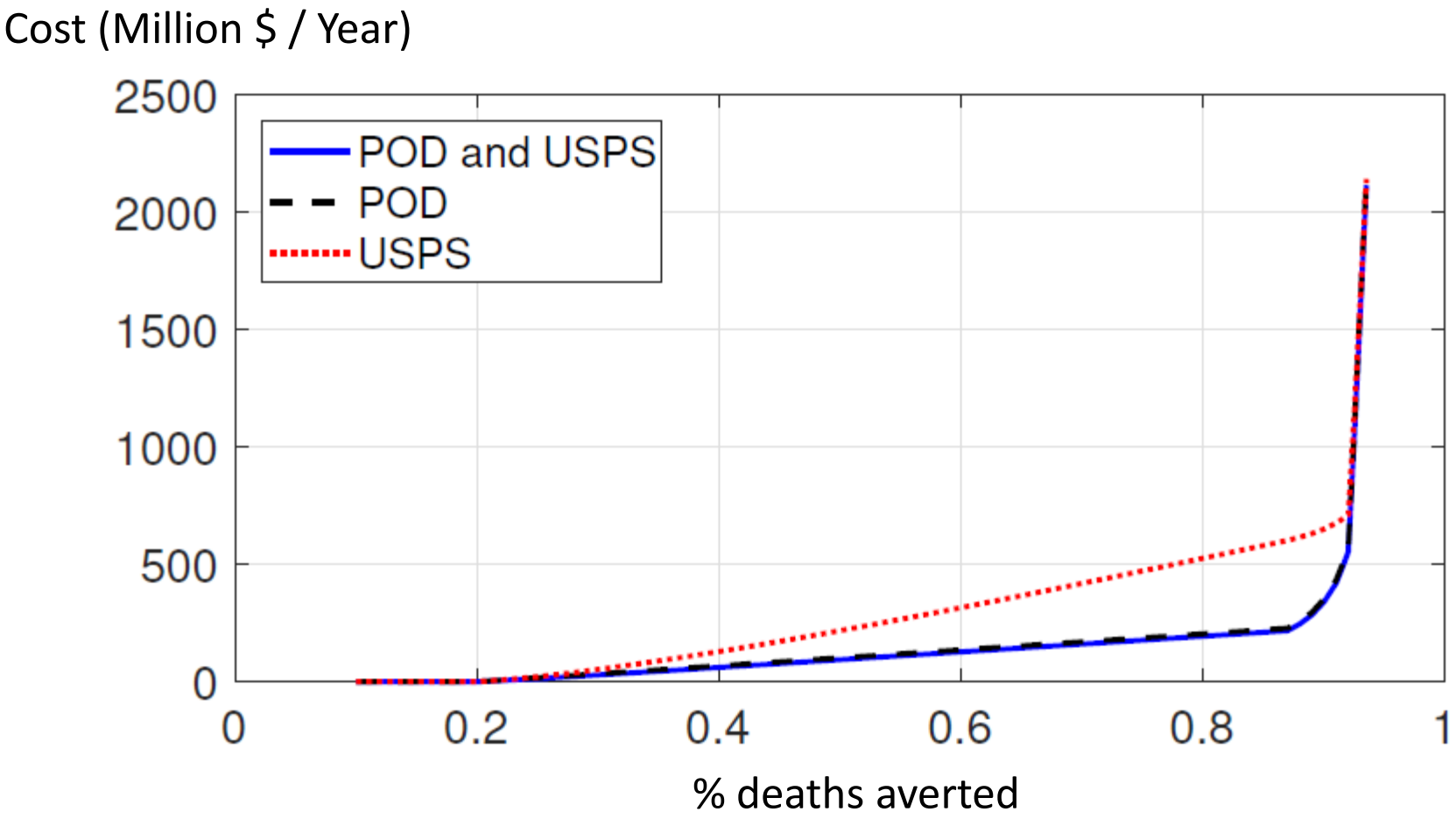


Value of Early Deployment

Cost (Million $ / Year)



Value of Different Delivery Modes



Summary

- End-to-end modeling of inventory and capacity design for a responsive supply chain
- Provably optimal and tractable solution technology
- Direct application to modeling prepositioning strategies for anthrax attacks

- Connecting several streams of literature:
  - Public health OR
  - Military and security
  - Robust optimization
  - Nonlinear optimization

Follow-up Work

- Theory
  - Generalization of several results in the robust optimization literature from 2016 – Current

- Applications
  - Robust classification: robust nonlinear optimization with explicit summation structure
  - Designing resilient social network: defender-attacker-defender problem on a network

Thank You!

- Collaborators
- MAS Society
- Koopman Prize Committee

Paper available:

David Simchi-Levi, Nikolaos Trichakis, Peter Yun Zhang (2019) Designing Response Supply Chain Against Bioattacks. Operations Research 67(5):1246-1268.

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Koopman Prize
2020

Is awarded to

David Simchi-Levi, Nikolaos Trichakis, and Peter Yun Zhang

For their outstanding paper titled

"Designing Response Supply Chain Against Bioattacks"

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