Modeling Integrated Public Health and Health Care Delivery System Response to Anthrax

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Goals of Mass Prophylaxis

- 48 Hours! (the “when”)
- Maximize “Pills in People” (the “what”)
- Multiple secondary goals (the “why”):
  - Prevent illness
  - Social stability
  - Prevent surge on medical treatment facilities
  - Supply chain stability

What outcome metrics can define operational parameters for successful campaigns?
Modeling Schema

Event

Pre-hospital management

Surge arrivals

Hospital or network capacity

Staff
Medical supplies

Beds

Surge Discharge

Treated
Died

Home

Out-of-region facility

SNF
Modeling Schema

Event

Pre-hospital management

Public Health System

Surge arrivals

Hospital or Health System

Staff

Medical supplies

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Surge Discharge

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Died

Home

Out-of-region facility

SNF
Weill Cornell Regional Hospital Caseload Calculator (AHRQ, 2003)

- State transition (compartment) model
- Excel-based, end-user oriented
- Contributed to 48h goal for CRI
### Caseload Calculator Inputs

1. Please select the disease and incidence curve from the list below.

<table>
<thead>
<tr>
<th>Caseload Calculator Results</th>
<th>2</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Anthrax, USA-USSR Normal curve (mean 3.3, st. dev. 3.0)</td>
<td></td>
</tr>
<tr>
<td>2. Anthrax, (Brookmeyer) Log-normal curve (mean 2.398, st. dev. 0.713)</td>
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<td>3. Anthrax, Log-normal curve (mean 6, st. dev. 2)</td>
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<tr>
<td>4. Anthrax, Normal curve (mean 5, st. dev. 2)</td>
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<tr>
<td>5. Anthrax, Gamma curve (alpha 9, beta 0.666)</td>
<td></td>
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<tr>
<td>6. Anthrax, Poisson distribution (mean 6)</td>
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</tr>
<tr>
<td>7. Anthrax, Weibull curve (Brookmeyer, alpha 0.00785, beta 1.07)</td>
<td></td>
</tr>
<tr>
<td>8. Bubonic Plague, Log-normal curve (mean 4.3, st. dev. 1.3)</td>
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<tr>
<td>9. Bubonic Plague, Log-normal curve (mean 2.5, st. dev. 1.2)</td>
<td></td>
</tr>
</tbody>
</table>

2. What is your total population/community size?

   2,000,000 people

3. How many people are exposed to the pathogen? (e.g. What is the attack size?)

   50,000 people exposed

4. What percentage of exposed people develop symptoms if no treatment?

   85%

5. How many days after the attack can the prophylaxis campaign begin? (i.e. 1 = day of attack)

   2 day(s) after the attack

6. From the start of the campaign, how many days does it take to reach maximum prophylaxis capacity?

   1 day(s) after the attack

7. What is the maximum number of people to whom you could deliver prophylactic antibiotics per day at peak operational capacity?

   1,000,000 people per day which equals a 2 day campaign
## Protection via Prophylaxis with Brookmeyer Anthrax Incidence Curve (Optimal Case)

<table>
<thead>
<tr>
<th>Campaign Duration</th>
<th>Delay in Detection</th>
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<tbody>
<tr>
<td></td>
<td>Immediate</td>
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<tr>
<td>10 Days</td>
<td>84%</td>
</tr>
<tr>
<td>9 Days</td>
<td>87%</td>
</tr>
<tr>
<td>8 Days</td>
<td>90%</td>
</tr>
<tr>
<td>7 Days</td>
<td>93%</td>
</tr>
<tr>
<td>6 Days</td>
<td>95%</td>
</tr>
<tr>
<td>5 Days</td>
<td>97%</td>
</tr>
<tr>
<td>4 Days</td>
<td>99%</td>
</tr>
<tr>
<td>3 Days</td>
<td>99%</td>
</tr>
<tr>
<td>2 Days</td>
<td>100%</td>
</tr>
<tr>
<td>1 Days</td>
<td>100%</td>
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</table>
Increasing Hospital Surge with Slow Mass Prophylaxis: Impact of Duration of Campaign

Weill Cornell Regional Hospital Caseload Calculator Output

Increasing Hospital Admissions vs. Immediate Prophylaxis

Avg. 2% Increase/ Day Longer @ Day 2

Delay in Start of Prophylaxis Campaign
Weill Cornell Regional Hospital Caseload Calculator Output

Increasing Hospital Surge with Slow Mass Prophylaxis: Impact of Delay to Initiation of Campaign

Average 4% Increase/Day Delay @ Day 2

<table>
<thead>
<tr>
<th>Increase Hospital Admissions vs. Immediate Prophylaxis</th>
</tr>
</thead>
<tbody>
<tr>
<td>7 Days</td>
</tr>
<tr>
<td>----------</td>
</tr>
<tr>
<td>%</td>
</tr>
<tr>
<td>Avg. 4%</td>
</tr>
</tbody>
</table>

Duration of Prophylaxis Campaign

1 Day Campaign | 3 Days | 5 Days | 7 Days
RHCC Operational Parameters

- For every day that an ideally-deployed anthrax mass prophylaxis campaign is shortened, there may be a 2-6% decrease in overall hospitalizations.

- To accomplish this in the first week, POD efficacy must be increased by anywhere from 14% (7→6d) to 33% (3→2 days).

- *These are large increases in POD efficacy!*
Determinants of POD Efficacy

1. “Fill correctly”
   - Inter-POD network load balancing
   - Intra-POD load balancing
2. “Process efficiently”
   - Staff availability and effectiveness
3. “Sustain appropriately”
   - Supply chain responsiveness and resiliency
Evaluation of Alternative POD Designs

- Construct a stochastic simulation model that dynamically measures throughput capacity and patient flow times
- Experiment with alternative POD design strategies considering the effects of:
  - Timing of the demand for service over the planning horizon
  - Quantity of demand over time at each POD
  - Capacity (quantity and capabilities) of POD staff
## 1a. External Load Balancing

<table>
<thead>
<tr>
<th>POD</th>
<th>Throughput</th>
<th>Average number of people</th>
<th>Throughput</th>
<th>Average number of people</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Balanced</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Unadjusted</td>
<td>5911(±13)</td>
<td>62.57(±7)</td>
<td>5918(±14)</td>
<td>3603(±12)</td>
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<tr>
<td>Adjusted</td>
<td>5993(±16)</td>
<td>59.59(±7)</td>
<td>5988(±19)</td>
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<tr>
<td><strong>Moderately Unbalanced</strong></td>
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<td></td>
<td></td>
<td></td>
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<tr>
<td>Unadjusted</td>
<td>6001(±18)</td>
<td>1206(±14)</td>
<td>3.17(±0.10)</td>
<td>0.89(±0.02)</td>
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<tr>
<td>Adjusted</td>
<td>5981(±16)</td>
<td>605(±14)</td>
<td>30.82(±3)</td>
<td>30.57(±3)</td>
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<tr>
<td><strong>Significantly Unbalanced</strong></td>
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<td></td>
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<tr>
<td>Unadjusted</td>
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<td>1791(±16)</td>
<td>3.16(±0.1)</td>
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<tr>
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<td>593(±13)</td>
<td>27.80(±3)</td>
<td>27.30(±3)</td>
</tr>
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</table>

### Per POD Per hour

- Balanced: 493
- Moderately Unbalanced: 425
- Significantly Unbalanced: 400
1a. External Load Balancing

<table>
<thead>
<tr>
<th>POD</th>
<th>Throughput</th>
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<td>Per POD Per hour</td>
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<td></td>
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<td>493</td>
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**Role for Direct-to-Population Communications**

<table>
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**Average number people**

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</tbody>
</table>
Traditional 500pph POD

- Classic station set-up
  - Greeting, Triage, Medical Evaluation, Dispensing
  - 5% G→ME, 5% T→ME

- Exponential processing times
  - G (20sec), T(1min), ME(5min), D(30sec)

- Optimized staffing using BERM
  - 4 Greeters, 9 Triage, 5 Med Eval, 5 Dispensers

- (G, T, D) considered cross-trainable

- 12-hour shift
1b. Internal Load Balancing: Baseline POD @500pph

- Throughput
  - 497.3pph (+/- 1.3)
- Flow time
  - 3.5 minutes
- Average # in Queue
  - Greet: 0.9 +/- 0.03
  - Triage: 4.6 +/- 0.3
  - MedEval: 2.3 +/- 0.3
  - Dispense: 2.9 +/- 0.1

![Diagram showing total patients in POD with categories: Greeting, Triage, Medical Eval, Dispensing]
1b. Internal Load Balancing: Baseline POD @600pph

- Throughput
  - 563.8pph (+/- 1.3)
- Flow time
  - 24.3 min. (0→45 m)
- Average # in Queue
  - Greet: 3.0 +/- 0.12
  - Triage: 195.9 +/- 12.7
  - MedEval: 8.9 +/- 1.3
  - Dispense: 12.6 +/- 1.0
1b. Internal Load Balancing: Baseline POD @600pph

Total Patients in POD

Throughput 563.8 pph (+/- 1.3)
Flow time 24.3 min (+/- 45 m)
Average # in Queue
- Greet 3.0 +/- 0.12
- Triage 195.9 +/- 12.7
- MedEval 8.9 +/- 1.3
- Dispense 12.6 +/- 1.0

Role for Improved POD Design and Mgmt
2. Time = Staff

Staffing Needs, Anthrax POD, High Complexity (BERM Floorplan)
2. Time = Staff

Role for Fundamentally Different Type of Activation Exercises
3. Inventory (Re-)Allocation

What should we order now?

$T_{i0} = 5$ periods

What should we ship now, and how should we ship it?

$T_{ij} = 2$ periods

Communication

Central Warehouse

Patients
3. Inventory (Re-)Allocation

$T_{i0} = 5$ periods

What should we order now?

Role for Fundamentally Different Type of Continuity Exercises

Central Warehouse

What should we ship now, and how should we ship it?

Communication

Patients
POD Alternatives

● “One-Stop Shop” in the POD
  — Eliminate the standard multi-station approach to internal POD design (goes further than
  — Extensive cross-training required
  — Drive-through may be variant of this
  — Certain stations may remain distinct due to different cadre of worker
One-Stop-Shop POD @600pph (Same total # staff)

- Throughput
  - 597.3pph (+/- 1.4)
- Flow time
  - 3.2 minutes
- Average # in Queue
  - G-T-D: 3.2 +/- 0.2
  - MedEval: 7.4 +/- 0.9
Other Alternatives

- Assortment of POD and non-POD approaches
  - Primary Care Provider Sites
  - Med Kit
  - Postal
  - Others to be discussed
Modeling Realistic PODs

- Though the effects of uncertainty can be mitigated to some extent through collaboration and communication, fundamental uncertainty will always exist.
- Systems need to be designed so that they are robust in the presence of this uncertainty.
- Models should capture and represent the implications of uncertainty on outcomes.
POD Planning Goal

POD systems needs to be *maximally effective and efficient* under conditions of *extreme uncertainty* relating to care-seeking and *resource availability*. 
We are creating a collection of interacting models for designing POD systems that

- Represent the dynamic nature of arriving care-seekers and calculate optimal time-varying POD resource requirements
- Allocate arriving care-seekers optimally among PODs so as to minimize POD resource requirements and service times
- Establish POD layout strategies that minimize care-seeker service times (maximize POD worker effectiveness)

We are determining corresponding heuristics for managing real time POD operations

Much of this work remains contingent on funding
Final Comment

Strategic, tactical, and operational decision making with:

*awareness of the uncertain nature of the operational environment, and*

*the interaction of that environment with response mechanisms employed*

will lead to improved outcomes.
New web site for BERM and associated models

*www.simfluenza.org*
Research Team & Collaborators

- Weill Cornell Medical Center and Cornell University Operations Research and Information Engineering
  - Jack Muckstadt, PhD
  - Wei Xiong, PhD
  - Shirish Chinchalkar, PhD
  - Peter Jackson, PhD
  - Shane Henderson, PhD
  - Huseyin Topaloglu, PhD
- College of William and Mary
  - David Murray, PhD
- DHHS, Agency for Healthcare Research and Quality
  - Sally Phillips, RN, PhD
- DHHS, NIGMS
  - Irene Eckstrand, PhD
- DHHS, NIH/NIAID
  - Richard Hatchett, MD
- New York-Presbyterian Hospital
  - Jaclyn van lieu Vorenkamp, MD
  - Nick Cagliuso, PhD
  - Eliot Lazar, MD
  - Laura Forese, MD
- Cayuga Medical Center
  - David Evelyn, M.D.
- Cornell Operations Research Students
  - Kathleen King
  - Andrew Lazar
  - Antoine Cossart
  - Lei Yao
  - Stephen Bakke
  - Ji Kim
  - Jeff Schvey
  - Caitlin Hawkins
  - James Sanders
  - James Codella