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The Fourth Annual DHS University Network Summit
Panel 22 - Transportation System Resiliency
Modeling Resilience of Transportation Systems

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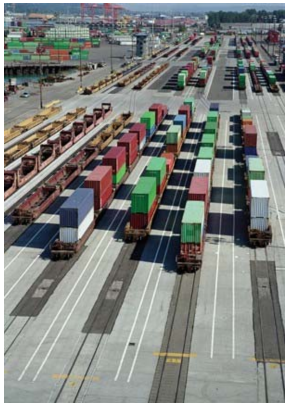
Why Transportation Resiliency?

- Scope of Transportation Sector in US in 2007[1]
  - 13 billion tons of freight
    - > 8.9 billion by Truck
    - >1.9 billion by Rail
    - > 400 million by Water
    - >3 million by Air
  - valued at $11.8 trillion
  - transported 3.5 trillion ton-miles



http://blog.fleetowner.com/trucks_at_work/wp-content/uploads/2009/07/gil2.thumbnail.jpg

- Potential Economic Impact[2]
  - Estimated $50 to $100 Million cost impact incurred per day of disruption
  - Disruptions can reduce shareholder wealth 8-10%, with recovery times of more than 50 trading days

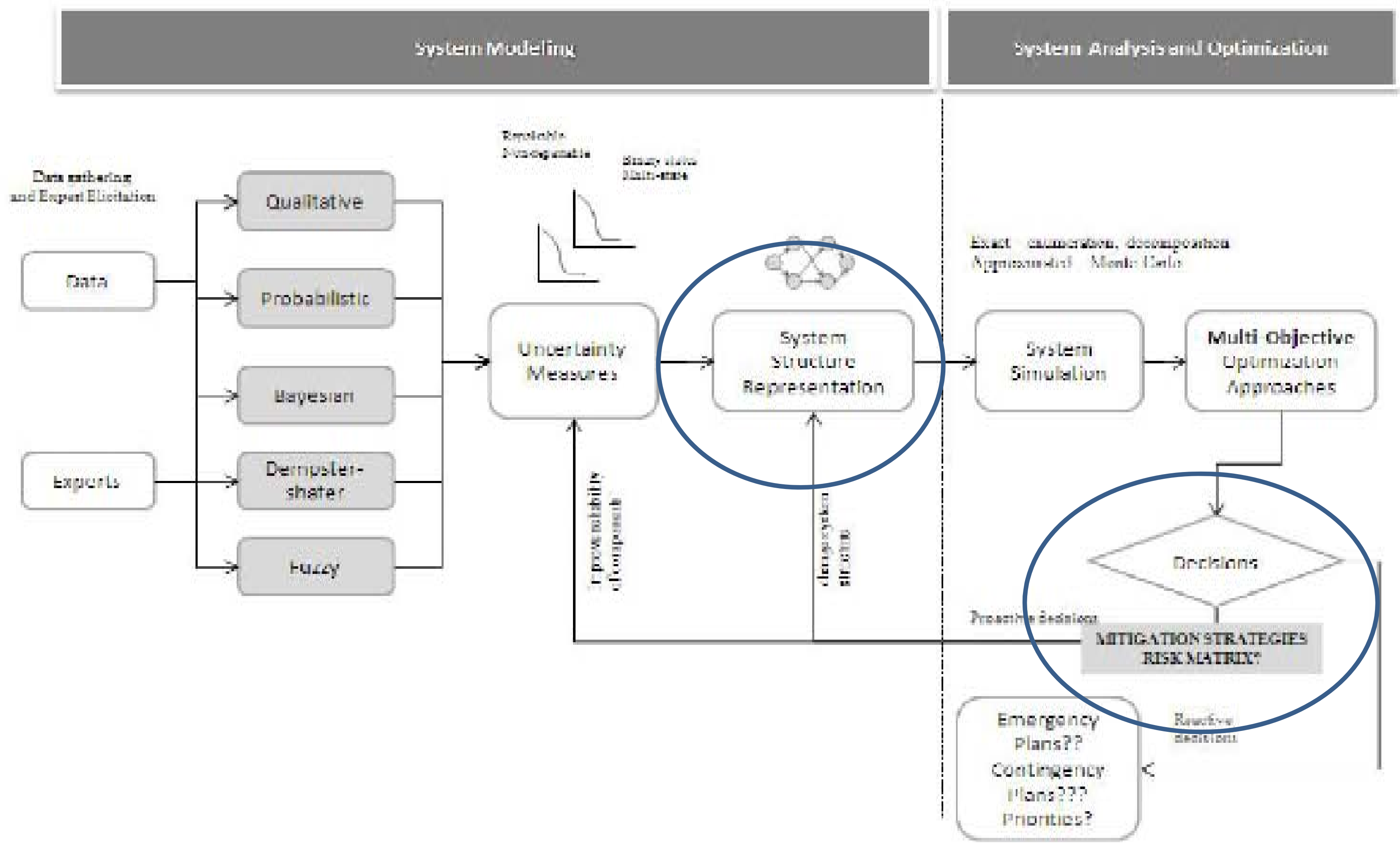
1. U.S. Department of Transportation Special Report -018: Highlights from 2007 Commodity Flow Survey Preliminary data, September 2009
2. Hanfeild, R., Reducing the impact of disruptions to the supply chain, SASCOM magazine, **http://scm.ncsu.edu/public/risk/risk7.html**

Motivation – Supply Chain Disruptions

- Anthrax spores were discovered in October 2001 at USPS processing facility in (Washington D. C)
- West coast port lockout in 2002
- In 2005, hurricane Katrina damaged plants and warehouses and routes.

http://www.storycircle.org/katrina

Modeling and Analysis Framework



Types of Models

- Descriptive
  - Which infrastructure elements are the most critical?
  - What is the consequence of a particular failure?
  - What is the predicted outcome of a given fortification plan?
- Prescriptive
  - How should a resilient network be designed?
  - How should fortification resources be allocated amongst transportation infrastructure elements

http://stpartners.net/Preactor1.html

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Southeast Transportation Corridor

- **Customers**: Atlanta, GA and Columbia, SC
- **Suppliers**: Dallas, TX and St. Louis, MO
- Arcs are subject to disruption
- When disruptions occur, goods are transported from suppliers to customers through *available arcs* to minimize total distance

Modeling Approaches

- Interdiction
  - Failure of one or more infrastructure caused by an intelligent attacker
  - Usually represents the “worst case”
- Fortification
  - Protecting infrastructure elements against different modes of failure
  - How should fortification resources be allocated among transportation infrastructure elements?

http://urbanhabitat.org/node/402

http://www.delawareliberal.net/2008/09/26/the-irony-is-amazing-if-you-think-about-it/

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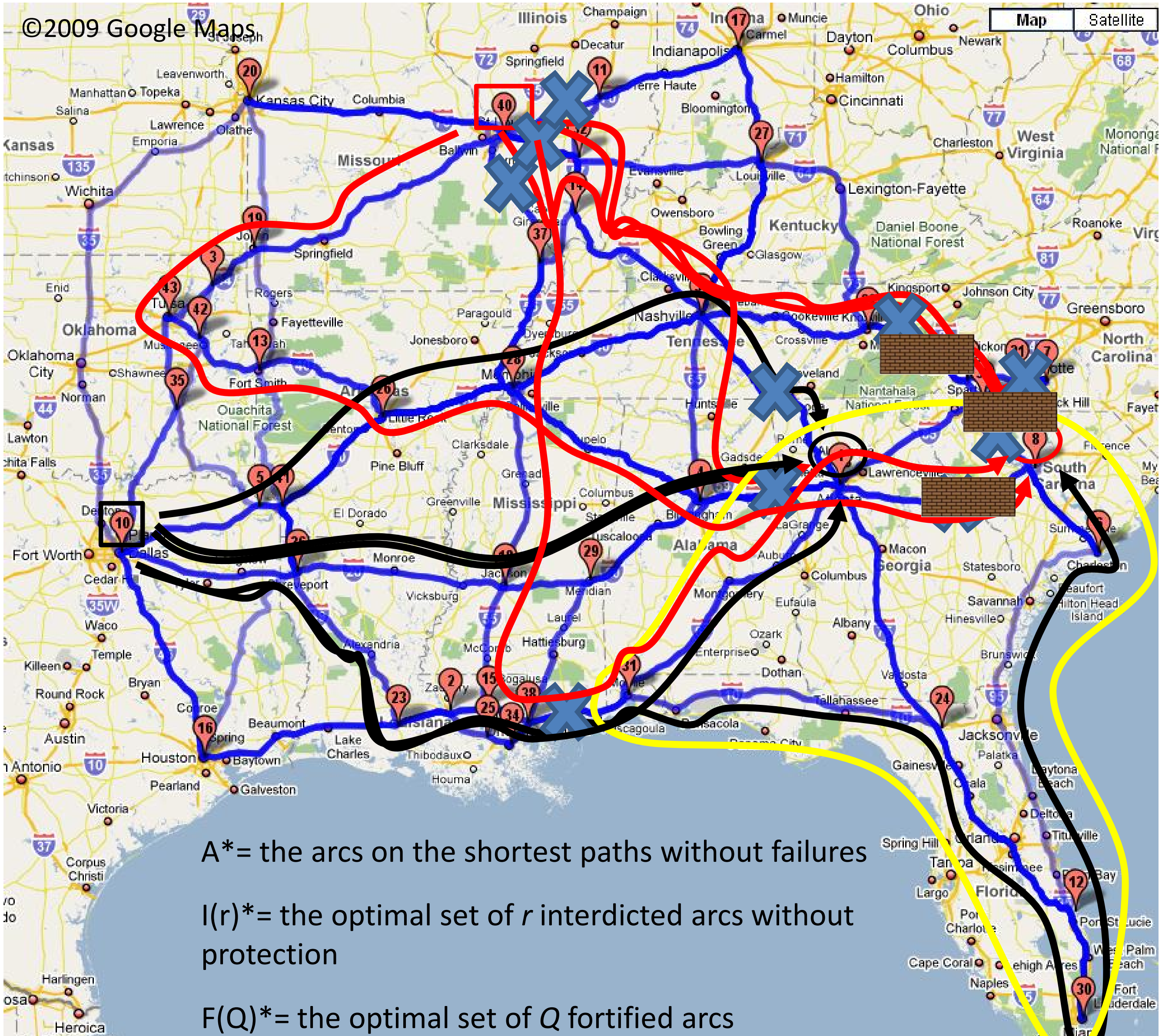

A*= the arcs on the shortest paths without failures

I(r)*= the optimal set of *r* interdicted arcs without protection

F(Q)*= the optimal set of *Q* fortified arcs

Scenario:

Interdictions:

Fortifications:

Total distance:

Observation 1: at least one arc in I(r)* is also in A*

Observation 2: I(r)* may be completely different from I(r+1)*

Observation 3: F(Q)* has at least one arc in I(r)*

Observation 4: F(Q)* may contain arcs not in I(r)*

Risk Fortification

- Modeling schemes
  - Each disruption scenario has a probability
  - Each arc has a probability of failure
- Elicit probabilities from team of experts
- Objective: minimize expected cost
- Decision: choose the fortification strategy that minimizes the expected total cost over all possible failure scenarios
- Model: two-stage stochastic programming model
  - 1^{st} stage: select arcs to fortify
  - 2^{nd} stage: minimum cost network flow problem (after failures occur)

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Protections: 2

Probability of failure: 0.10

Avg. total distance: 1594

Observation 6: the optimal fortification set is different for interdiction and random failures

Ongoing Research

- Challenges
  - Interdiction: problem has multiple stages
  - Random failures: the number of scenarios is typically very large
  - Modeling dynamic networks
- Additional modeling
  - Multiple modes of transportation
  - Integrating risk assessment and optimization
  - Capacitated arcs
- Additional solution approaches
  - Alternate problem formulations
  - Efficient ways of solving sub-problems
  - Efficient sampling of scenarios