Critical infrastructure, evacuation, risk modeling: my five minutes…….

Richard Church, UCSB

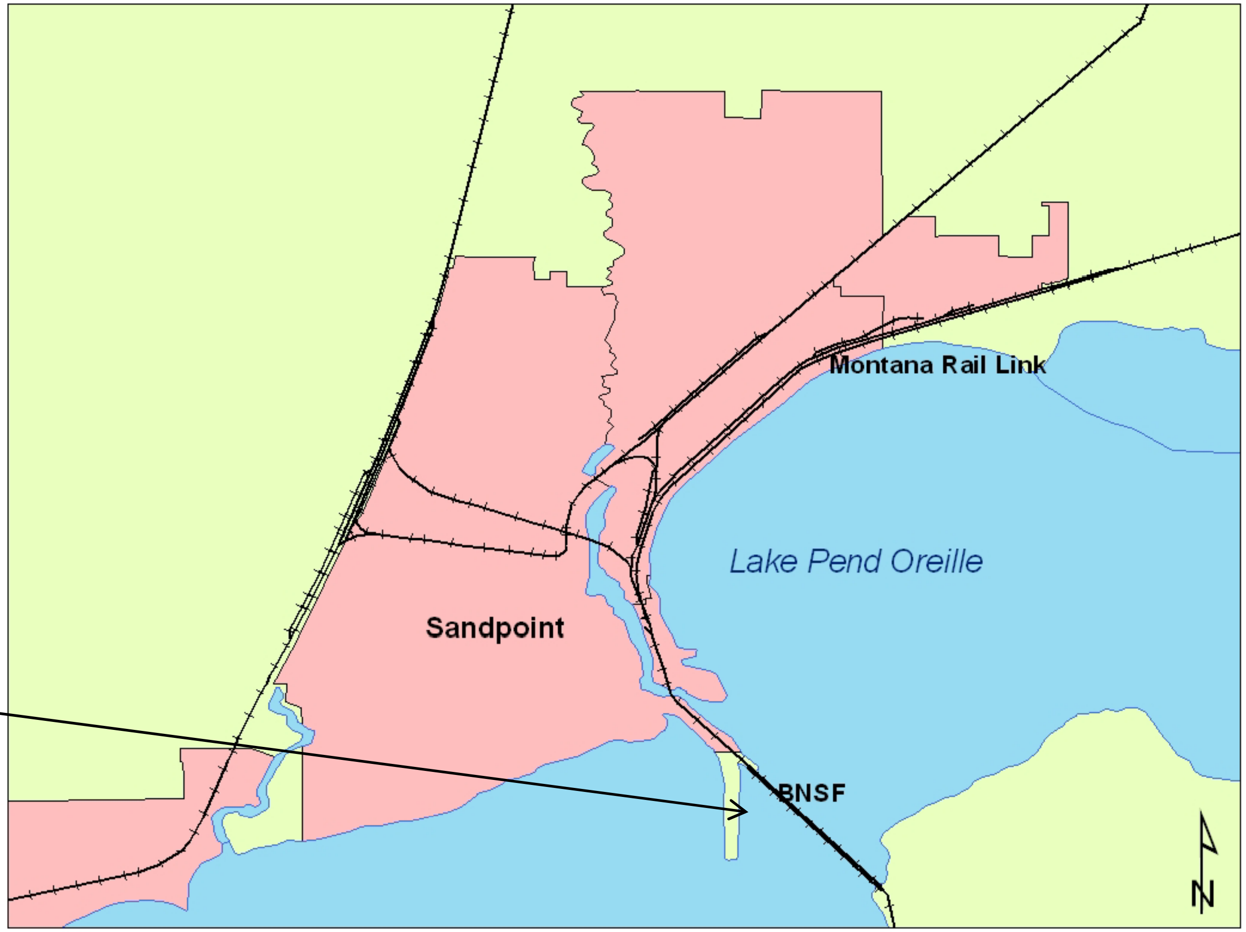
Modeling Tacks

- Modeling Use, under normal conditions
- Modeling Use, under extraordinary conditions
  - Area-wide emergency evacuation
  - Modeling rail network operations after a loss of a brid
  - Identifying area based vulnerabilities in evacuation
- Identifying critical infrastructure elements
  - Network/Nodal interdiction modeling
- Optimizing Security/fortification resources
  - Network/nodal components in a supply system
- Geographic search for sensitive locations
- Network investment/contraction

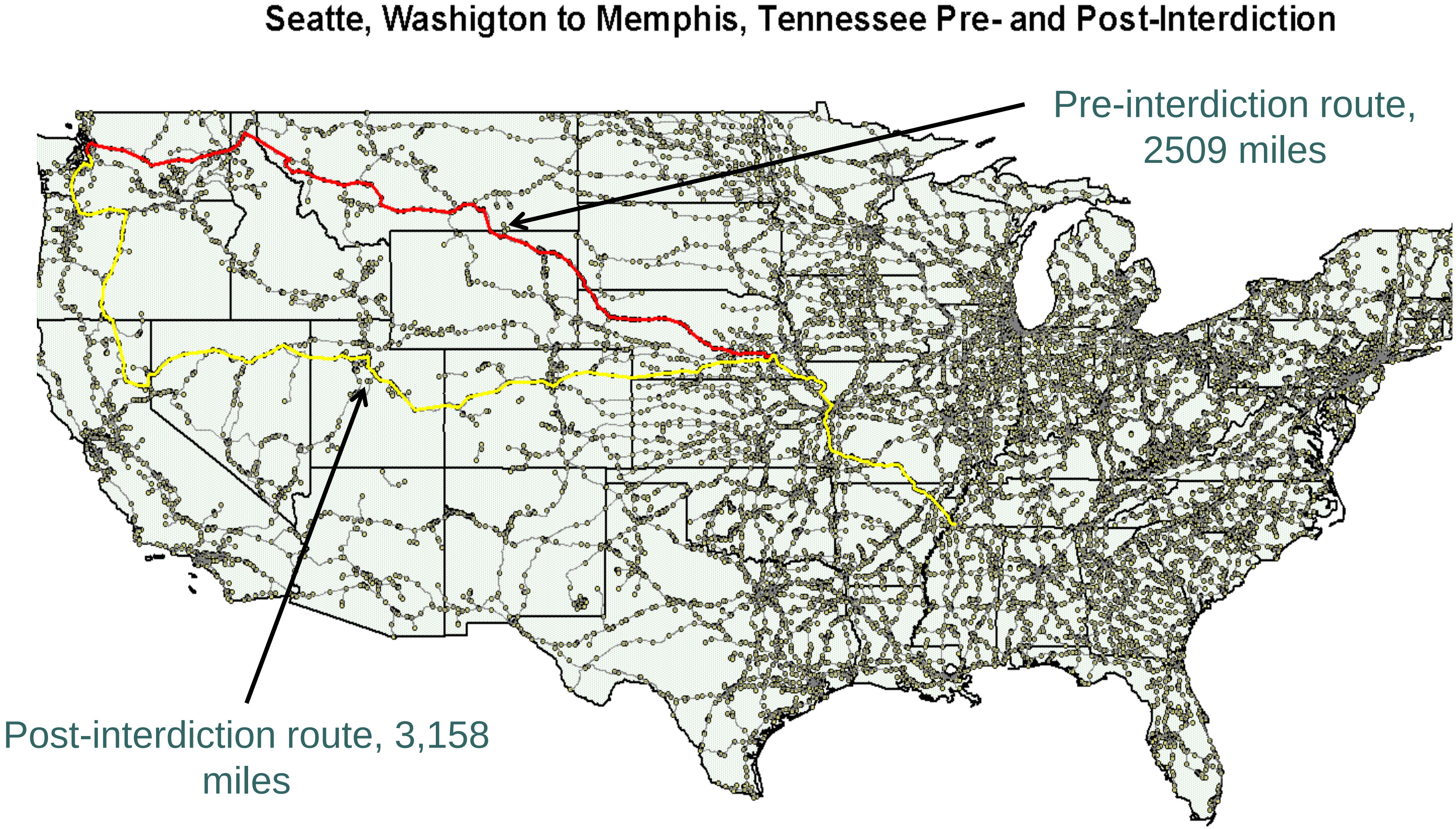
Rail Network, example

Sandpoint, Idaho

BNSF Bridge

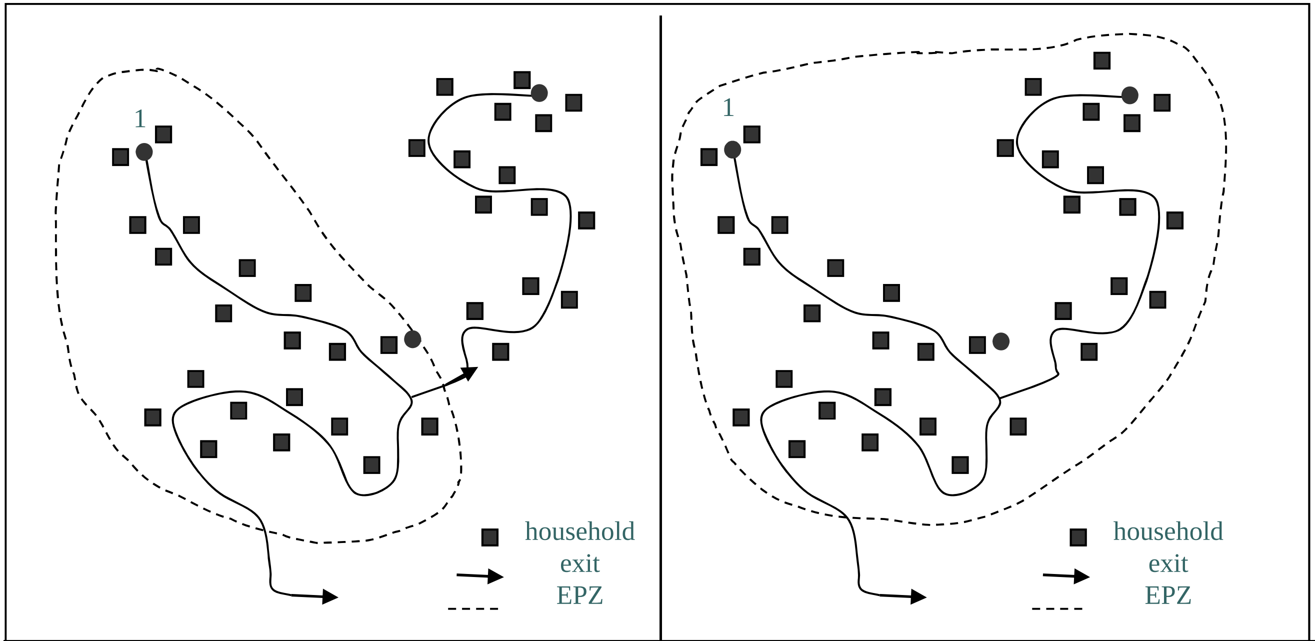


Rail Network Vulnerabilities



Evacuation Vulnerabilities

Defining Bulk-Lane Demand



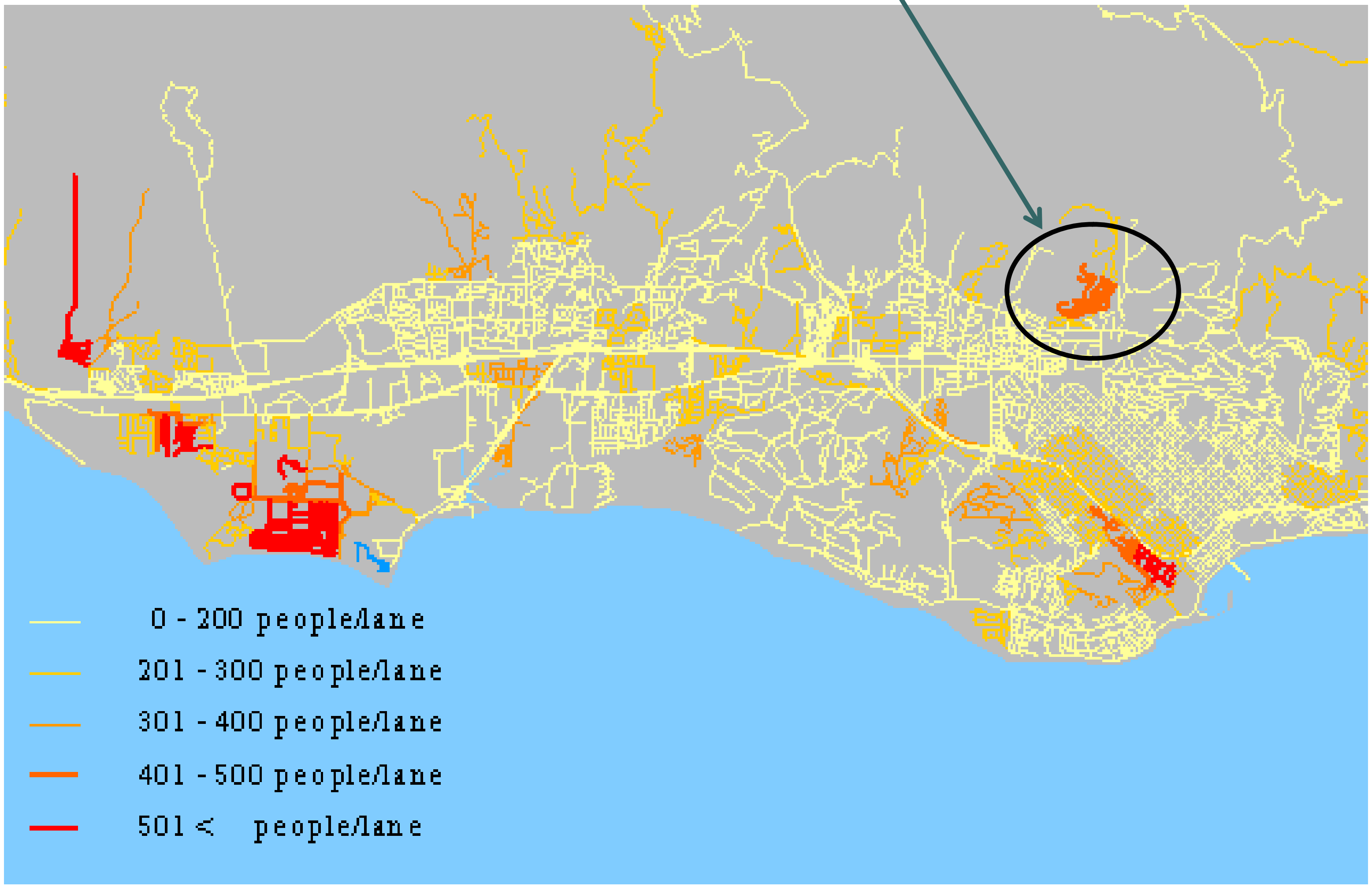
$$\frac{20h\cdot(2.5p/h)\cdot(1/2v/p)}{2\,lanes}=12.5v/l$$

$$\frac{35h\cdot(2.5p/h)\cdot(1/2v/p)}{1\,lanes}=43.75v/l$$

Mapping Bulk-Lane Demand

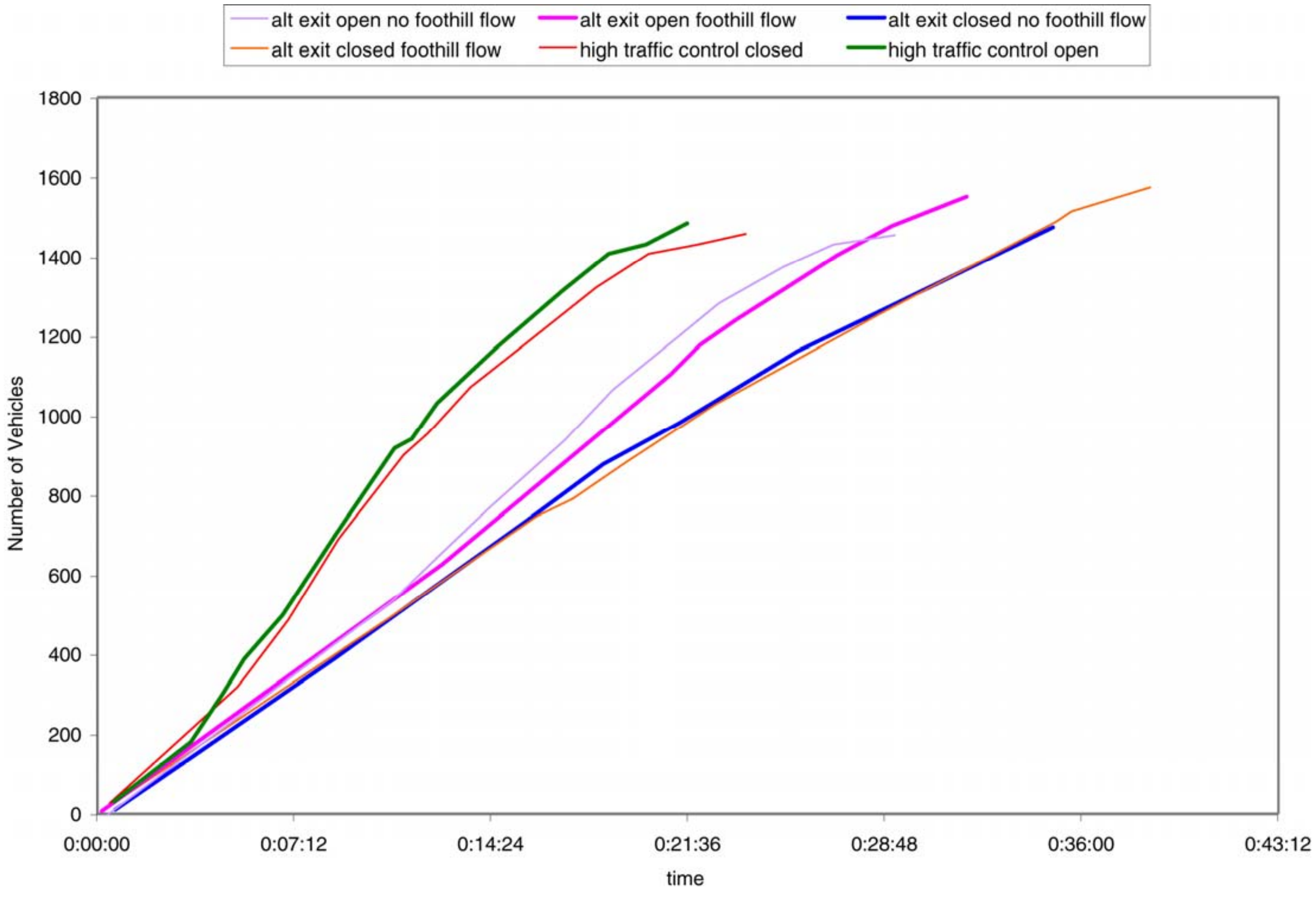
Vulnerability Mapping

Mission Canyon Neighborhood



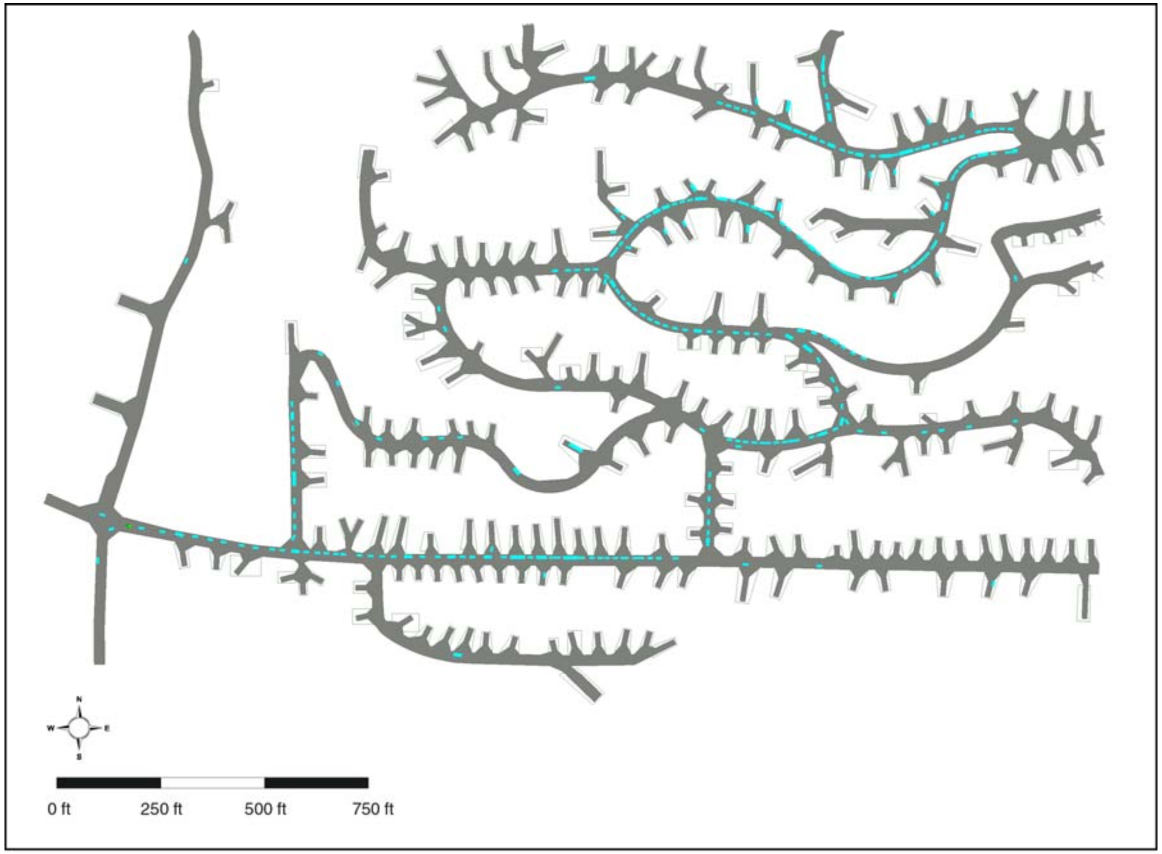
Network simulation

Simulating the clearing time for a neighborhood

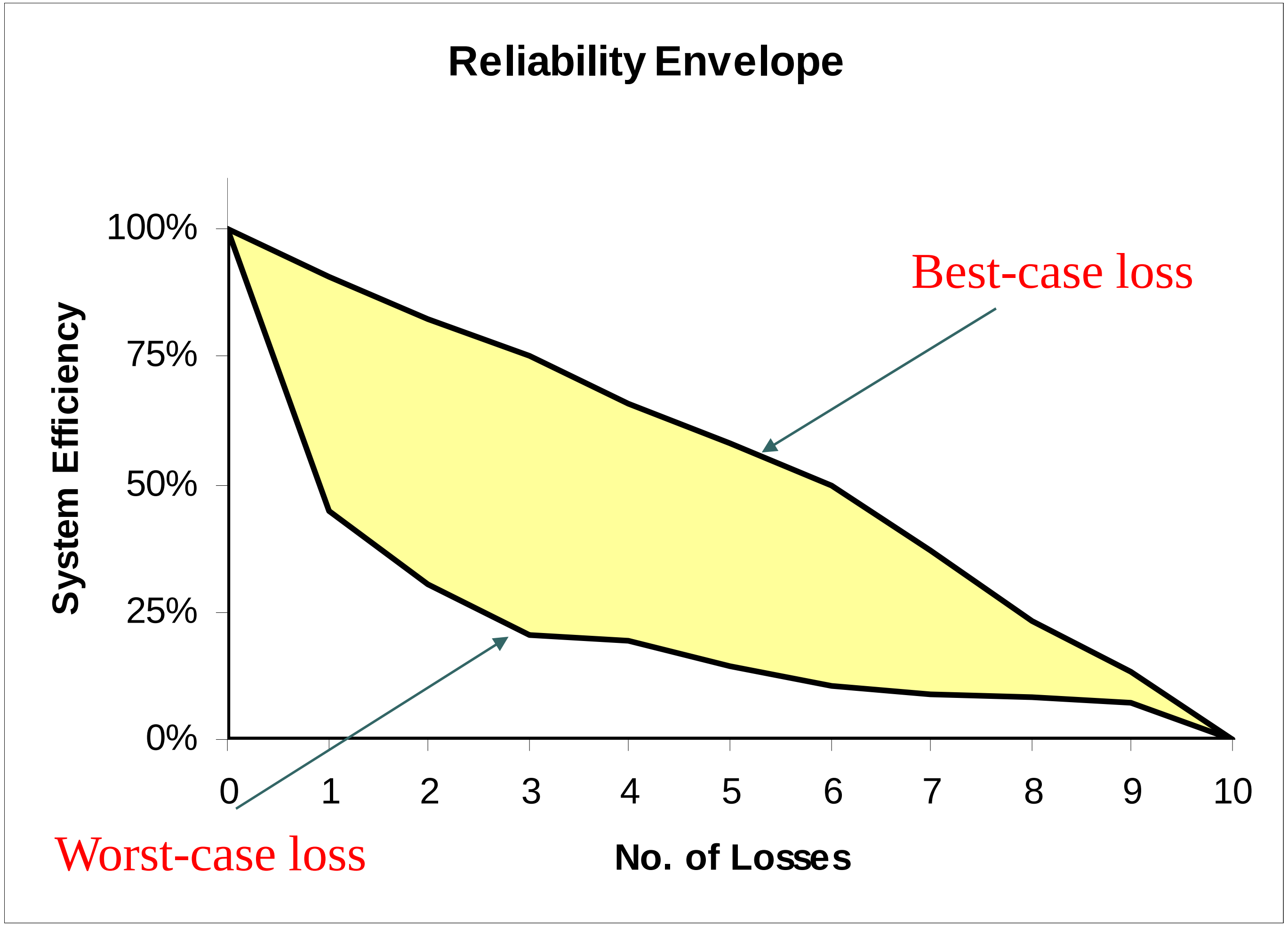


Microscale traffic simulation

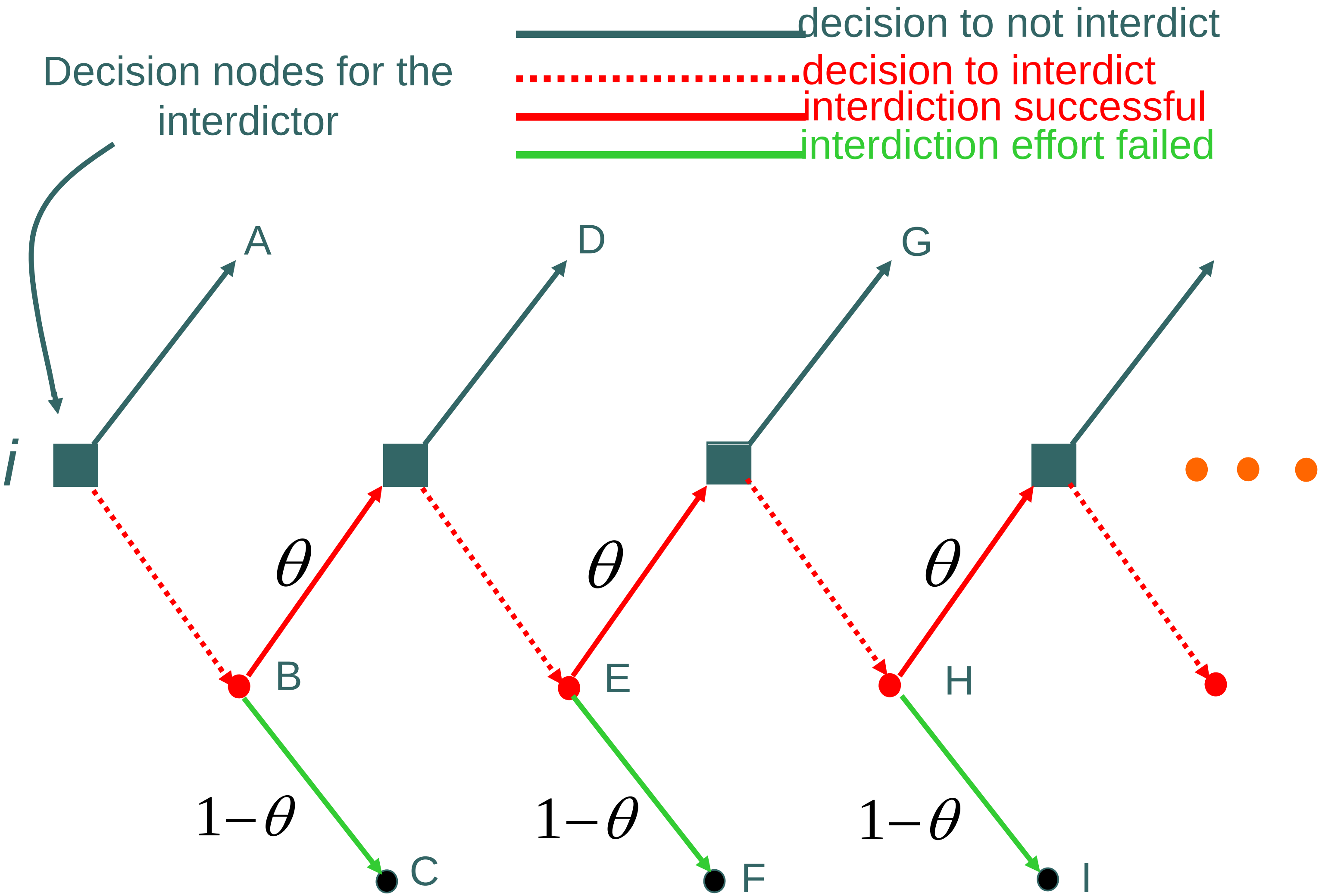
Dynamic Visualization



Modeling the reliability of a supply system



Looking probabilistically…….



$$d_i^k = \sum_{l=1}^{k} \theta^{l-1}(1-\theta) d_{ii_l} + \theta^k d_{ii_{k+1}}$$

Worst-Case Probabilistic Model

$$\max \quad \sum_{i\in I}\sum_{k=1}^{r} a_i d_i^k T_{ik} + \sum_{i\in I} a_i d_i^0 (1-s_{i_1})$$

maximize expected
Service cost

s.t.

$$T_{ik} \le s_l, \quad \forall\, i = I, k = 1,\ldots,r,\ l \in F_k(i)$$

$$\sum_{k=1}^{r} T_{ik} \le 1, \quad \forall i \in I$$

$$\sum_{j\in F} s_j = r$$

Worst-Case RIP

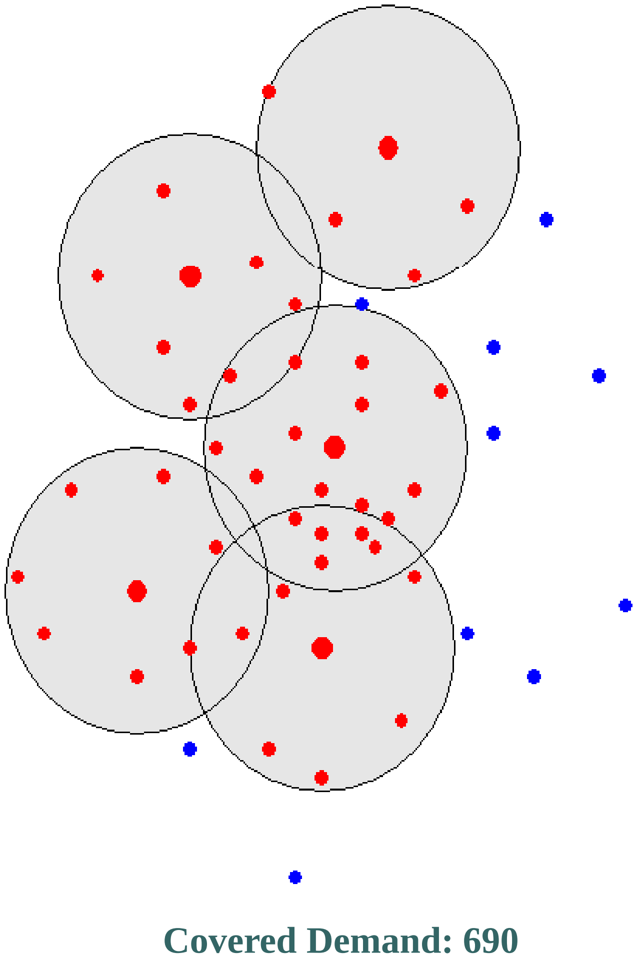
$$T_{ik} \in \{0,1\},\ \forall\, i \in I, k = 1,\ldots,r$$

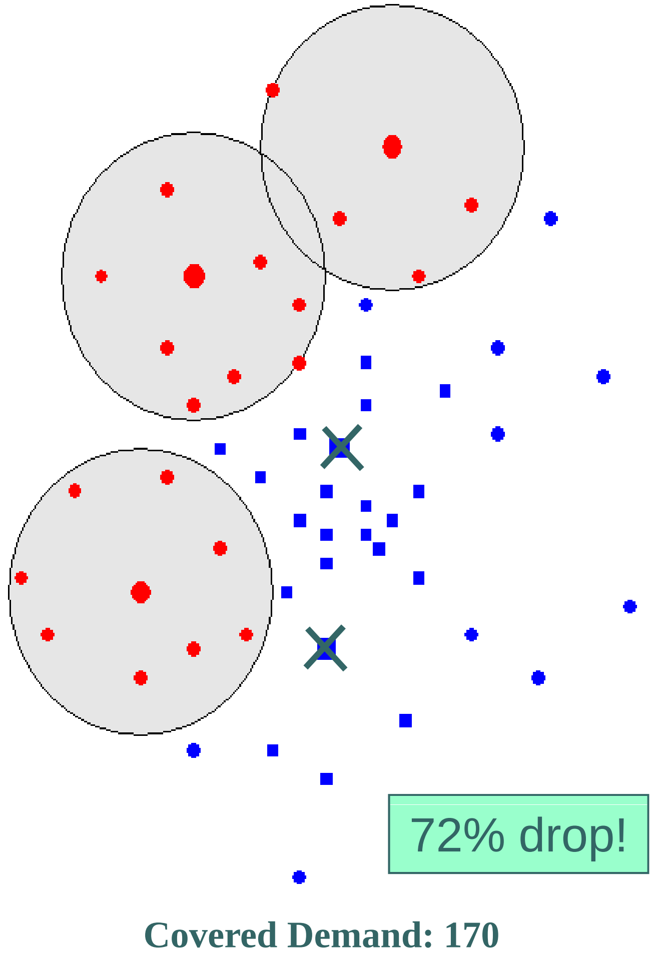
$$s_j \in \{0,1\},\ \forall j \in F$$

Optimization model development

- Interdiction, find most critical facilities
- Fortification/security, find the ones to protect
  to keep a system functioning as best as possible
- Resilient design, design a system in so that it
  can operate in worst case circumstances
- Optimal Coping mechanisms…….

Interdicting an optimal max covering solution



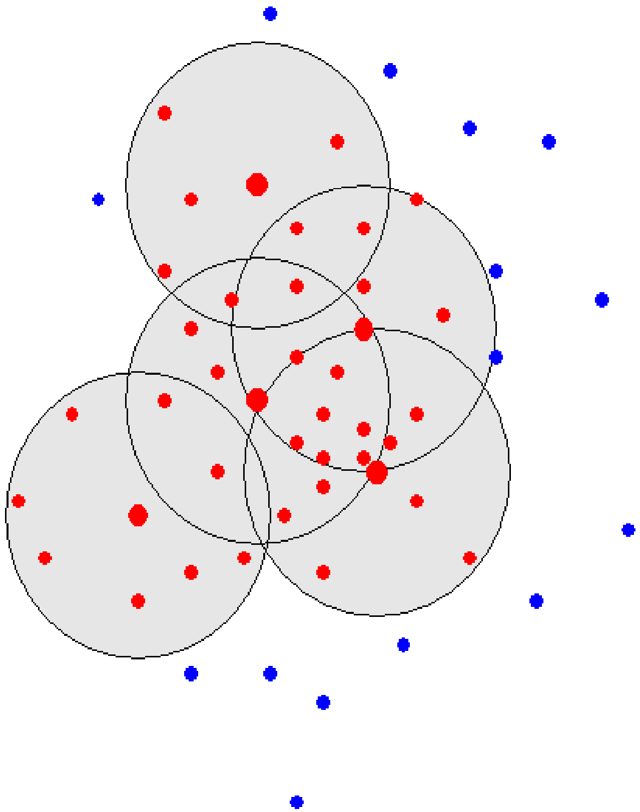


a. Optimal max cover solution (p = 5) **b.** Optimal interdiction (r = 2)

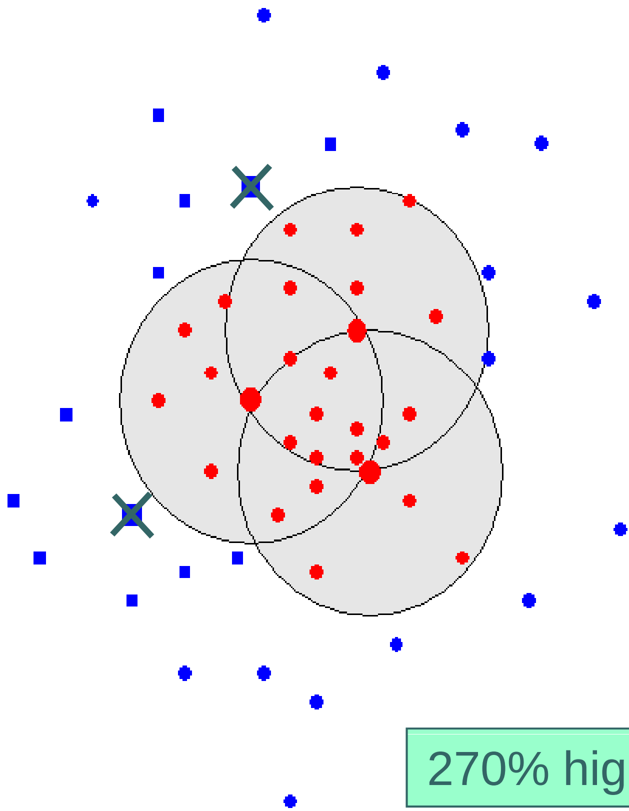
Interdicting a near optimal max covering solution

Initial coverage: 567 vs 609

Final coverage: 475 vs 170



Covered Demand: 567



270% higher

Covered Demand: 475

a. Near optimal max cover solution (p = 5)

b. Optimal interdiction (r = 2)