Operations Research for Public Health Preparedness

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The process of responding to a bioterrorism attack starts with detection and investigation.

Prepositioning → Outbreak

Environmental Monitoring → Clinical Diagnosis → Syndromic Surveillance

Outbreak Investigation → Decision to respond → Distribution to PODs

Dispensing at PODs
Points of Dispensing (PODs) provide mass vaccination or dispensing of medication.
The medication supply chain must move quickly to distribute medications.

Strategic National Stockpile → Local Depot (RSS) → POD → residents
→ POD → residents
→ POD → residents
→ POD → residents
→ POD → residents
Planning Problems

• What is the best way to preposition medication?
• How should medication be delivered to points of dispensing (PODs)?
• What is the best POD layout?
• How many staff do we need?
• How long will people wait in line?
Prepositioning medical countermeasures affects the mortality of an anthrax attack.

Potential exposure = someone will seek prophylaxis but cannot become ill.
28 compartments track the number of exposed, ill, recovered, and dead.
The compartment changes first after changing disease status and then after changing treatment status.

\[ Y_i(t) = X_i(t) + \sum_{j=1}^{28} \phi_{ji}(t) - \sum_{j=1}^{28} \phi_{ij}(t) \]

\[ X_i(t + 1) = Y_i(t) + \sum_{j=1}^{28} \psi_{ji}(t) - \sum_{j=1}^{28} \psi_{ij}(t) \]
## Scenario timeline.

<table>
<thead>
<tr>
<th>Time (hours)</th>
<th>Event</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>Attack occurs.</td>
</tr>
<tr>
<td>48</td>
<td>Attack detected. PODs start opening.</td>
</tr>
<tr>
<td>53</td>
<td>Local supplies become available.</td>
</tr>
<tr>
<td>64 (or 76)</td>
<td>Push pack supplies becomes available.</td>
</tr>
<tr>
<td>84</td>
<td>Vendor-managed inventory becomes available.</td>
</tr>
<tr>
<td>96</td>
<td>All PODs at maximum capacity.</td>
</tr>
</tbody>
</table>

Population size = 5,000,000.
Number exposed = 50,000, 500,000, and 1,250,000.
Percentage of non-exposed persons who will seek prophylaxis (potential exposures) = 1%, 10%, and 50%.
Adherence rate = 65% and 90%.
Model output can estimate exposed population by condition over time.
Deaths decrease as more medication is predispensed.

Deaths as Medkits Distribution Increases
(alphalpha = 90%, \( t = 24 \) hours)

\( N = \) the number exposed.
\( b = \) the fraction of non-exposed persons who will seek prophylaxis (potential exposures).
\( \alpha = \) prophylaxis adherence rate
\( t = \) delay until push pack is available
The last leg of medication distribution is from a local RSS to the PODs.
PODs will receive batch deliveries, which must arrive before supplies are exhausted.
Inventory slack routing problem (ISRP) formulation maximizes minimum slack.

\[
\max S = \min_{v=1,\ldots,V; j=1,\ldots,r_v} \{ s_{vj} \}
\]

\[
s_{vj} = \min_{k \in \sigma_{vj}} \left\{ T_1 + Q_{vjk} / L_k - (t_{vj} + w_{vj}) \right\}
\]

\[
Q_{vjk} = \sum_{(a,b) \in E_{vjk}} q_{abk}
\]

\[
\sum_{(a,b) : t_{ab} \leq t_{vj}} \sum_{k \in \sigma_{ab}} q_{abk} \leq I(t_{vj}) \quad v = 1,\ldots,V; j = 1,\ldots,r_v
\]

\[
t_{vj} \geq t_{v,j-1} + y_{v,j-1} \quad v = 1,\ldots,V; j = 2,\ldots,r_v
\]

\[
\sum_{k \in \sigma_{vj}} q_{vjk} \leq C_v
\]

\[
\sum_{v=1}^V \sum_{j=1}^{r_v} q_{vjk} = (T_2 - T_1) L_k \quad k = 1,\ldots,n
\]

\[
t_{vj} \geq 0
\]
Waiting at a POD

Patients wait in line for flu shots in Silver Spring, Maryland.
From Patient Flow …

Arrival → Triage → Registration

Holding Room → Symptoms Room

Exit ← Vaccination ← Screening

Consultation
…to Simulation Model

- Simulation model created using Arena®.
Queueing Network Analysis

Patient

Workstation

Queue

Server
Performance Measures

Clinic Capacity

\[ R = \min_{i=1,\ldots,I} \left\{ \frac{m_i r_1}{t_i r_i} \right\} \]

Station utilization

\[ u_i = \frac{r_i \cdot t_i}{m_i \cdot k_i} \]

Station cycle time

\[ CT_i = w_i + t_i + W_i \]

Total cycle time

\[ TCT = \frac{1}{r_1} \sum_{i=1}^{I} r_i CT_i \]
The Clinic Generator spreadsheet takes inputs from the user and modifies the Clinic Template file to create a custom clinic planning model that the user can modify as desired.
### Inputs

#### Demand

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Size of population to be treated</td>
<td>10100</td>
</tr>
<tr>
<td>Time allotted for treatment (days)</td>
<td>4</td>
</tr>
<tr>
<td>Daily hours of operation</td>
<td>8</td>
</tr>
<tr>
<td>Number of clinic sites</td>
<td>1</td>
</tr>
<tr>
<td>Required throughput (patients per hour)</td>
<td>316</td>
</tr>
</tbody>
</table>

#### Staffing (per clinic site)

<table>
<thead>
<tr>
<th>Station name</th>
<th>Staff per shift</th>
<th>Minimum staff per shift</th>
</tr>
</thead>
<tbody>
<tr>
<td>Triage</td>
<td>10</td>
<td>10</td>
</tr>
<tr>
<td>Flu Vaccination (All ages)</td>
<td>12</td>
<td>12</td>
</tr>
<tr>
<td>Total Service Staff</td>
<td>22</td>
<td>22</td>
</tr>
<tr>
<td>Total Staff</td>
<td>57</td>
<td>Set all to minimum</td>
</tr>
</tbody>
</table>

### Outputs

#### General Performance

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Time in clinic (min)</td>
<td>7.12</td>
</tr>
<tr>
<td>Average number of patients in clinic</td>
<td>37</td>
</tr>
<tr>
<td>Bus interarrival time (min)</td>
<td>0.19</td>
</tr>
<tr>
<td>Clinic capacity (patients per hour)</td>
<td>329</td>
</tr>
<tr>
<td>Total staff per shift across all clinics</td>
<td>57</td>
</tr>
</tbody>
</table>

#### Station-level Results

<table>
<thead>
<tr>
<th>Station name</th>
<th>Wait time (min)</th>
<th>Queue length</th>
<th>Utilization</th>
</tr>
</thead>
<tbody>
<tr>
<td>Triage</td>
<td>1.26</td>
<td>7</td>
<td>92.2%</td>
</tr>
<tr>
<td>Flu Vaccination (All ages)</td>
<td>1.96</td>
<td>10</td>
<td>95.8%</td>
</tr>
</tbody>
</table>

Values in red signify below-minimum staffing levels. Values in red denote the "worst" station for that characteristic.
Comparing the approximations to simulation yielded mixed results.

Cycle time from simulation (min) with lower and upper bound (confidence interval for 95%)

Average of cycle time from simulation with lower and upper bound

Cycle time from formula

Entitiy cycle time in clinic (min)

Resident arrival rate to clinic (percentage of clinic capacity)
Public health emergency preparedness planners around the country are using CPMG.

Download: www.isr.umd.edu/Labs/CIM/projects/clinic
Final Thoughts

- Modeling should create a conversation, not just answer a question.
Acknowledgements

• Centers for Disease Control and Prevention
• National Association of County and City Health Officers
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  – Kay Aaby
  – Rachel Abbey
  – Carol Jordan
  – Kathy Wood
... and the students:
For more information

• Visit the project web site at http://www.isr.umd.edu/Labs/CIM/projects/clinic/
• Download the Clinic Planning Model Generator at http://www.isr.umd.edu/Labs/CIM/projects/clinic/cpmg.html
• Get publications about the work at http://www.isr.umd.edu/Labs/CIM/projects/clinic/publications.html
• Contact Jeffrey Herrmann at jwh2@umd.edu