The Value of Using Stochastic Mapping of Food Distribution Networks for Understanding Risks and Tracing Contaminant Pathways

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Outline

- A quick commercial for NISAC (National Infrastructure Simulation and Analysis Center)
- Some background on our work in the Ag&Food sector
- The main event – Stochastic mapping of food distribution networks

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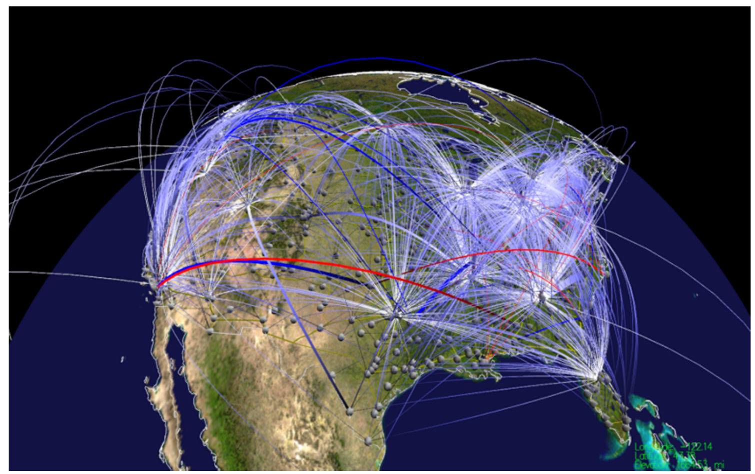
- **Patriot Act identified NISAC as the center for Critical Infrastructure Interdependency Modeling, Simulation, and Analysis.**

- **Provide a common, comprehensive view of U.S. infrastructure and its response to disruptions.**

- **Operationally-tested DHS rapid-response capability.**
    - 24/7 crisis action analysis

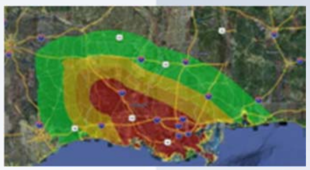


NISAC is a critical component in DHS/NPPD/IP's analytical capability

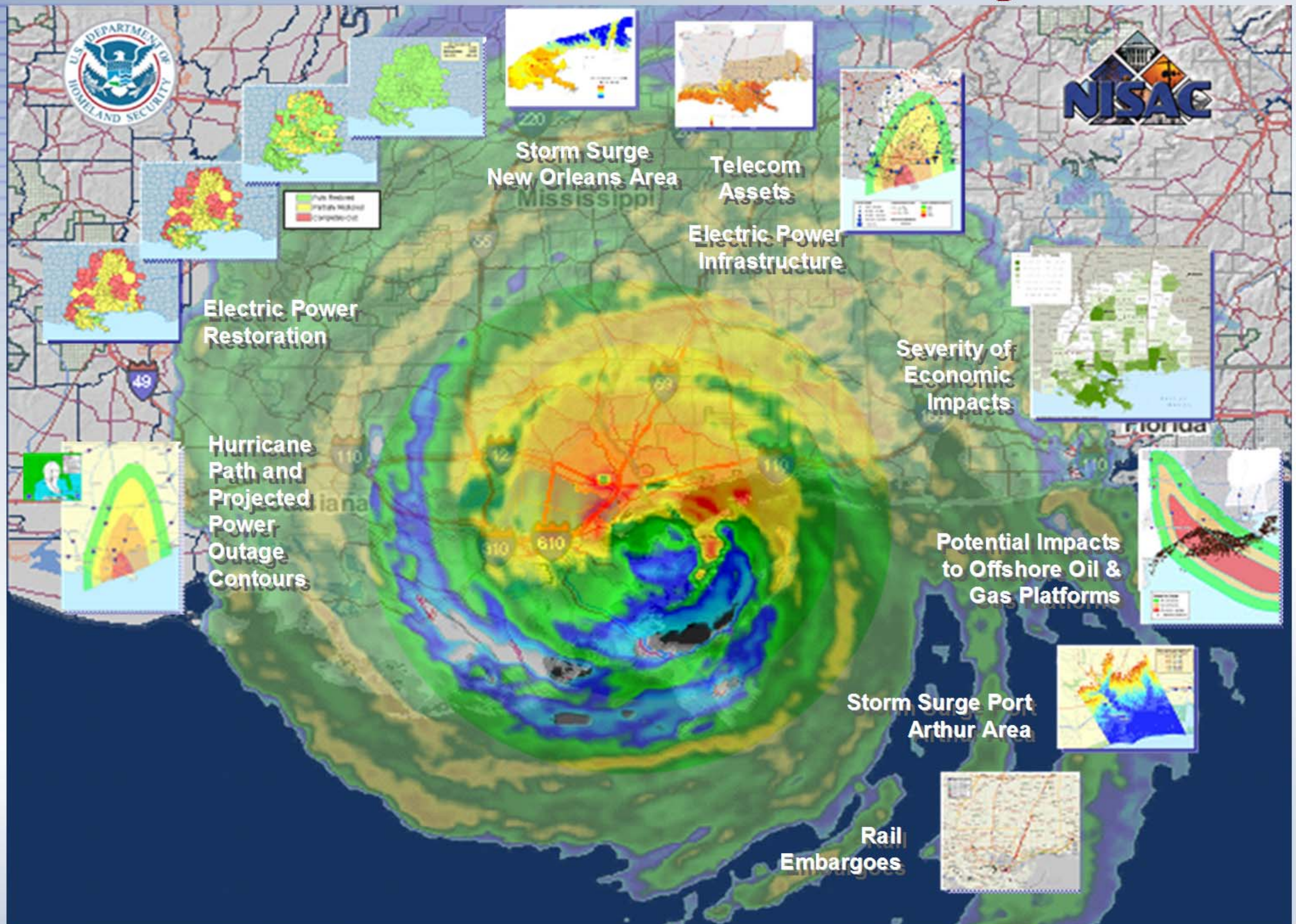
Hurricane Planning & Response

- Planning Scenarios

- Pre-Landfall Infrastructure & Population Impacts



- Post-Landfall Response & Recovery Issues



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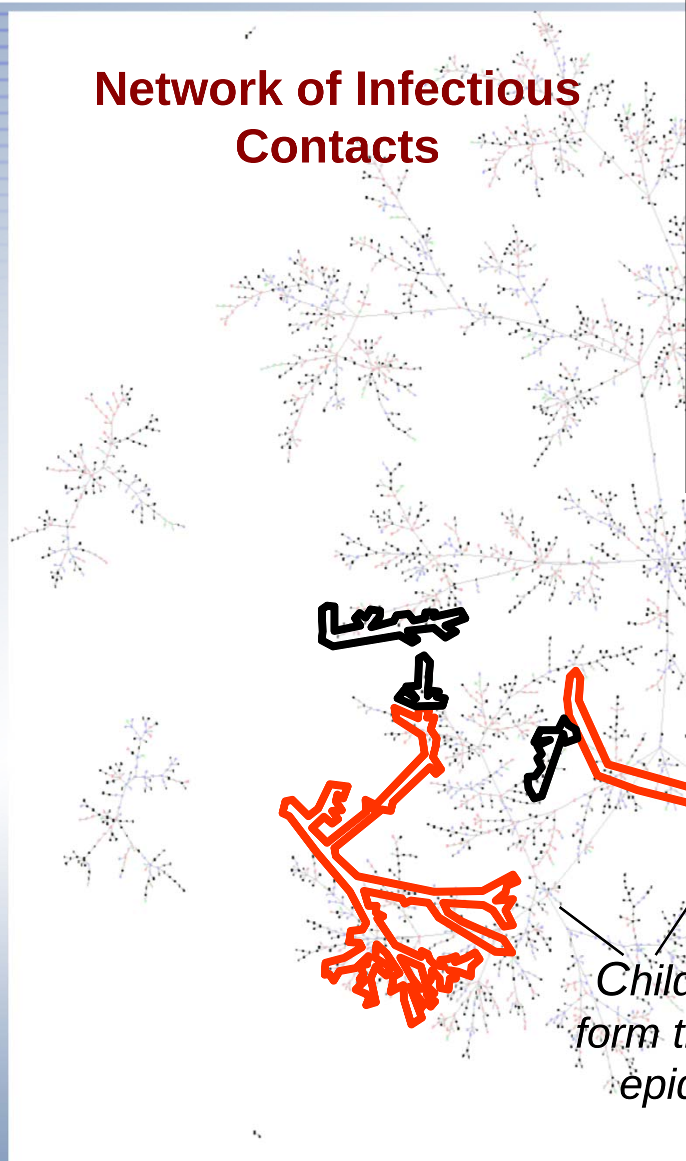
Pandemic Influenza Planning & Response

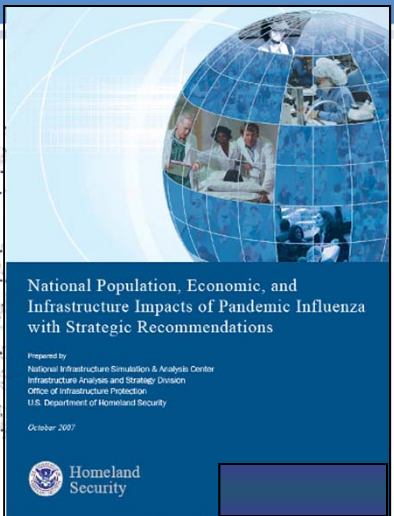
Modeling & Analysis:

- Community interactions (schools, workplace networks)
- Assessed effectiveness of response strategies
  - social distancing
  - vaccination

High-performance computing used to run 10's of millions of scenarios

Discovered social distancing best minimized disease spread, especially closing schools





NISAC Infrastructure Models

- **Transportation:**
  - FastTrans (Road Transportation).
  - Rail Network Analysis System (R-NAS).
  - Air Transportation Optimization Model (ATOM).
  - System for Import/Export Routing and Recovery Analysis (SIERRA).
  - Container Port Operations (Seattle, Portland, Houston).
- **Energy:**
  - Interdependency Environment for Infrastructure System Simulation (IEISS).
  - National Petroleum System (CIPDSS-National Petroleum).
  - National Natural Gas Network (Loki-GAM).
  - National Natural Gas System.
- **Water:**
  - Water Infrastructure Simulation Environment (WISE).
- **Telecommunications:**
  - Multi-scale Integrated Information & Telecommunications Simulator (MIITS).
  - Telecommunications Modeling Suite (N-SMART).
- **Public Health and Healthcare:**
  - EpiSimS (Disease Transmission).
  - Loki-Infect.
  - Healthcare System (HealthSim, CIPDSS-Healthcare).
- **Emergency Services:**
  - Resource Allocation Models.
  - Evacuation/Relocation
- **Chemical:**
  - Petrochemical network model (Loki-Petrochemical).
  - Global Petrochemical supply chain (N-ABLE).
  - Chlorine supply chain (N-ABLE).
- **Banking and Finance:**
  - Global Financial Network (Loki-GFN).
  - Large Transaction Network (FinSim, Loki-Transact).
- **Dams:**
  - Dam Inundation.
  - Dam System.
- **Agriculture and Food:**
  - Beef Cycle (CIPDSS-Ag).
  - Dairy Cycle and Supply Chains (CIPDSS-Ag).
  - Corn Cycle (CIPDSS-Ag).
  - Manufactured Food Supply Chain (N-ABLE).
- **Multiple Infrastructures:**
  - NISAC Agent-Based Laboratory for Economics (N-ABLE).
  - Fast-Analysis Infrastructure Tool (FAIT).
  - Hydra SOA Environment
  - Loki toolkit.
  - Interdependency Environment for Infrastructure System Simulation (IEISS).
  - Critical Infrastructure Protection Decision Support System (CIPDSS).

Some background on our work in the Agriculture and Food Infrastructure:

A Risk Assessment Approach to Food Defense

Food Defense

- **Food Defense** - the proactive management of the food supply chain to prevent the malevolent introduction of a pathogen or toxin for the purpose of causing injury or death to civilian populations and/or disrupting social, economic, or political stability.

- **Food Safety** - the proactive management of the food supply chain in order to minimize the occurrence and concentrations of harmful pathogens and toxins that occur naturally in food; and, minimize the use of toxic or otherwise harmful adulterants placed in food for for economic gain.

- **Food Security** - access by all people at all times to enough food for an active, healthy life.

- **Agroterrorism** - the deliberate introduction of an animal or plant disease with the goal of generating fear, causing economic losses, and/or undermining stability.

Food Defense Risk-Assessment History

OFFICIAL USE ONLY

SANDIA REPORT
SAND2009-0178
Official Use Only – Circumvention of Statute
Printed January 2009

Total Risk Assessment Methodology

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Name/Org: Diane Ross Date: 12/15/2008
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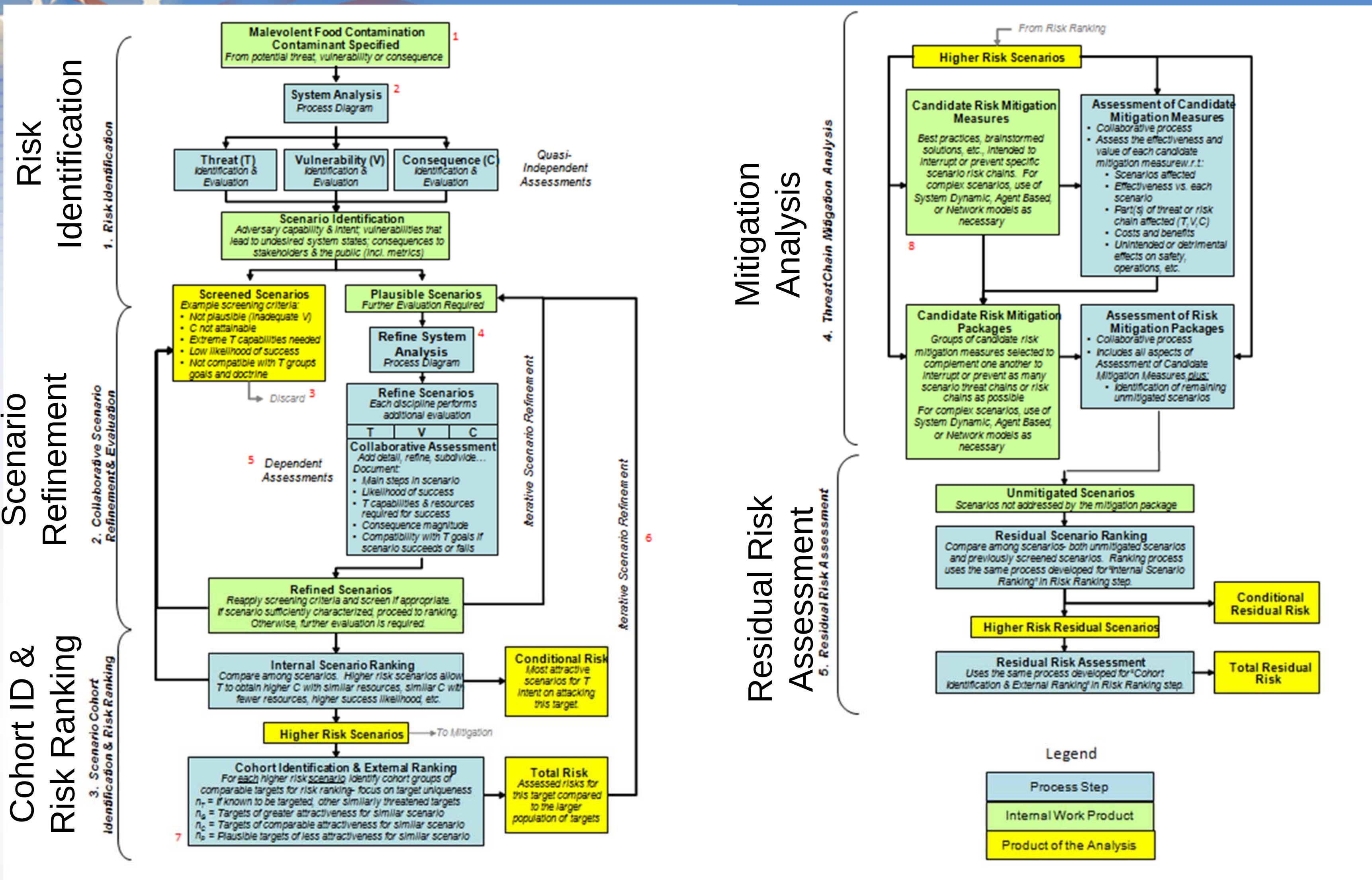
Risk-Assessment Flow Diagram



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Food Defense White Paper

NISAC adapts adversarial risk assessment methodology to Food & Ag Infrastructure and publishes food defense risk assessment representing Step 1, initial screening, of the risk-assessment methodology.

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Risk Attributes

- **Food system attributes that contribute to risk**
  - Historical Precedent
  - Speed of Distribution & Consumption
  - Contaminant Survives Processing & Distribution
  - Distribution Favors Broad Dissemination
  - Imported Ingredients
  - Employment Practices Facilitate Access
  - Potential for High-Magnitude Human Consequences
  - Potential for High-Magnitude Economic Consequences
  - Vulnerability of Transportation Modes
  - Contaminant Detection Unlikely
- **Contaminant attributes that contribute to risk**
  - Lethality
  - Ease of Production
  - Pertinent Properties
  - Political or Fear Factor
  - Time to Symptoms
  - Historical Precedent

- Food systems discussed
  - Dairy Products
  - Ground Beef
  - Fresh-Cut Produce
  - High Fructose Corn Syrup
  - Wheat Gluten
  - Cocoa

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Examples of Screened High-Risk Food Products

	PT1	PT2	PT3	PT4	PT5
Accessibility of Possible Attack Locations					
Acquisition of Agent					
Lethal Concentration Possible					
Compatible With Distribution?					
Agent Survives Processing?			**	**	
Known Contamination Incidents		*			*
Agent Detected by Normal QA?					
Distribution Topology					
Distribution Consumption Time					
Possible Process Steps for Attack					
Contamination in Foreign location Possible					

The Nation’s food supply is vulnerable to attack
Actions can be taken to minimize the likelihood of a successful attack

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Fresh-Cut Produce Risk-Assessment

Because fresh produce is identified as “high-risk”, steps 2 and 3 of the risk-assessment methodology are applied to test the **food defense risk hypothesis:** ***an adversary would see fresh produce as an attractive way to deliver a biological or chemical agent to a large population***.

In contrast, the food safety risk hypothesis is: *the cultivation, processing, and distribution of fresh produce favors the growth of naturally occurring pathogens that, without active management, present a public health risk.*

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Approach to the Analysis

- **Hypothesized scenario**
  - The attacker – **Al Qaeda**, or a terrorist group having similar motivations and capabilities
  - The attack agent –
  - The means of attack – the supply chain system associated with processing and distributing **fresh-cut produce** to **QSR retail outlets**
- **In performing the risk assessment, we answered a series of (20) explicit questions, posed to determine both**
  - The degree of **attractiveness** the scenario presents for the attacker
  - The magnitude of the **consequence** a successful attack would impose

Four categories of questions

- Terrorist threat attributes – the motivations and capabilities of the attacker
- Agent attributes – e.g., lethality, ease of purchase or manufacture, historical precedents
- Supply chain attributes
  - How would the adversary gain access?
  - Does the distribution topology favor widespread dissemination of the agent?
  - Is product distribution and consumption rapid enough to support the attack scenario?
- Agent / supply chain attributes
  - Does at least one viable agent introduction point exist?
  - Does the agent survive processing and distribution?
  - How much agent would be required to deliver a lethal dose?

As these questions were being answered, the scenario evolved, becoming more refined and more operational

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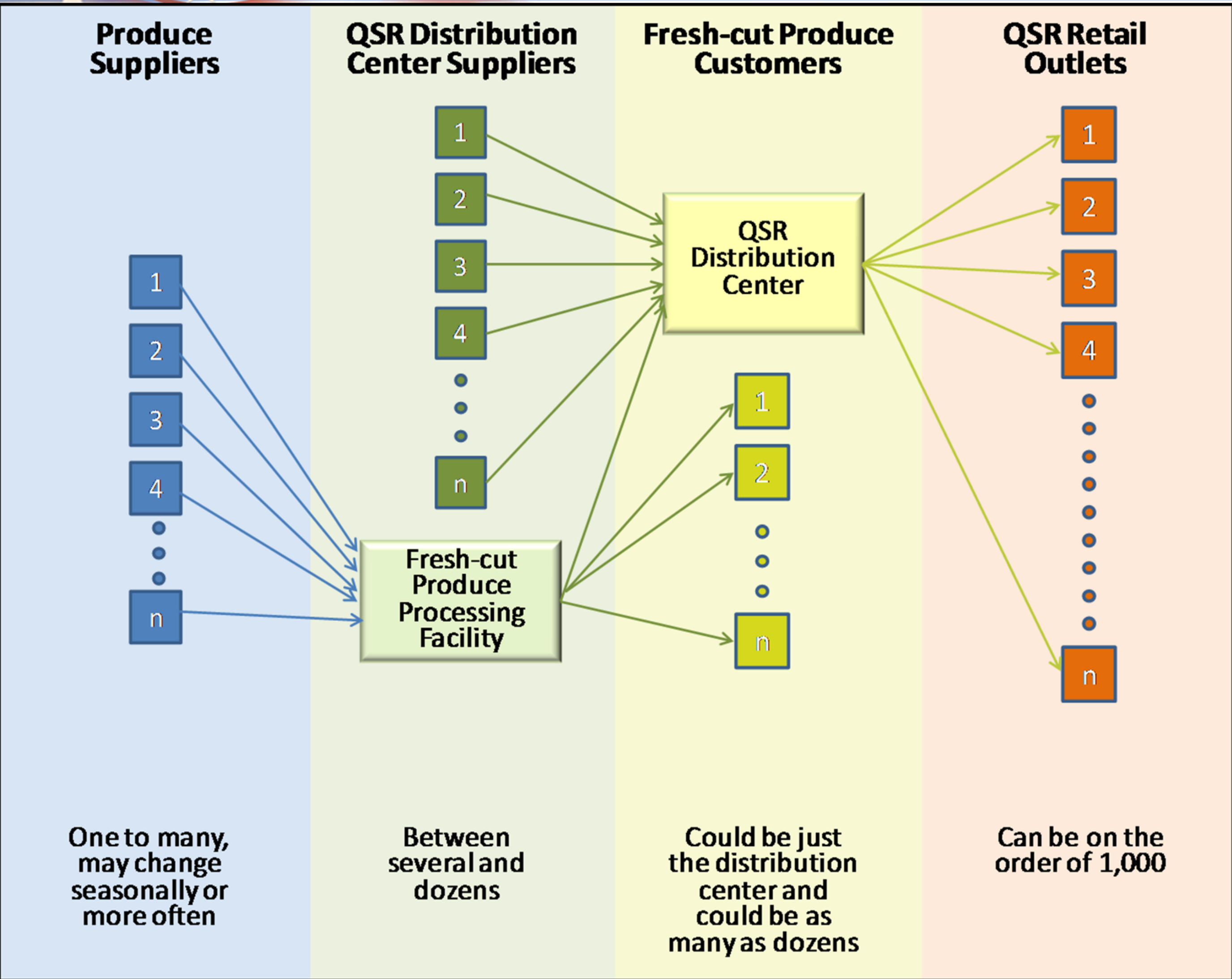
Conceptual Topology Diagram



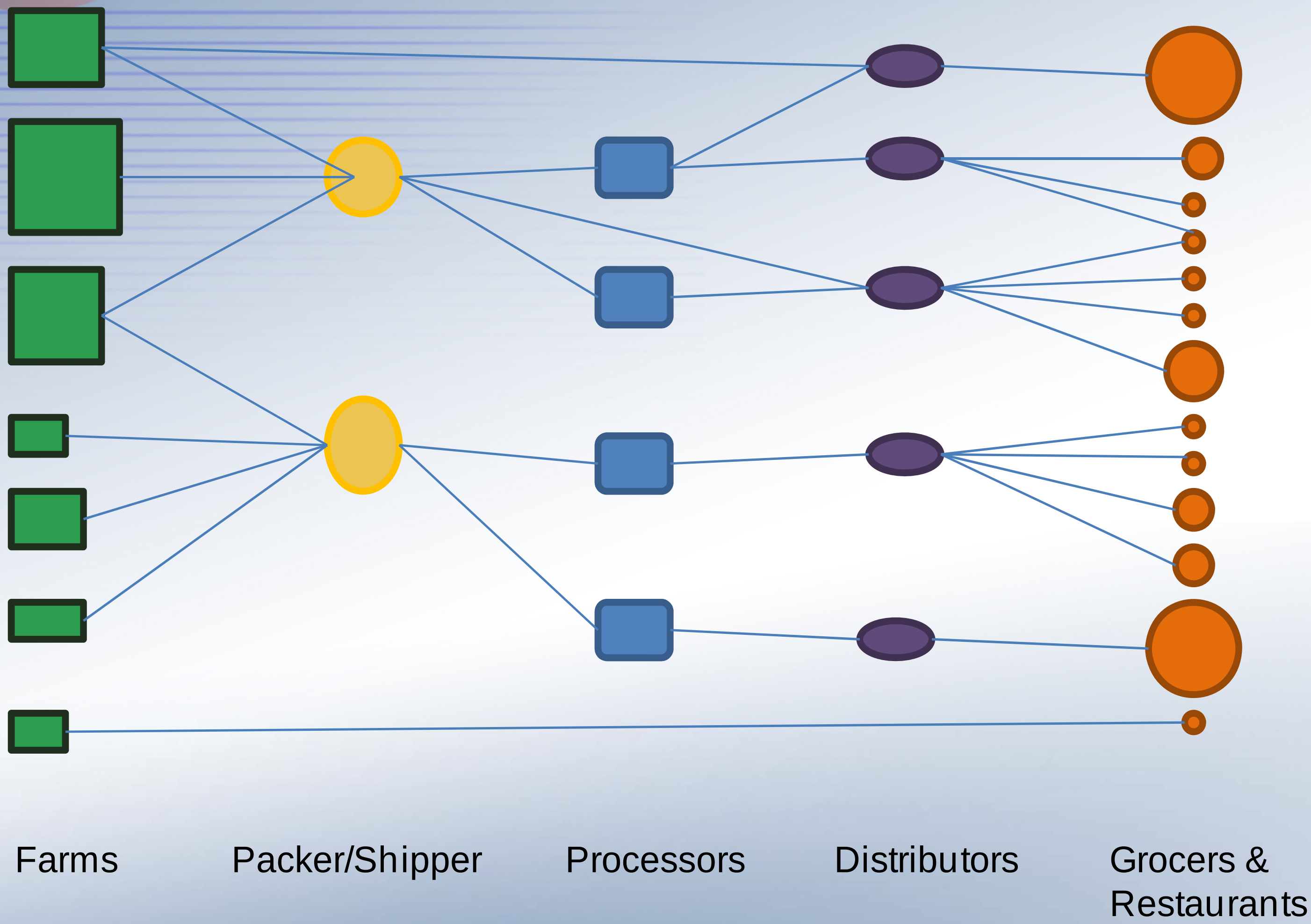
Understanding at the system level is required to understand the risks because any introduced pathogen or toxin will likely traverse many parts of the system before the consequences occur.

The current work – Stochastic mapping of food distribution networks

Objective – create a model that

- **Traces backward from the point(s) of contaminant detection to indicate where the likely sources of contamination might be**
- **Traces forward from the source of contamination to indicate where in the system the contaminated food would likely propagate**
- **Explicitly incorporates uncertainties**

Food Distribution Supply Chain – General Components and Their Connections



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Several factors contribute to the variability and uncertainty in food distribution network topologies

- Supply chain topology can vary markedly from one food marketing system and agricultural sector to another.
- Even within a single agricultural sector, some portions of the supply chain may be vertically-integrated and characterized by enduring supplier/customer relationships; while adjacent portions may be market-based and highly transitory.
- Customer/supplier relationships are sometimes considered to be proprietary information and can be closely held.
- Even among industry insiders, knowledge about supply chain topology can be relatively myopic. Many entities within the industry only know “one up and one down” – that is, they only know their direct supplier (one up) and their direct customer (one down).
- Spot-market relationships can be ephemeral, with suppliers changing from one day to the next.

Developing the stochastic network model

- **There is no textbook describing the characteristics of food marketing networks. Luckily, abundant tacit knowledge about these systems exists within industry and academia.**
- **For a specific agricultural sector, we define:**
  - the nodes
  - the rules that describe the operational behavior of each node
  - the rules that describe the interaction between nodes (links)
  - the probabilities of interactions
- **Incomplete data represent a significant source of uncertainty in creating the network topologies**
- **Monte Carlo analysis is used to explicitly incorporate uncertainties**
- **Stochastic network maps are used to display and analyze the results of stochastic modeling**

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Information Needed to Describe a Food Distribution Network

Name	Number of Outlets	Typical Sales Volume (units/day)	Typical Input Time in Inventory (day)	Typical Product Time in Inventory (day)
Retailer 1	23	2-10	3	
Retailer 2	25	6	1-4	
…				
Retailer N	6	7-10	4	
Distributor 1	1	50-100	0	
Distributor 2	2	120	0	
…				
Distributor N	1	75-90	1	
Grower 1	1	200-300	150-300	
Grower 2	1	100-120	150-450	
…				
Grower N	1	80	150-300	

Buyer	Seller: Distributor 1	Distributor 2	…	Distributor N	Grower 1	Grower 2	…	Grower N
Retailer 1								
Retailer 2								
…								
Retailer N								
Distributor 1								
Distributor 2								
…								
Distributor N								

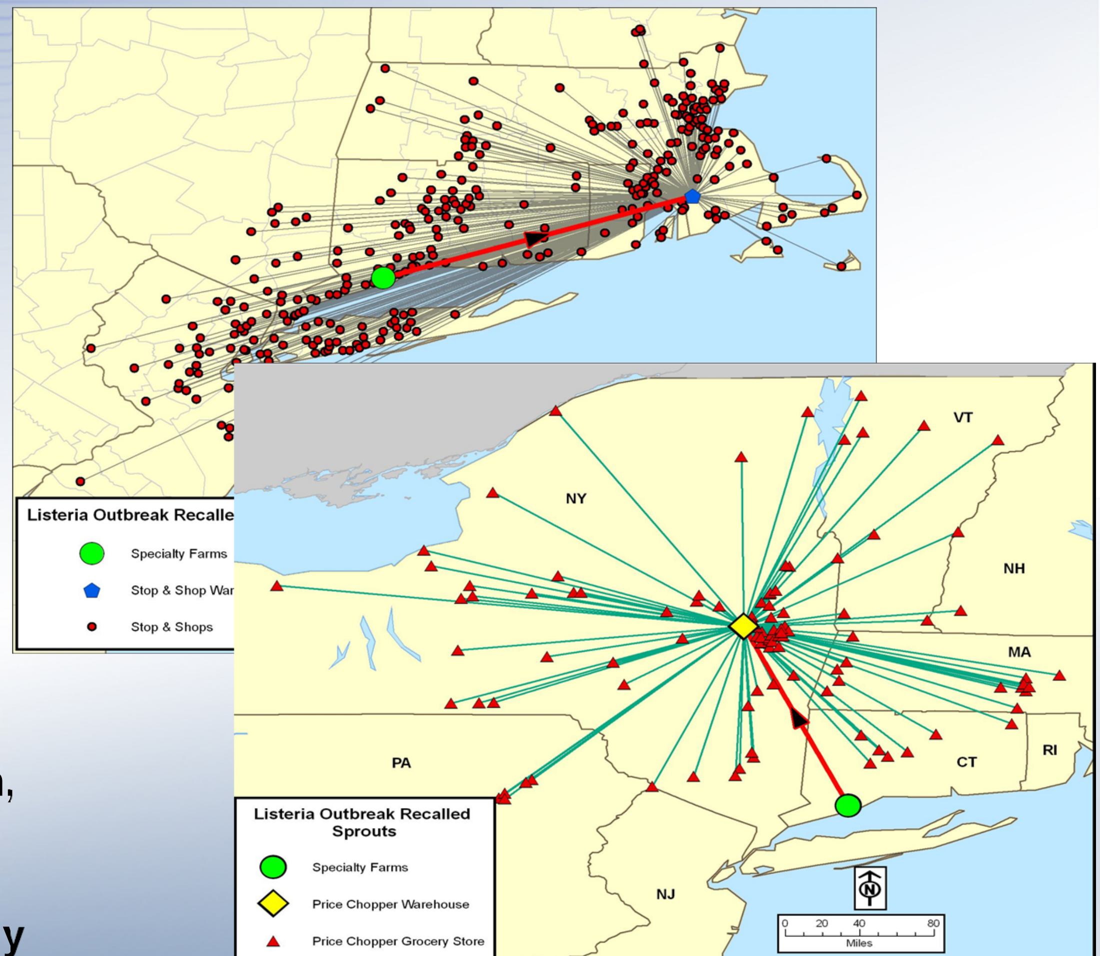
Constructing the Topological Map

- **Where data are changing too quickly, or are unavailable, there will be uncertainties – reflected in the Monte Carlo analysis.**
- **A probabilistic representation shows the possible pathways from producer through to consumer.**
- **Using the probability map produced by the model results, we should be able to see temporally and geospatially where:**
  1. products definitely went
  2. where they definitely did not go
  3. where they might have gone and the likelihood of each pathway
  4. where additional data collection is warranted.

Feeding the Model

Three complementary approaches to information gathering:

We're looking for general rules in the data that allow for robust prediction of likely pathways where there is uncertainty



- **Review of open sources to identify produce business models and to identify contamination incidents that could provide information on network characteristics and plausible contamination scenarios**
- **Interviews with food service providers and growers to validate conceptual model assumptions and identify data sources**
- **Analysis of food, transportation, economic and business databases for additional information on network topology**

Case Study: New Mexico Sprouts
Why Sprouts?

- **Historical precedent – Sprouts have been subject to numerous food safety recalls.**
- **Rapid distribution and consumption**
  - Sprouts that move through the distribution system quickly and are consumed quickly provide an inviting means to deliver pathogens or toxins to the populace.
  - The very short (7 day) shelf life of sprouts make the distribution networks tend to be far more regional than national, helping to make this, our first distribution network topology mapping exercise, somewhat more tractable.
- **Lack of a "kill step" – Non-cooked foods and food ingredients, such as sprouts, are particularly vulnerable to contamination.**
- **Distribution topologies favor wide distribution of food contaminants – Relatively large sprout-growing operations offer economies of scale. After growing and packaging, sprouts are widely distributed to a variety of regional customers.**
- **Sprout plant employment conditions facilitate placement of an insider – Many jobs in food processing are low skill, low wage, and subject to high turnover.**

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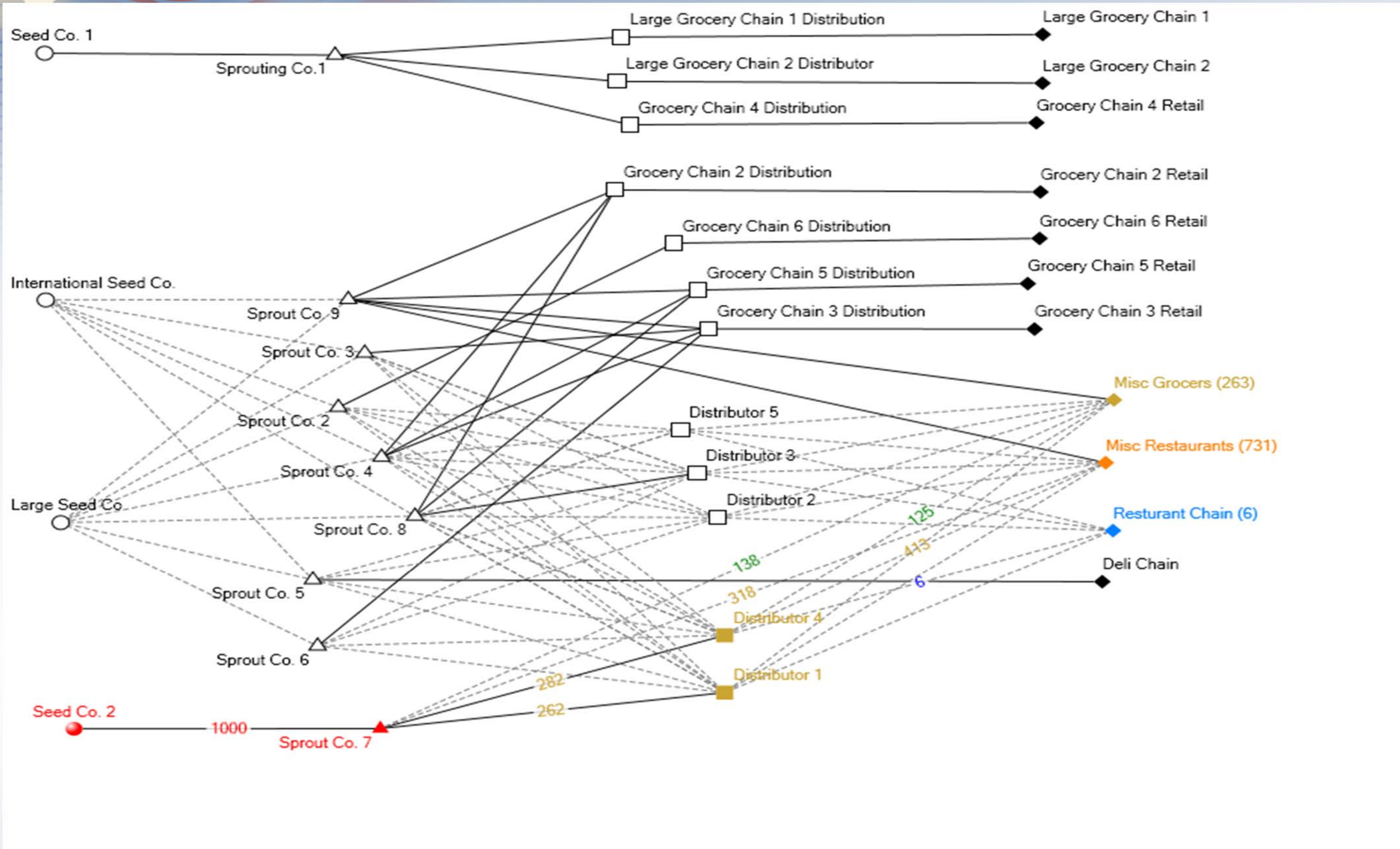
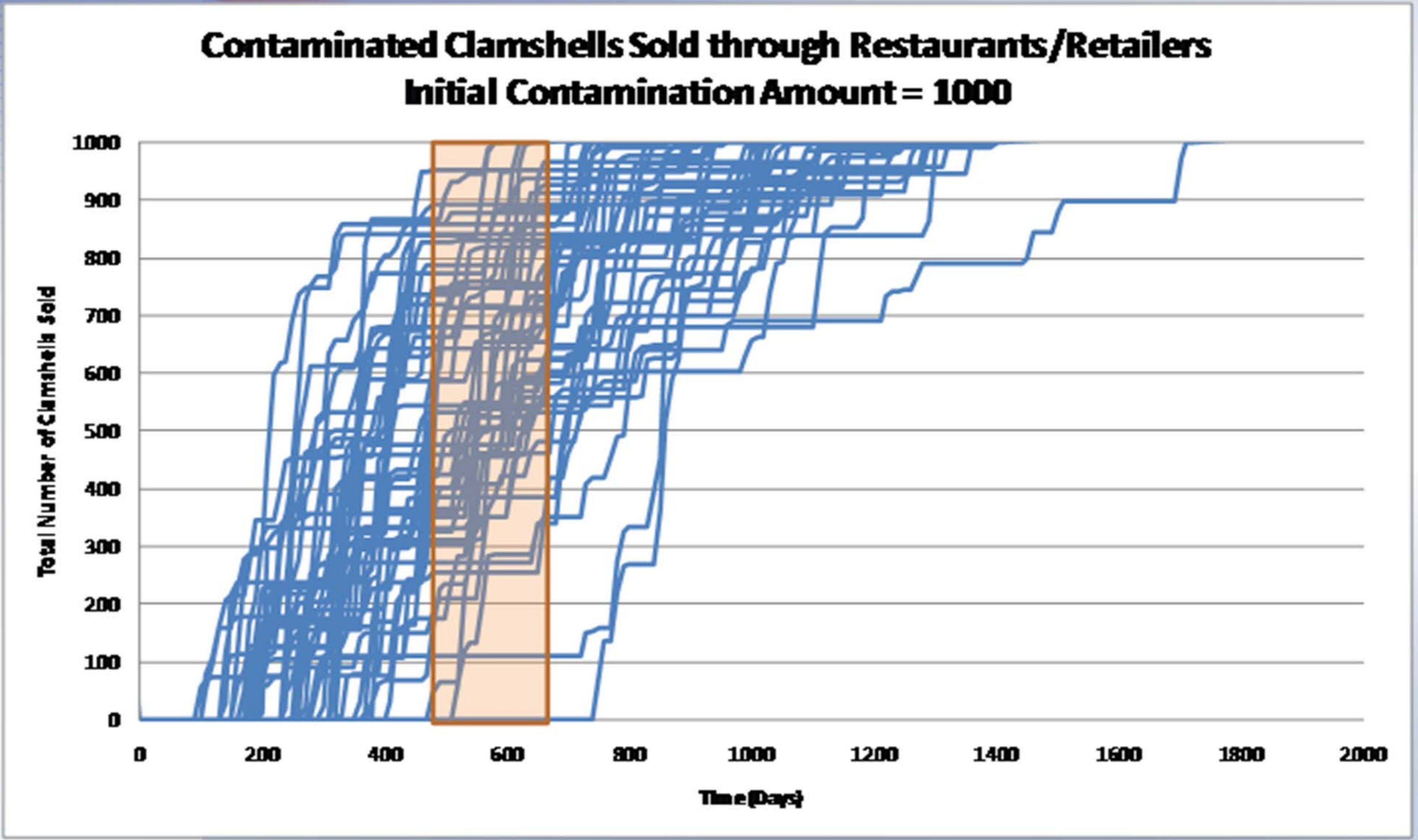
New Mexico Sprout Supply Chain



Sprout seed inventory management policy: random vs FIFO



Conditional vs unconditional probabilities FIFO case, 1000 units contaminated

	Sprout Co 1	Sprout Co 7	Sprout Co 2	Sprout Co 4	Sprout Co 10	Sprout Co 8
Large Grocery Chain 1	1.00	0.00	0.00	0.00	0.00	0.00
Deli Chain	0.00	0.18	0.27	0.18	0.09	0.09
Sprout Co. 7 Customers	0.00	1.00	0.00	0.00	0.20	0.00
Grocery Chain 2 Retail	0.00	0.07	0.13	0.40	0.53	0.20
Misc. Grocers	0.00	0.24	0.39	0.15	0.22	0.10
Misc. Restaurants	0.00	0.24	0.38	0.14	0.24	0.10
Grocery Chain 3 Retail	0.00	0.00	0.25	0.38	0.50	0.06
Large Grocery Chain 2	1.00	0.00	0.00	0.00	0.00	0.00
Restaurant Chain	0.00	0.24	0.38	0.14	0.24	0.10
Grocery Chain 4 Retail	1.00	0.00	0.00	0.00	0.00	0.00
Distributor 5 Customers	0.00	0.11	0.11	0.11	1.00	0.00
Grocery Chain 6 Retail	0.00	0.00	1.00	0.00	0.06	0.13
Grocery Chain 5 Retail	0.00	0.00	0.13	0.40	0.53	0.20
Unconditional Probability	0.16	0.20	0.32	0.12	0.20	0.08

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When should this modeling be done? And by whom?

When?

- **Performed prior to contamination events.**
  - Characterization of food distribution network topologies requires significant effort -- the network must be characterized ahead of time.
  - This is contrary to current practice. It is not uncommon that difficulties in ascertaining all the various network relationships can impede the progress in trace-back efforts after food contamination incidents.

Who?

- **The methodologies and modeling tools developed in this program could support industry engagement and enable proactive food supply chain analyses.**
  - Big retailers (grocery and foodservice)
  - FDA / USDA
  - Trade associations
  - Regional health departments

Conclusions

- **We developed a general methodology for stochastic mapping of food distribution networks and applied it to New Mexico edible sprouts.**
- **Simulations conducted over this stochastic network allow us to:**
  - Trace forward from the source of contamination to indicate where in the system the contaminated food would likely propagate;
  - Trace backward from the point(s) of contaminant detection to indicate where the likely sources of contamination might be;
  - Identify what information, if available, would reduce the uncertainty in the prediction of pathway and potential for consequence;
  - Help resolve vulnerabilities in the food distribution system that could be exploited by an adversary; and
  - Predict the potential success of competing risk management strategies for the reduction of consequence.
- **The amount of dispersion in the system impacts the success of recall efforts**
  - The magnitude of the contamination event affects the breadth of dispersion across the various retailers
  - Inventory management practice affects the degree of temporal dispersion

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