Operations Research for Public Health Preparedness

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IIE Transactions

Focused Issue on Operations Engineering and Analysis

Homeland Security Department

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

Prepositioning

Outbreak

Environmental Monitoring

Clinical Diagnosis

Syndromic Surveillance

Outbreak Investigation

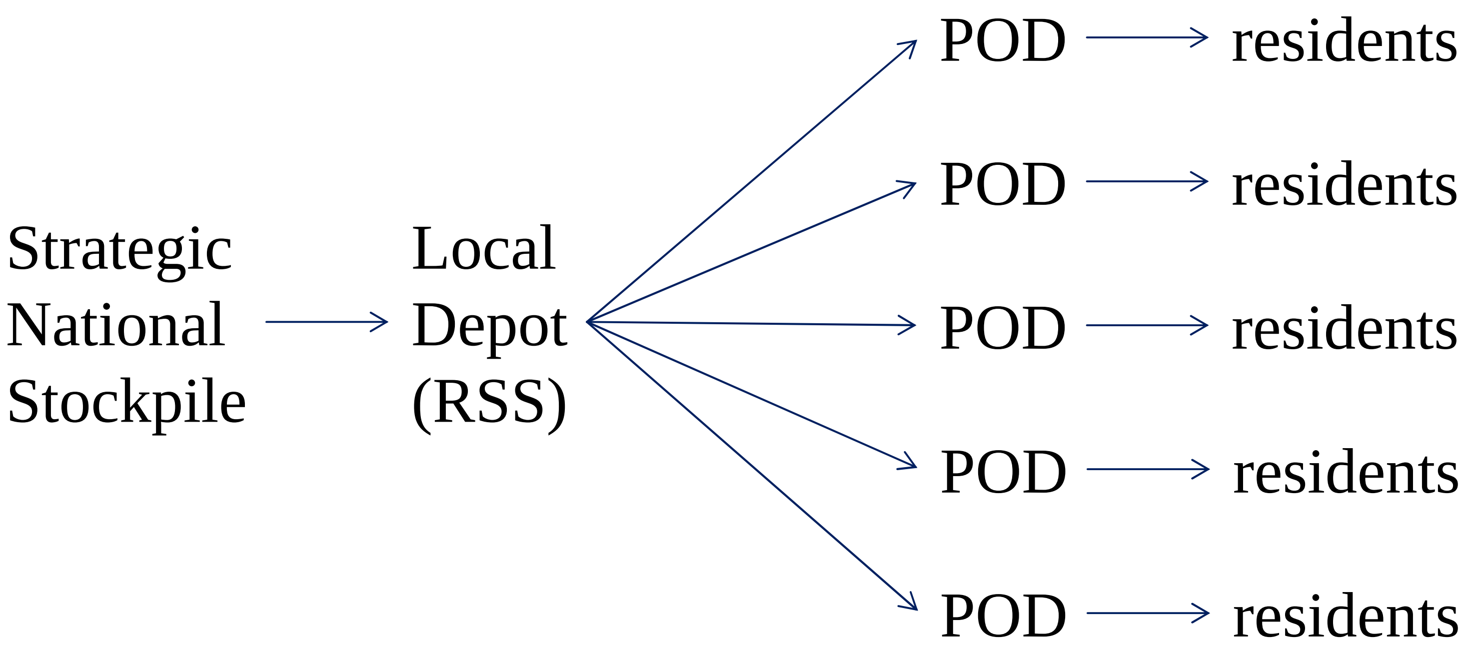
Decision to respond

Distribution to PODs

Dispensing at PODs

Points of Dispensing (PODs) provide mass vaccination or dispensing of medication.

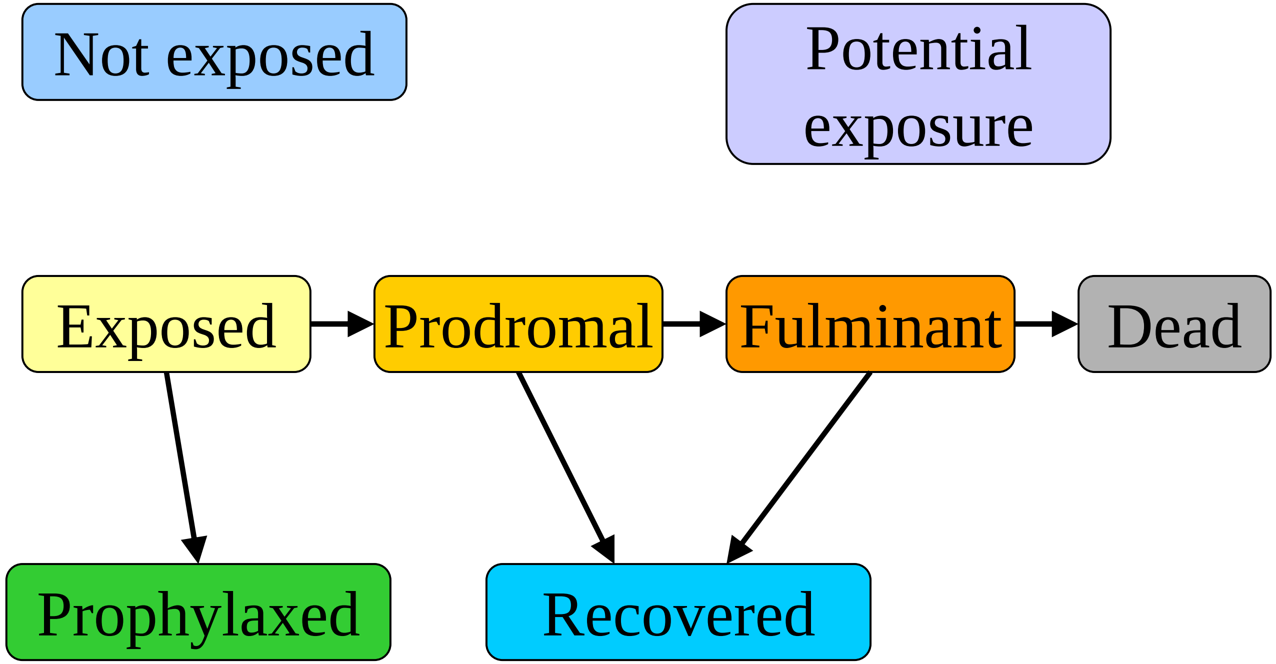
The medication supply chain must move quickly to distribute medications.



Planning Problems

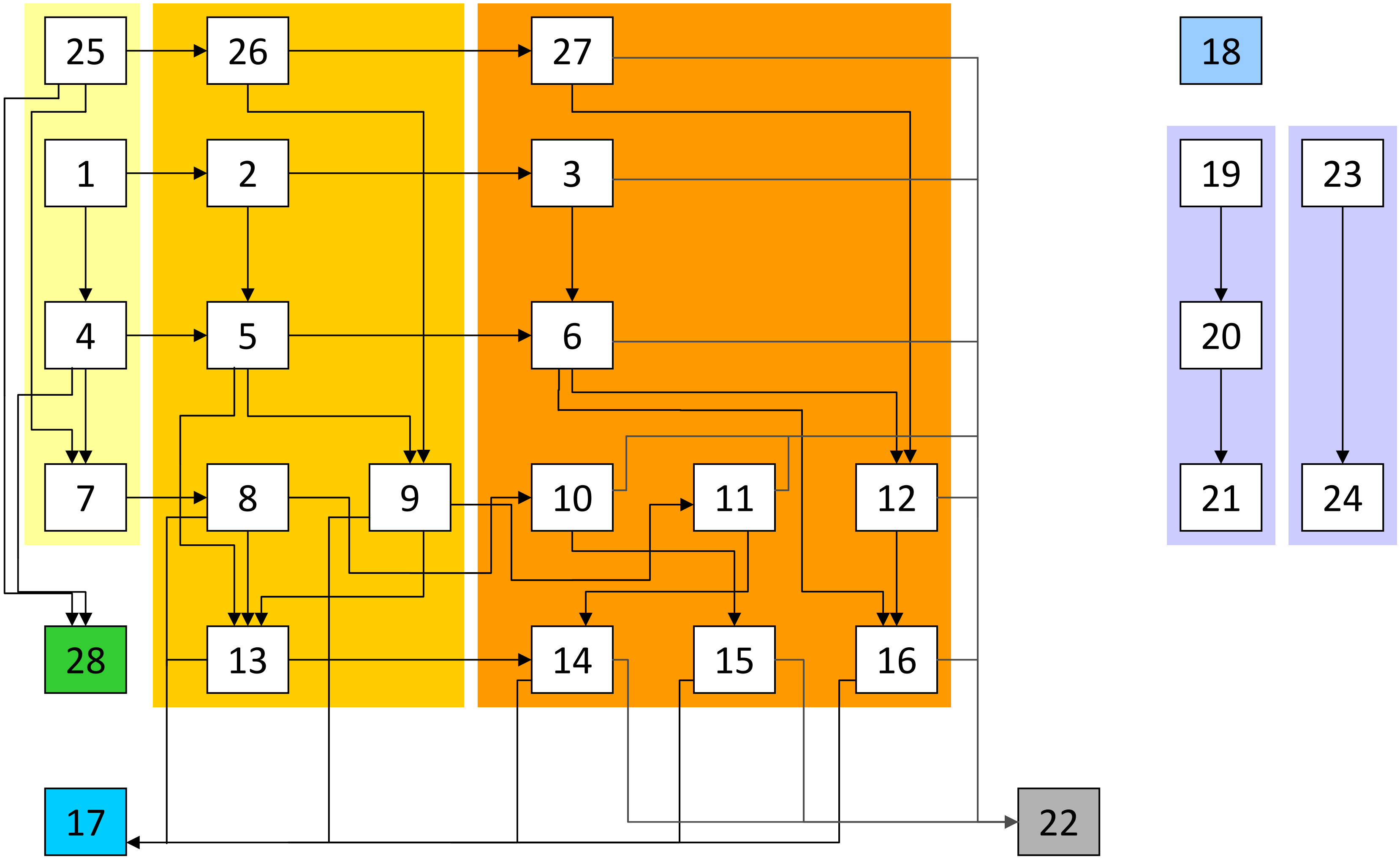
- What is the best way to preposition medication?
- How should medication be delivered to points of dispensing (PODs)?
- What is the best POD layout?
- How many staff do we need?
- How long will people wait in line?

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.

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

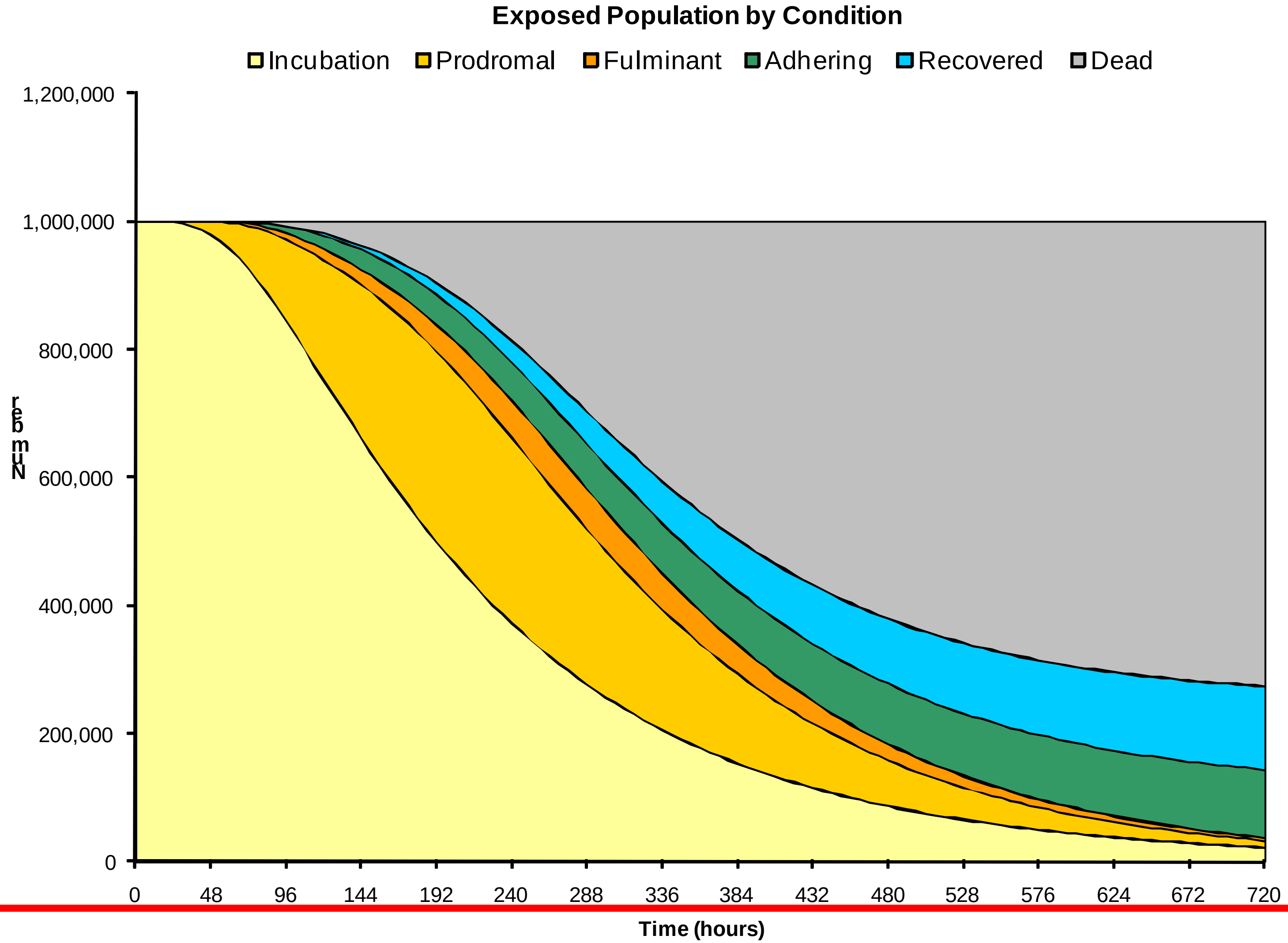
$$X_i(t+1) = Y_i(t) + \sum_{j=1}^{28} \psi_{ji}(t) - \sum_{j=1}^{28} \psi_{ij}(t)$$

Scenario timeline.

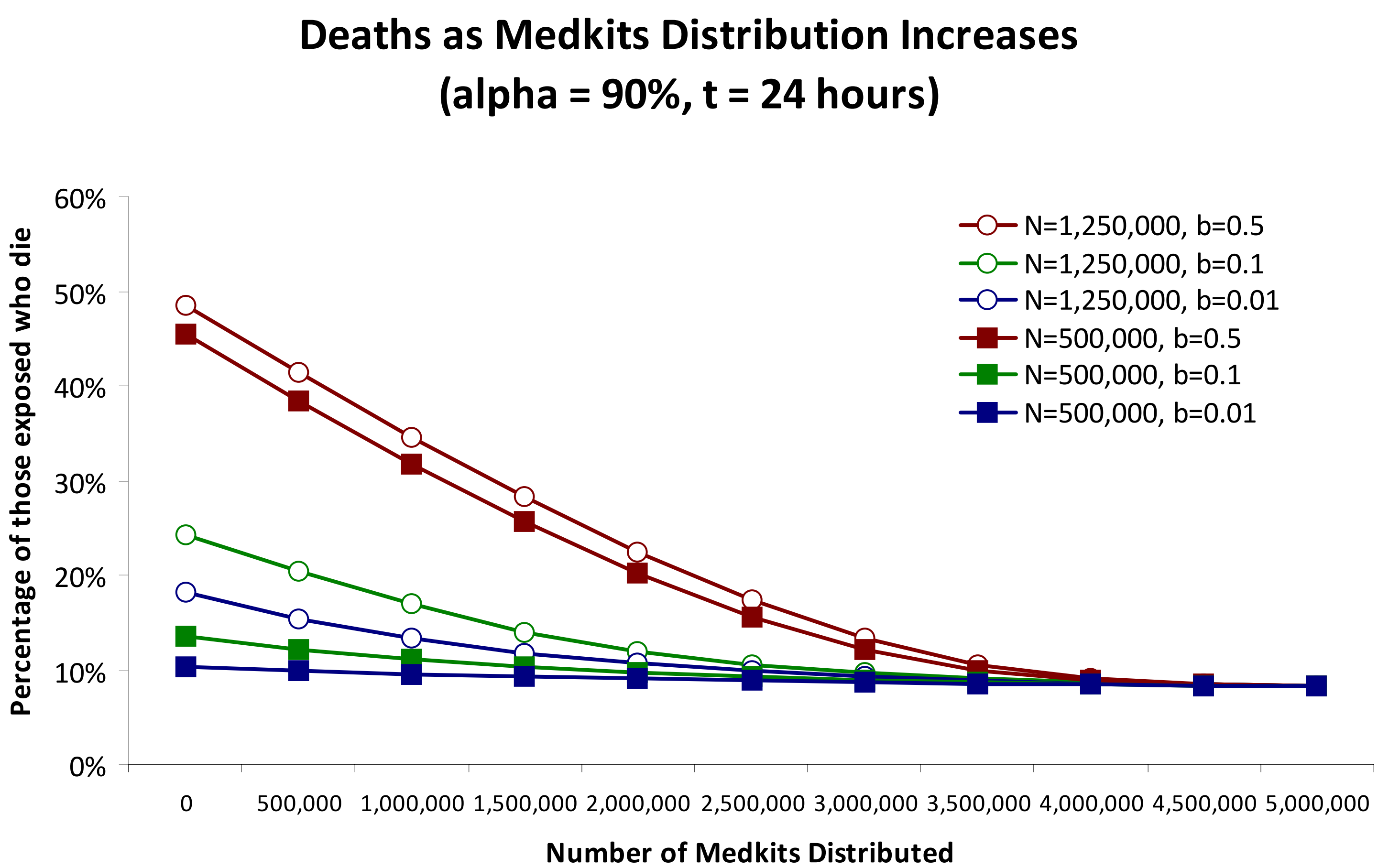
Time (hours)	Event
0	Attack occurs.
48	Attack detected. PODs start opening.
53	Local supplies become available.
64 (or 76)	Push pack supplies becomes available.
84	Vendor-managed inventory becomes available.
96	All PODs at maximum capacity.

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.



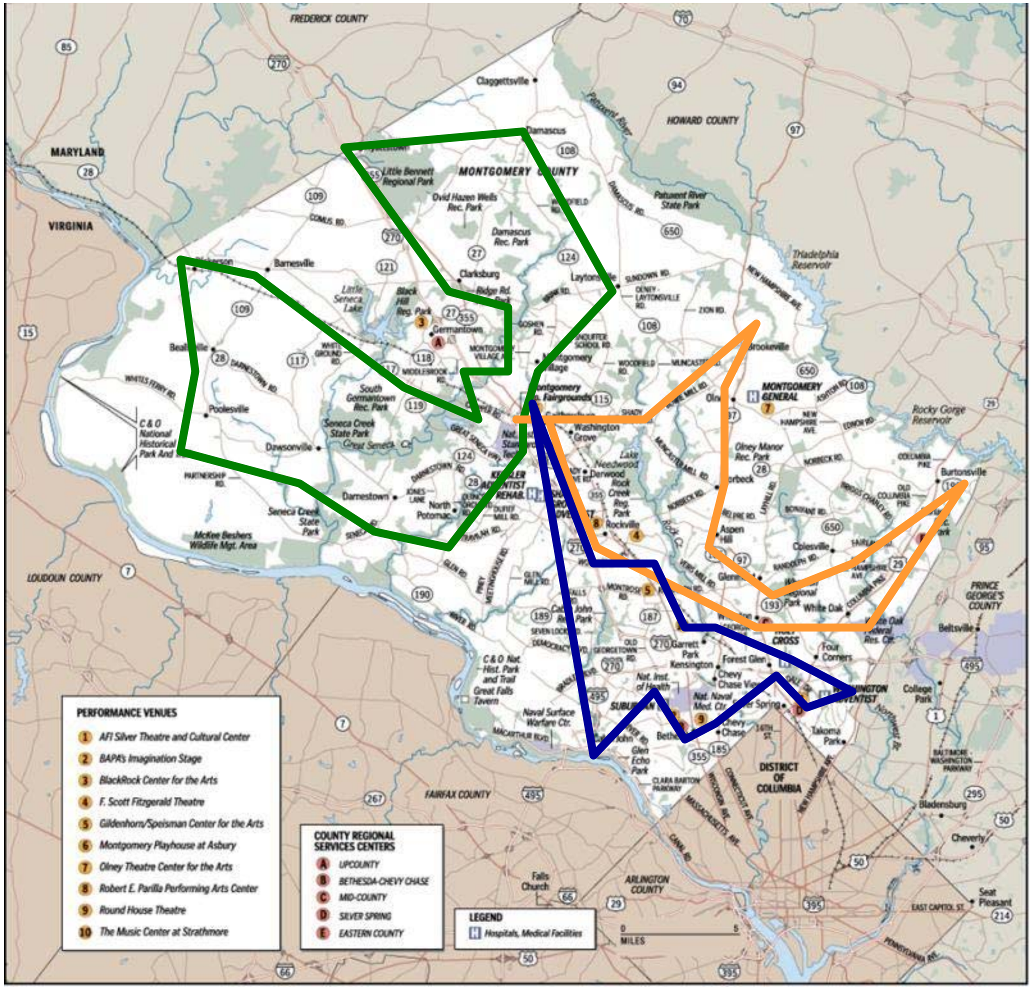
N = the number exposed.

b = the fraction of non-exposed persons who will seek prophylaxis (potential exposures).

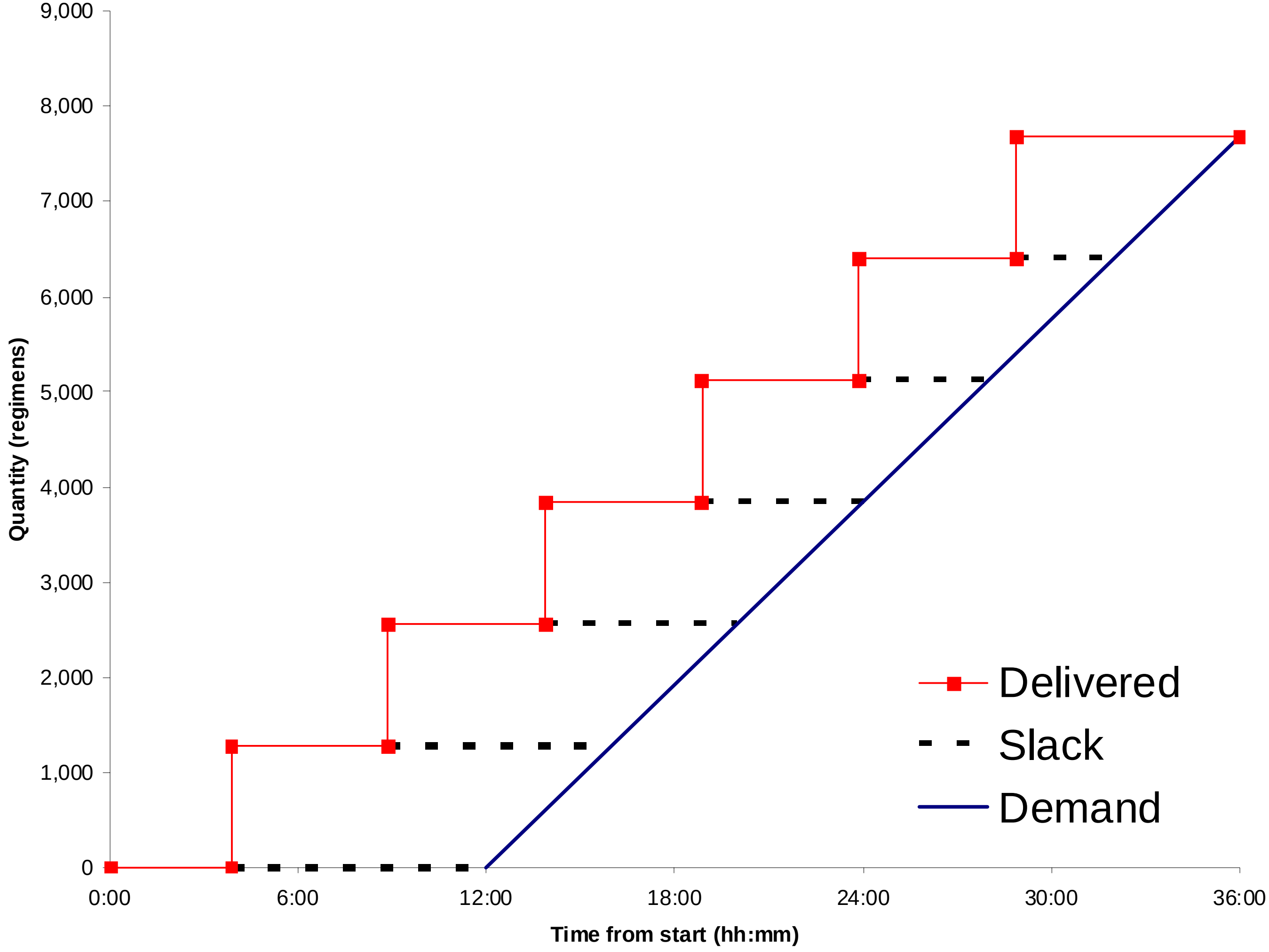
alpha = prophylaxis adherence rate

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.

$$\max S = \min_{v=1,\ldots,V;\, j=1,\ldots,r_v} \left\{ s_{vj} \right\}$$

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

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

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

$$t_{vj} \ge t_{v,j-1} + y_{v,j-1} \quad v = 1,\ldots,V;\ j = 2,\ldots,r_v$$

$$\sum_{k \in \sigma_{vj}} q_{vjk} \le C_v$$

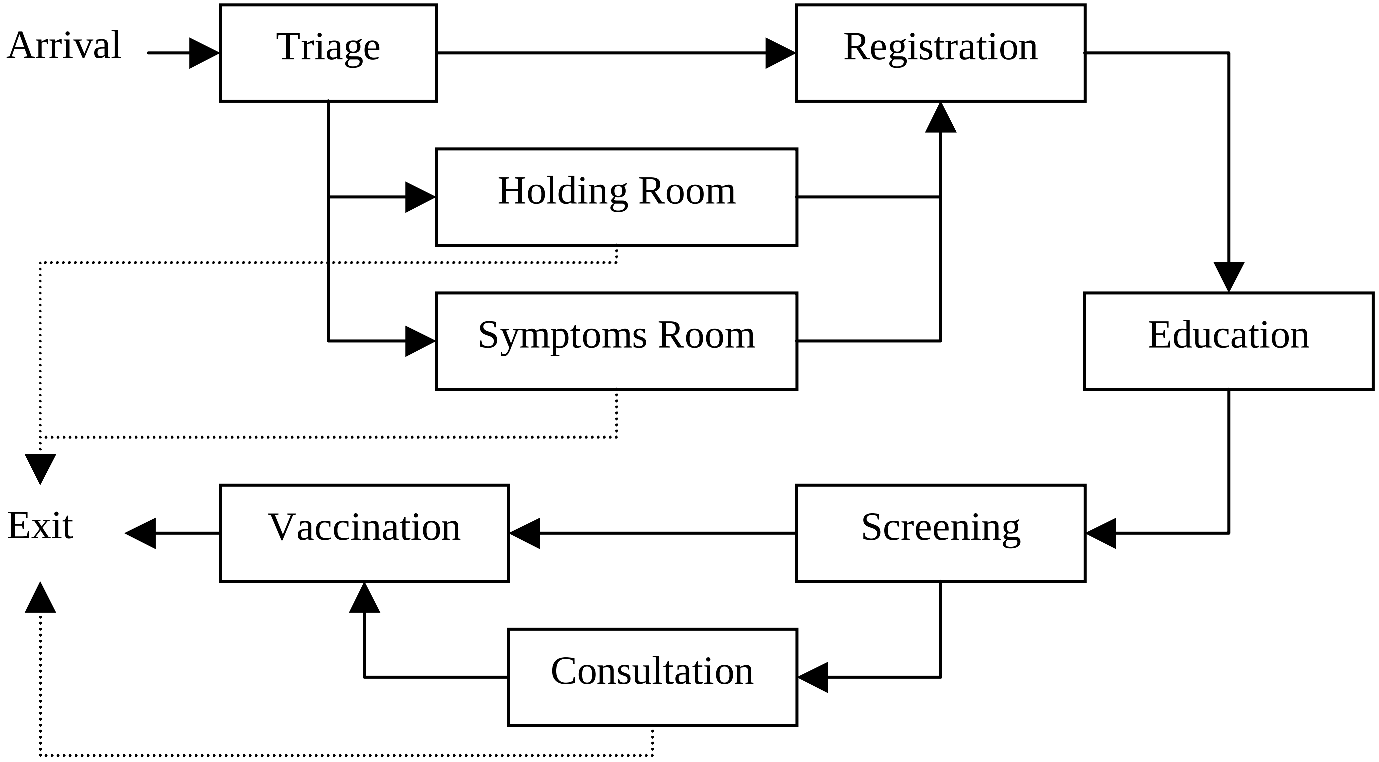
$$\sum_{v=1}^{V} \sum_{j=1}^{r_v} q_{vjk} = \left(T_2 - T_1\right) L_k \quad k = 1,\ldots,n$$

$$t_{vj} \ge 0$$

Waiting at a POD

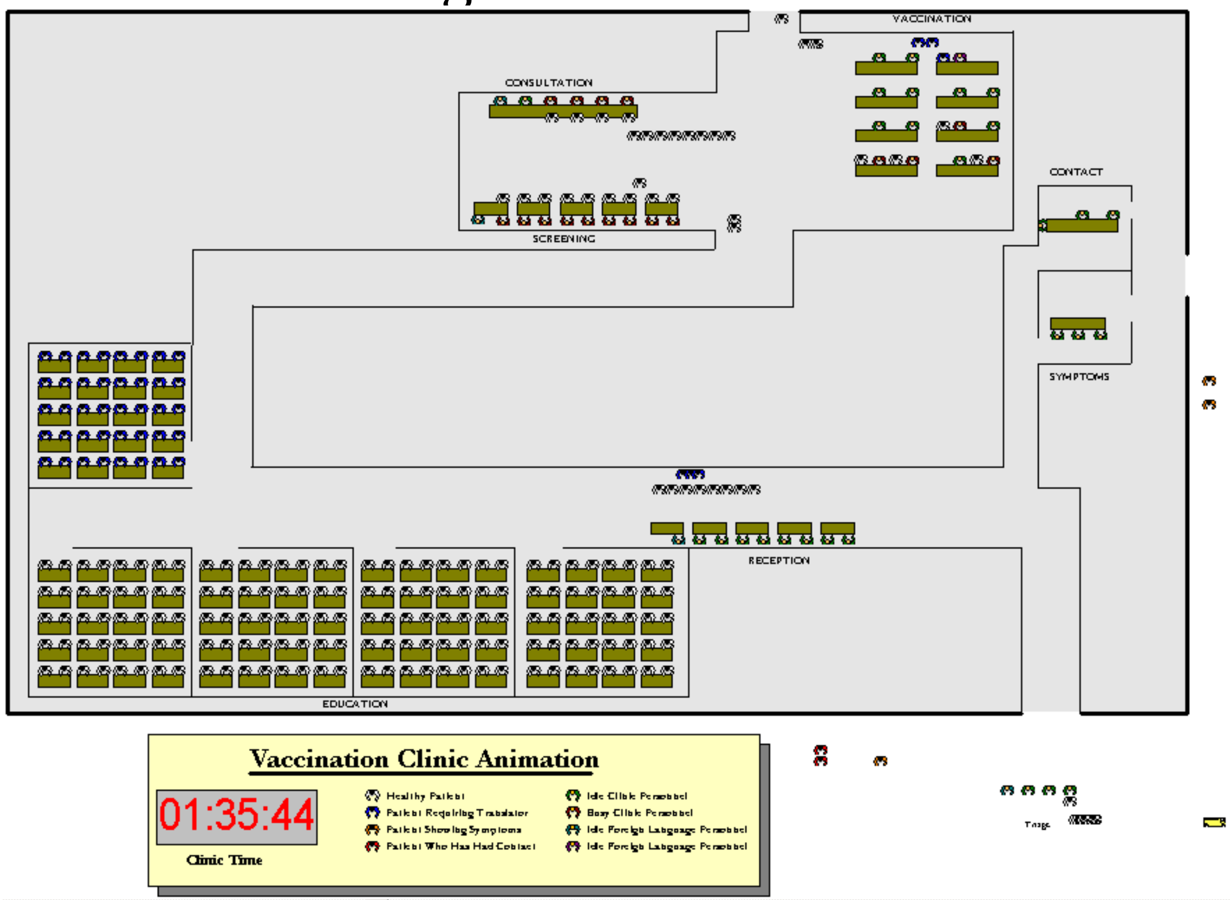
Patients wait in line for flu shots in Silver Spring, Maryland.

From Patient Flow …

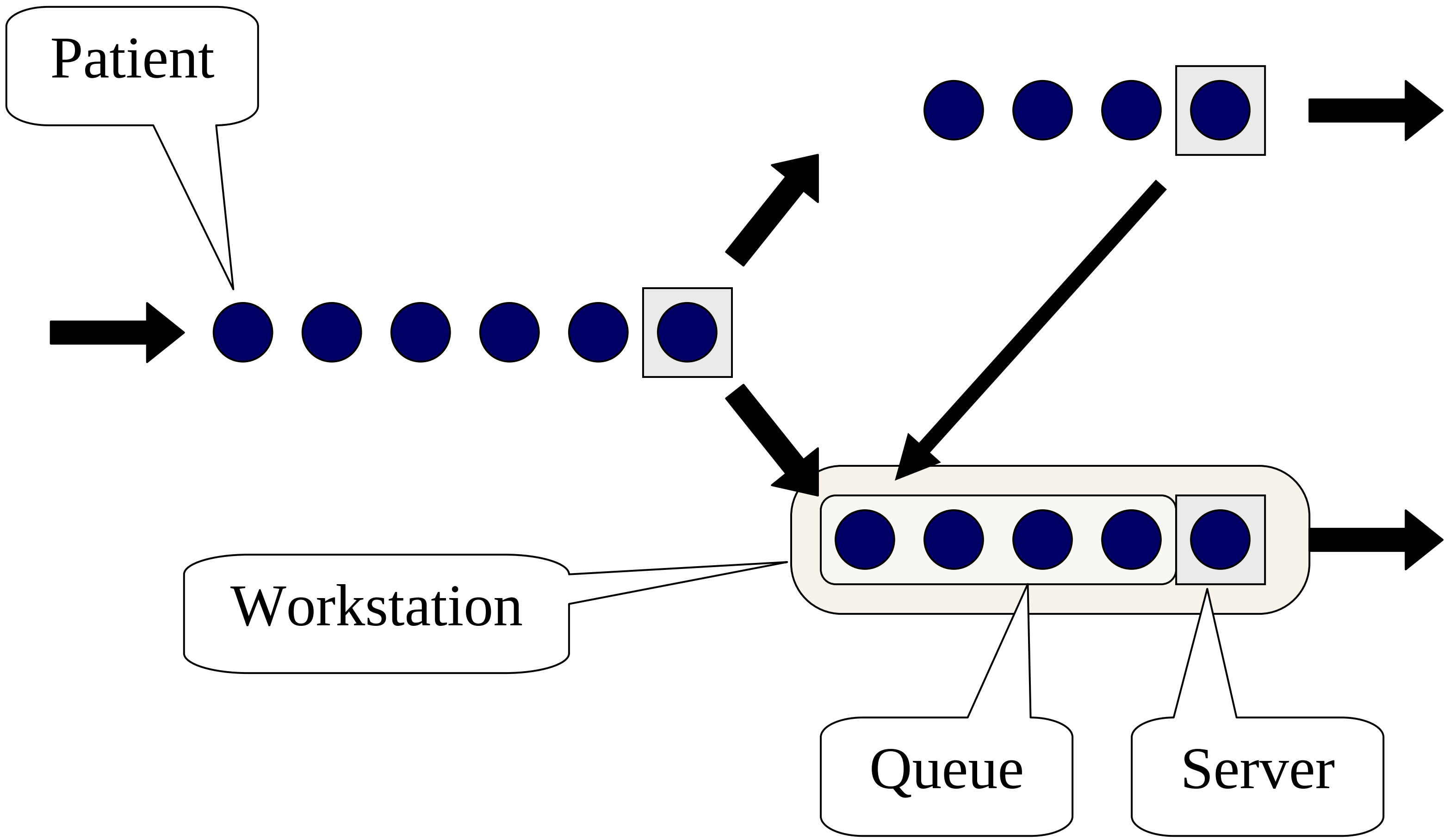


…to Simulation Model

- Simulation model created using Arena®.



Queueing Network Analysis



Performance Measures

Clinic Capacity

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

Station utilization

$$u_i = \frac{r_i \cdot t_i}{m_i \cdot k_i}$$

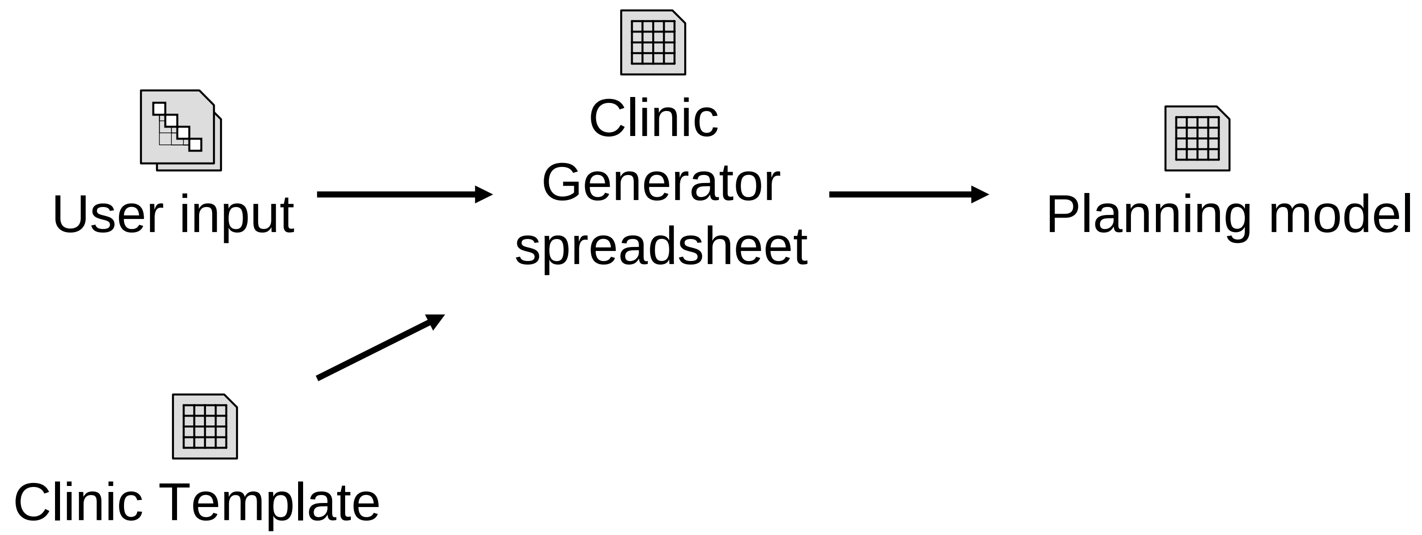
Station cycle time

$$CT_i = w_i + t_i + W_i$$

Total cycle time

$$TCT = \frac{1}{r_1} \sum_{i=1}^{I} r_i CT_i$$

Clinic Planning Model Generator



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.

Table of Contents | Model Parameters | Routing Table | Staffing | Report

Inputs

Demand

Size of population to be treated:	10100
Time allotted for treatment (days):	4
Daily hours of operation:	8
Number of clinic sites:	1
Required throughput (patients per hour):	316

Staffing (per clinic site)

Station name	Staff per shift	Minimum staff per shift
Triage	10	10
Flu Vaccination (All ages)	12	12
Total Service Staff	22	22
Total Staff	57	Set all to minimum

Values in **red** signify below-minimum staffing levels.

Outputs

General Performance

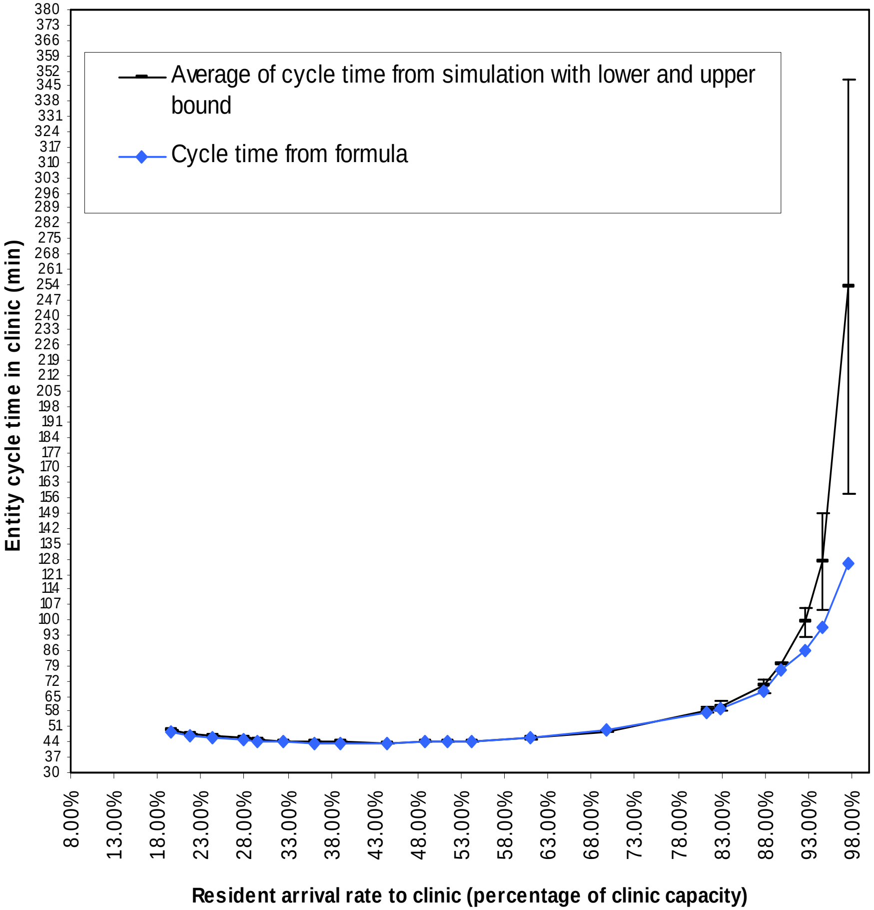
Time in clinic (min):	7.12
Average number of patients in clinic:	37
Bus interarrival time (min):	0.19
Clinic capacity (patients per hour):	329
Total staff per shift across all clinics:	57

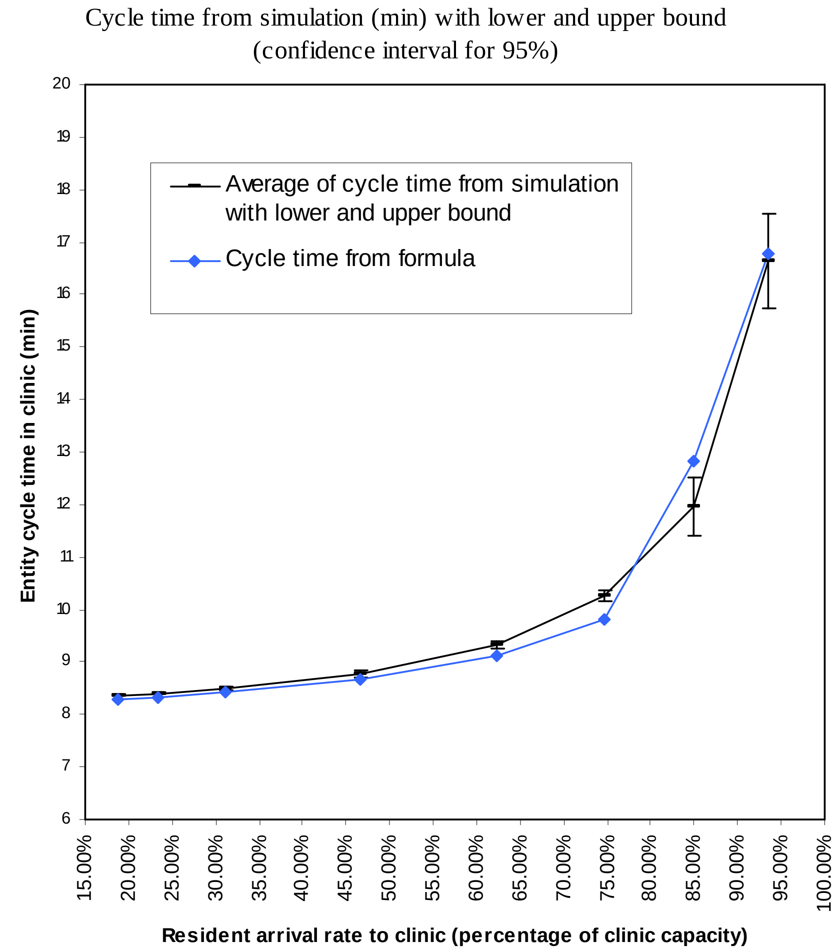
Station-level Results

Station name	Wait time (min)	Queue length	Utilization
Triage	1.26	7	92.2%
Flu Vaccination (All ages)	**1.96**	**10**	**95.8%**

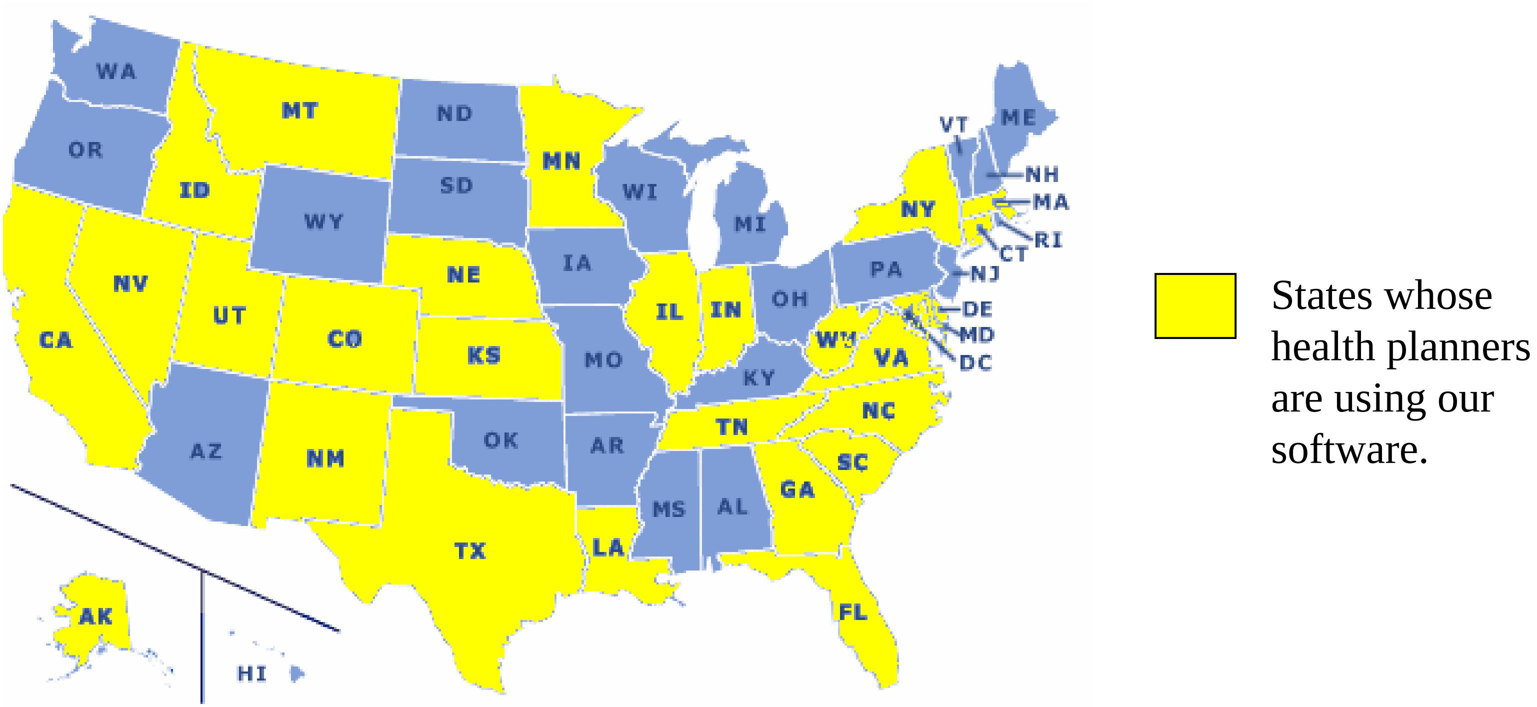
Values in **red** denote the "worst" station for that characteristic.

Comparing the approximations to simulation yielded mixed results.





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