Cover Page Meeting 01

Public Health Services and Systems Research
Project Title: Modeling Supply Chain System Structure to Trace Sources of Food Contamination
Project I.D.: 71273
Legal Name of Applicant Organization: Massachusetts Institute of Technology

Presenter Name: Abigail Horn

Affiliation: Engineering Systems Division, Massachusetts Institute of Technology

Title of Presentation: Modeling Supply Chain System Structure to Trace Sources of Food Contamination: Problem Framing

This presentation was made at multiple locations:

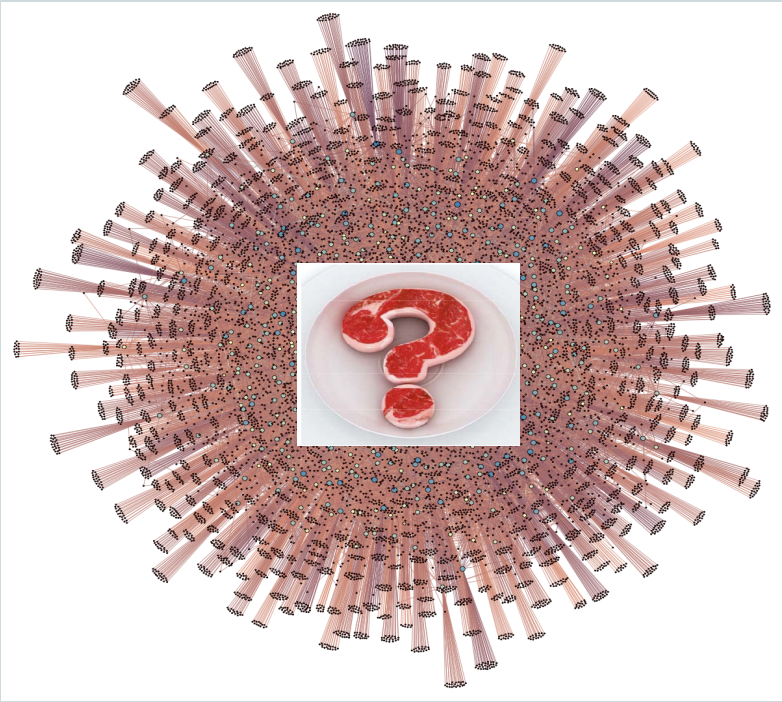
Meeting 1 Name: Institute for Operations Research and the Management Sciences (INFORMS) Annual Meeting
Meeting 1 Name of organization: Institute for Operations Research and the Management Sciences (INFORMS)
Meeting 1 Date and place of presentation: October 6, 2013, Minneapolis, MI

Meeting 2 Name: Services Research Symposium
Meeting 2 Name of organization: IBM T. J. Watson Research Center
Meeting 2 Date and place of presentation: October 22, 2013, Yorktown Heights, NY

Meeting 3 Name: Center for Complex Systems and Enterprises Seminar Series
Meeting 3 Name of organization: Stevens Institute of Technology
Meeting 3 Date and place of presentation: November 18, 2013, Hoboken, NJ

Meeting 4 Name: Technology, Management, and Policy (TMP) Consortium 2014 Meeting
Meeting 4 Name of organization: Instituto Superior Téchnico, on behalf of TMP
Meeting 4 Date and place of presentation: June 23, 2014, Lisbon, Portugal
Proceedings available online at: http://in3.dem.ist.utl.pt/tmp2014/final_programme.asp

Modeling Supply Chain System Structure to Trace Sources of Food Contamination



Technology, Management, and Policy
Graduate Consortium Meeting
June 23, 2014

ABIGAIL HORN,
Engineering Systems Division, MIT

DOCTORAL COMMITTEE:
PROF. RICHARD LARSON (Chair)
DR. STAN FINKELSTEIN
PROF. CÉSAR HIDALGO

In 2006 there was an outbreak of E. coli O157:H7 in spinach in the US

Known Impact of 2006 spinach outbreak:

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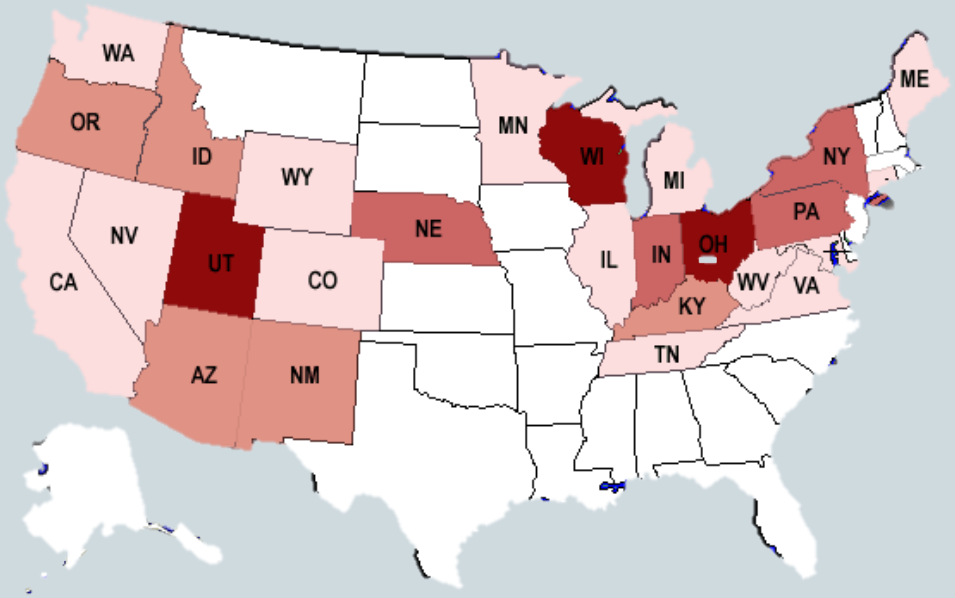
Known Impact of 2006 spinach outbreak:

- 276 Illnesses
- 102 Hospitalizations
- 3 Deaths
- 26 States with cases
- $350 million direct losses to spinach industry



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Could Damage Have Been Prevented?

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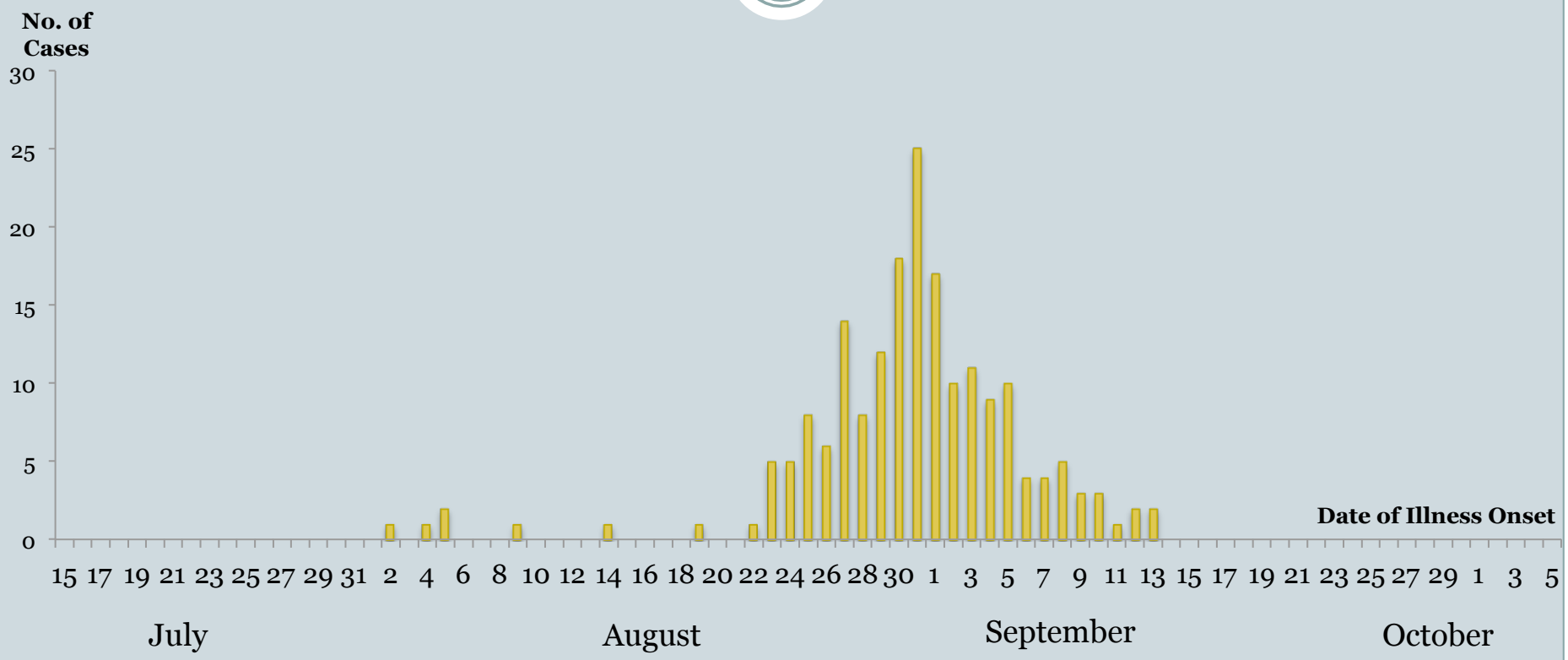

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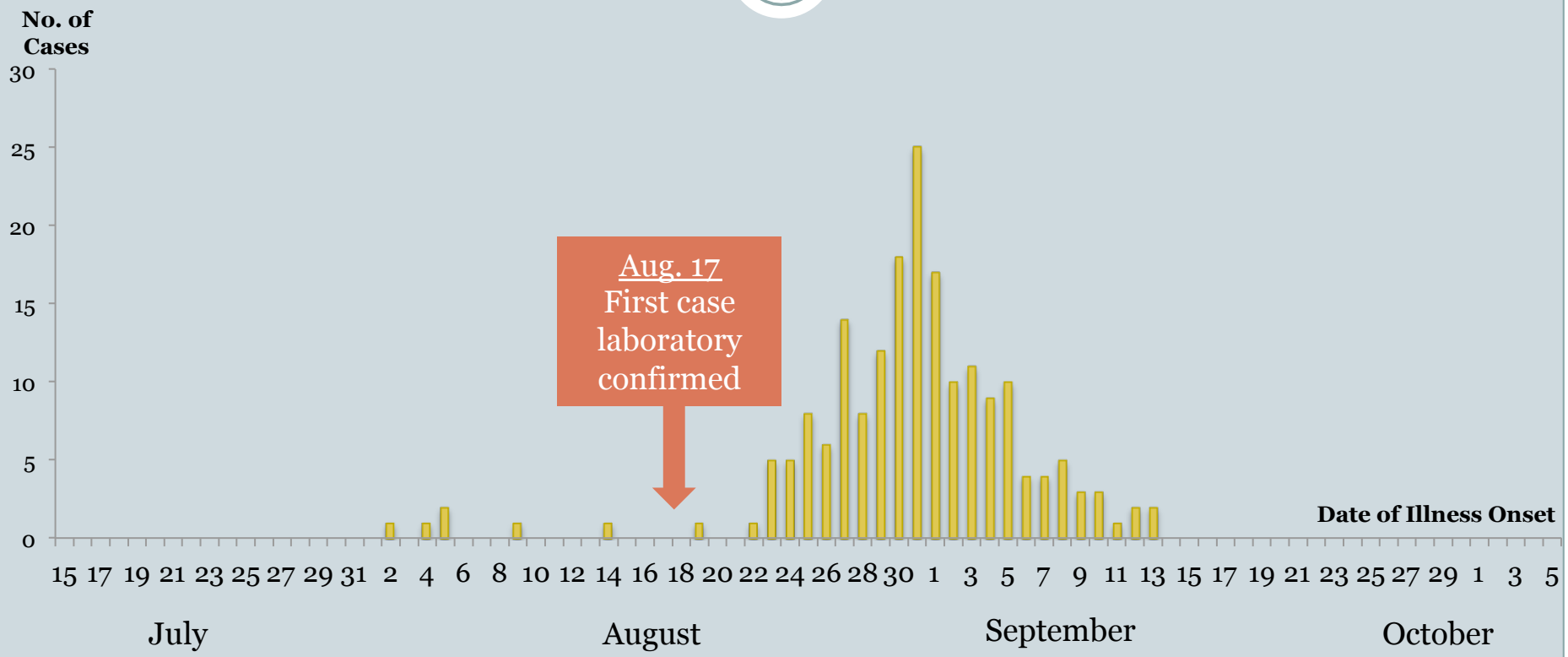

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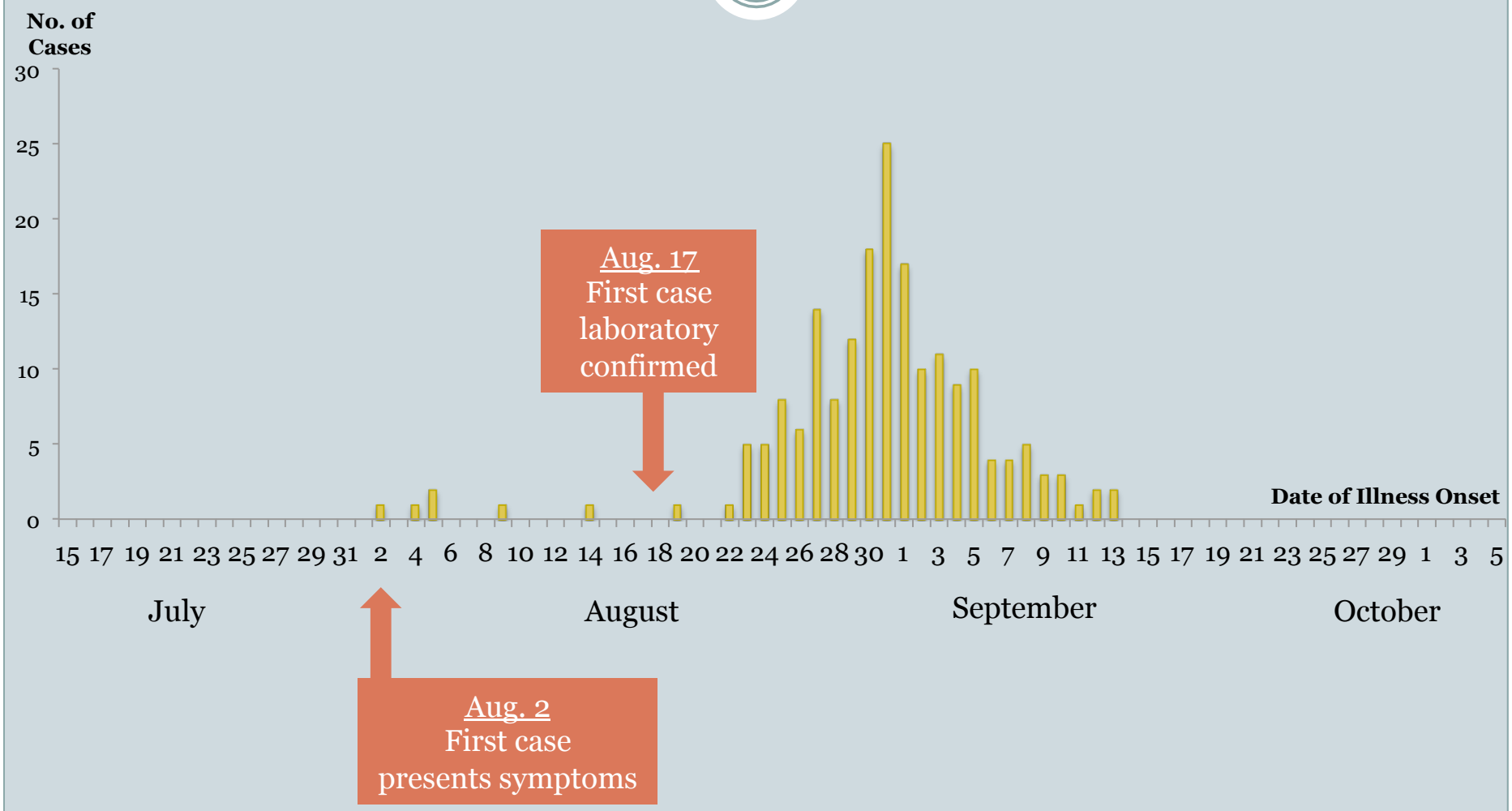

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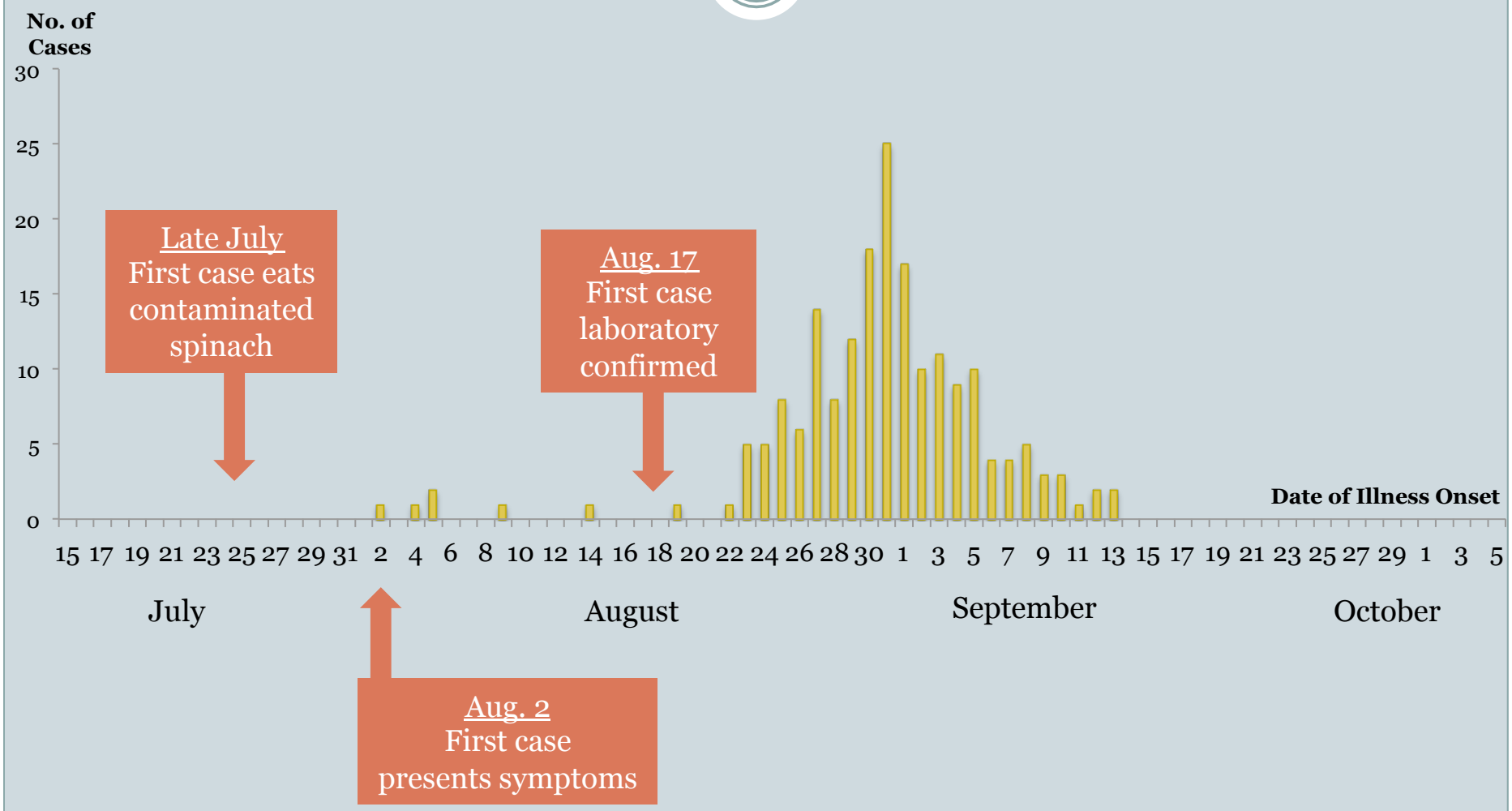

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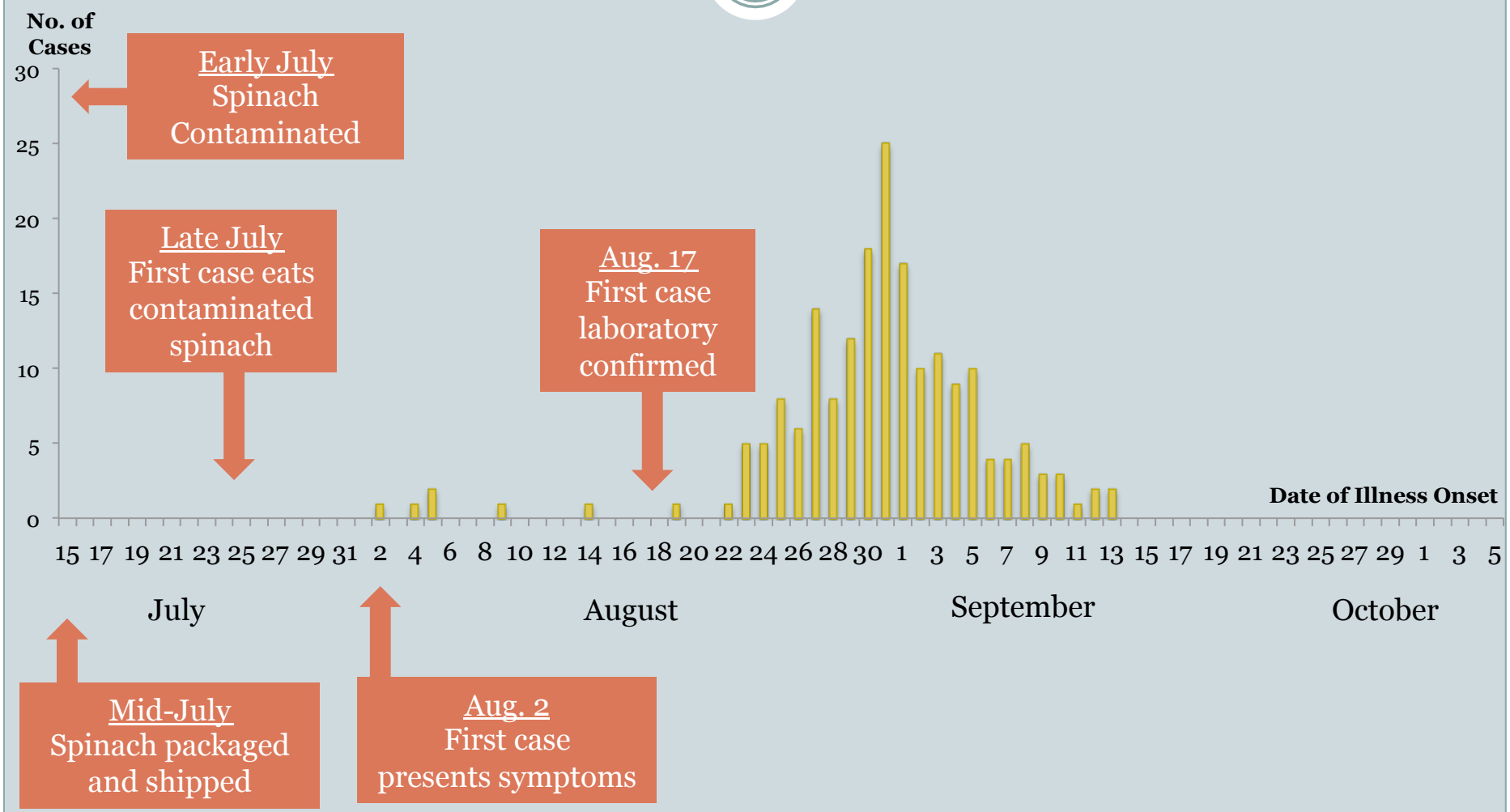

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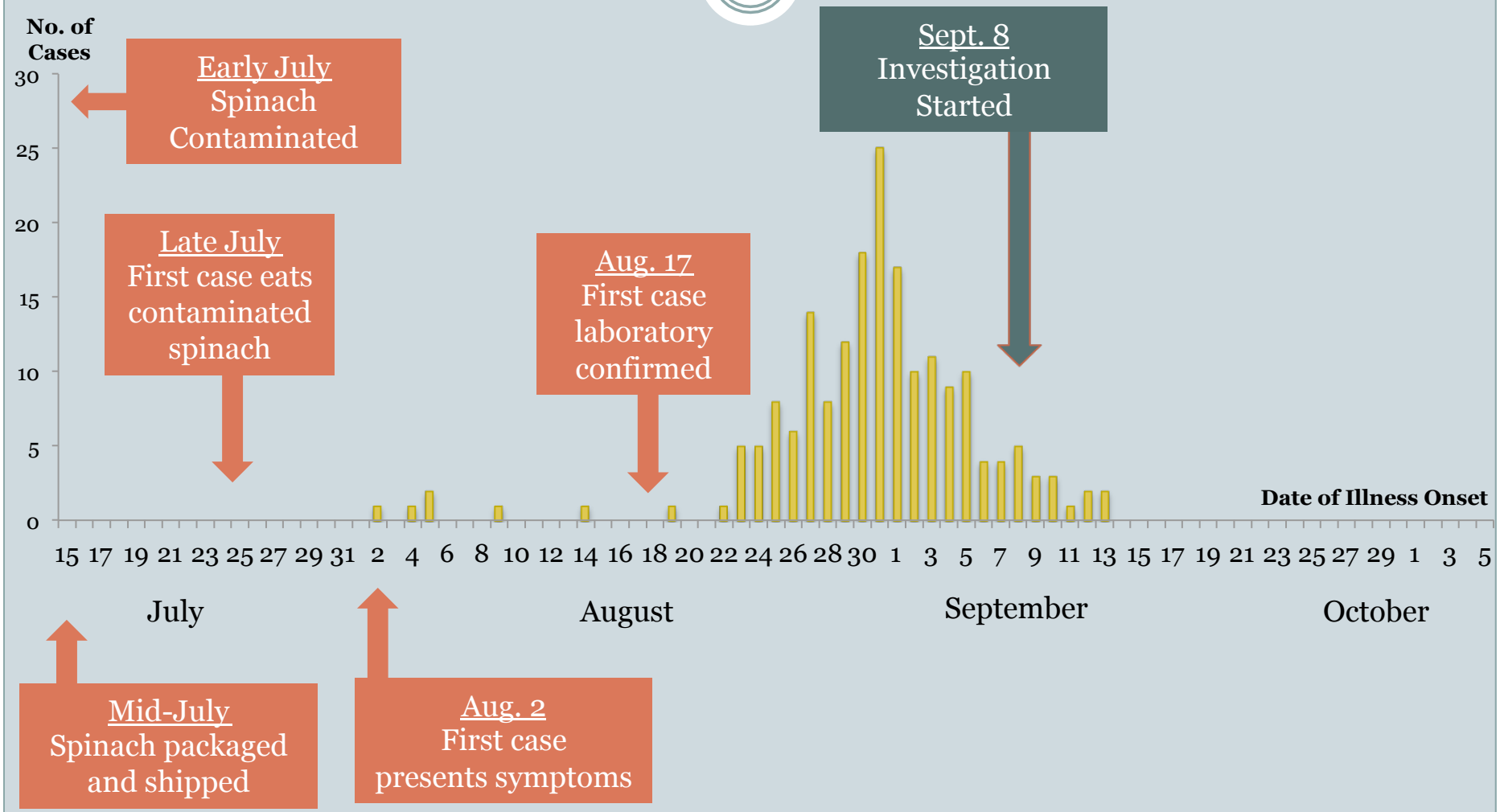

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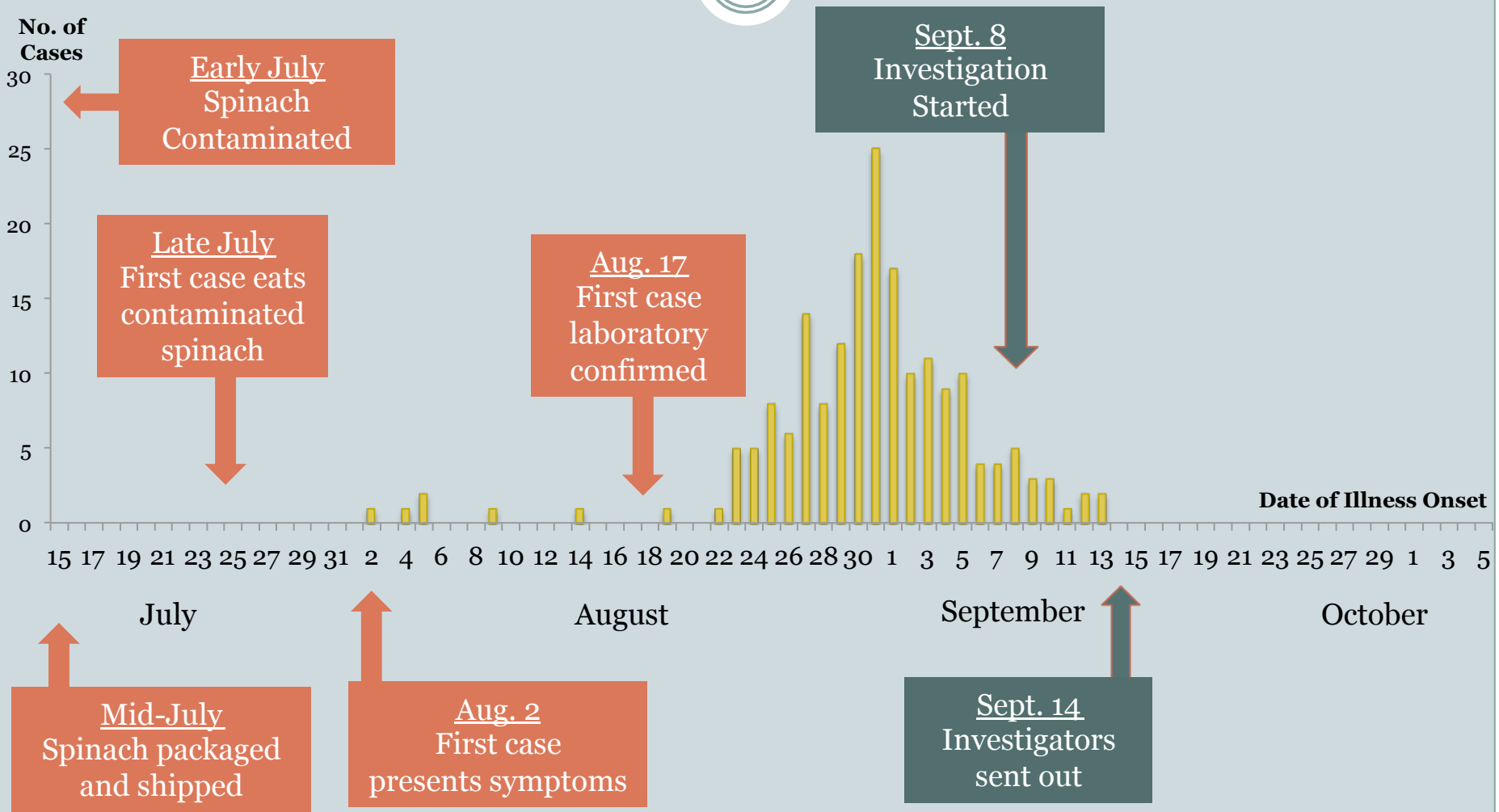

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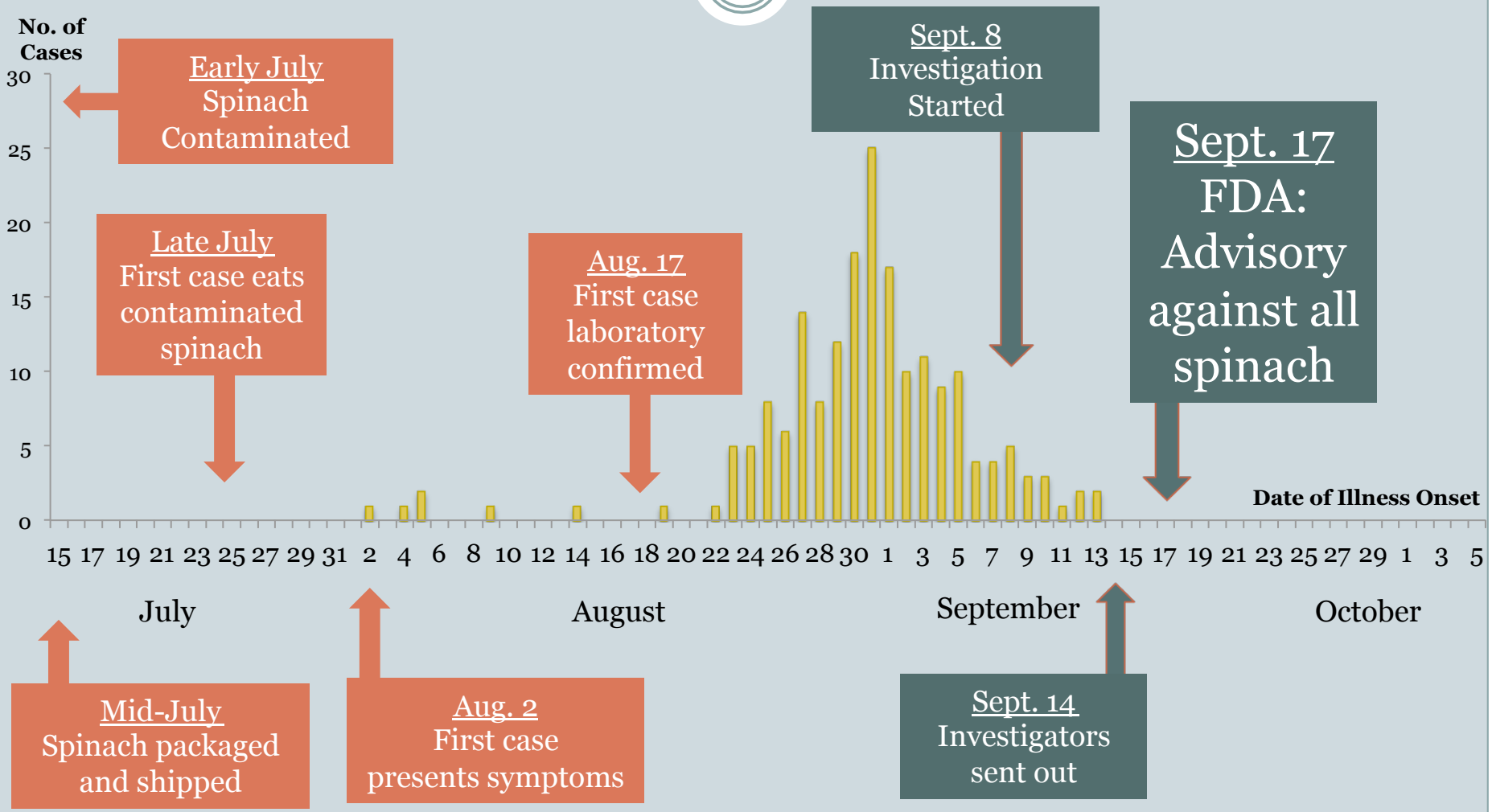

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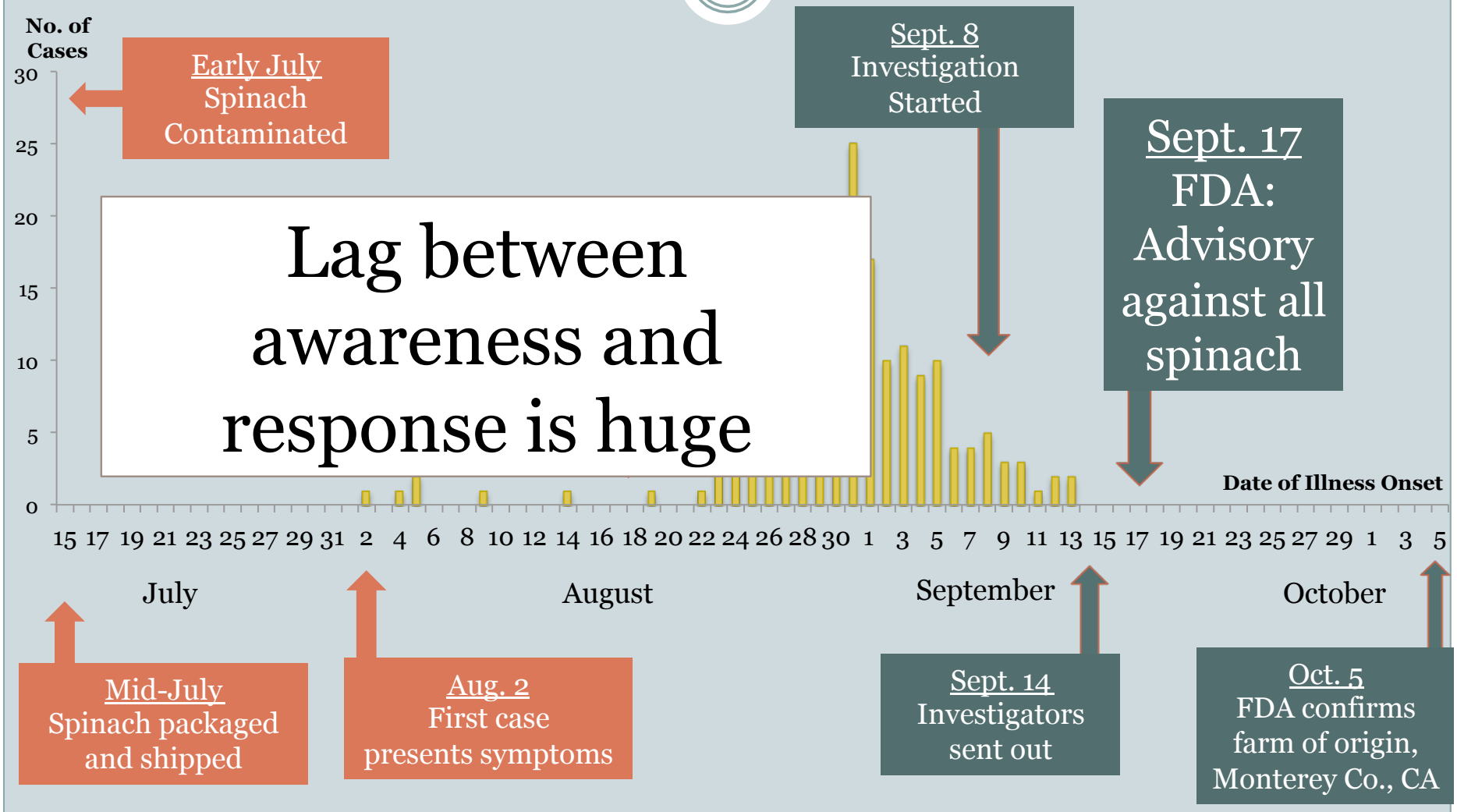

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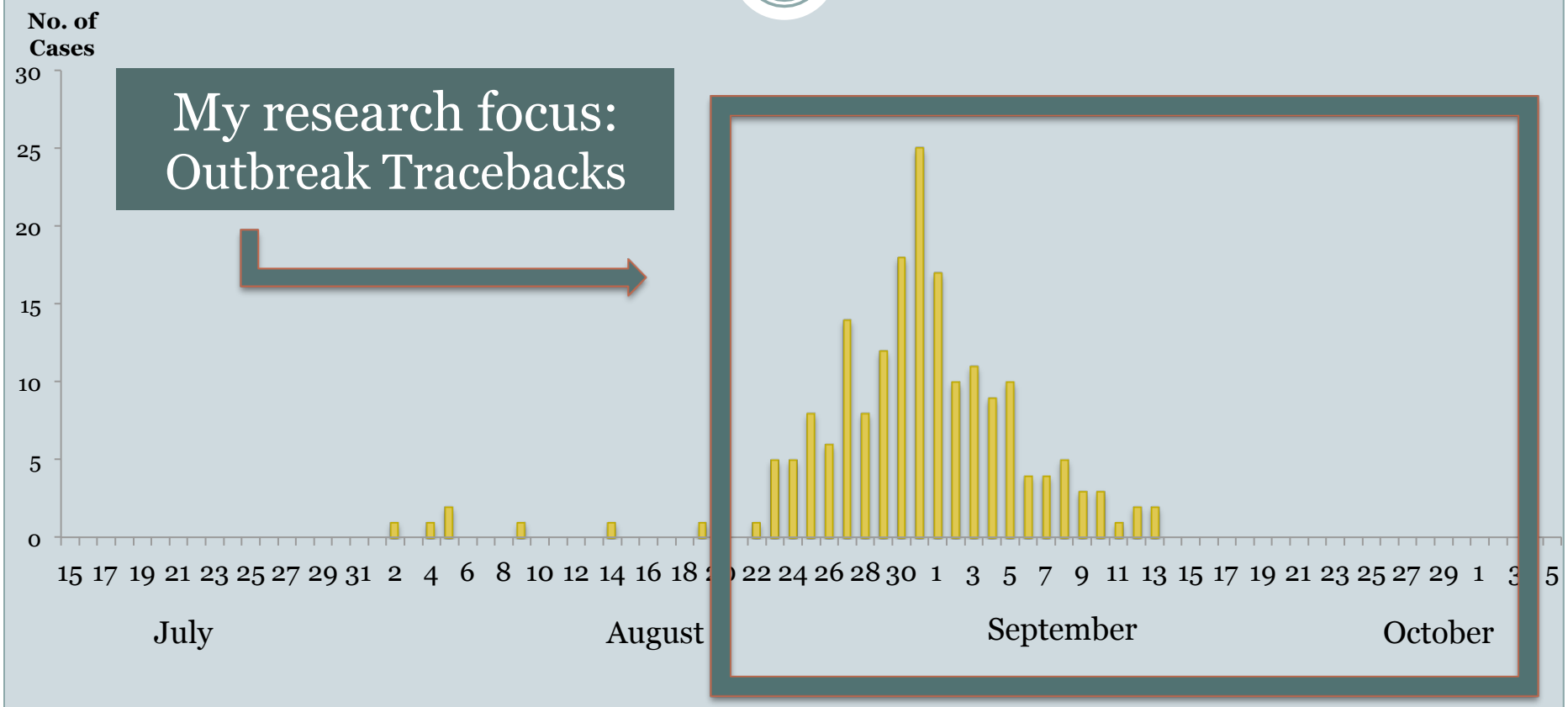
Tactical Response to Outbreaks



Bayesian Updating Network Approach

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Method should allow for **dynamic updating**

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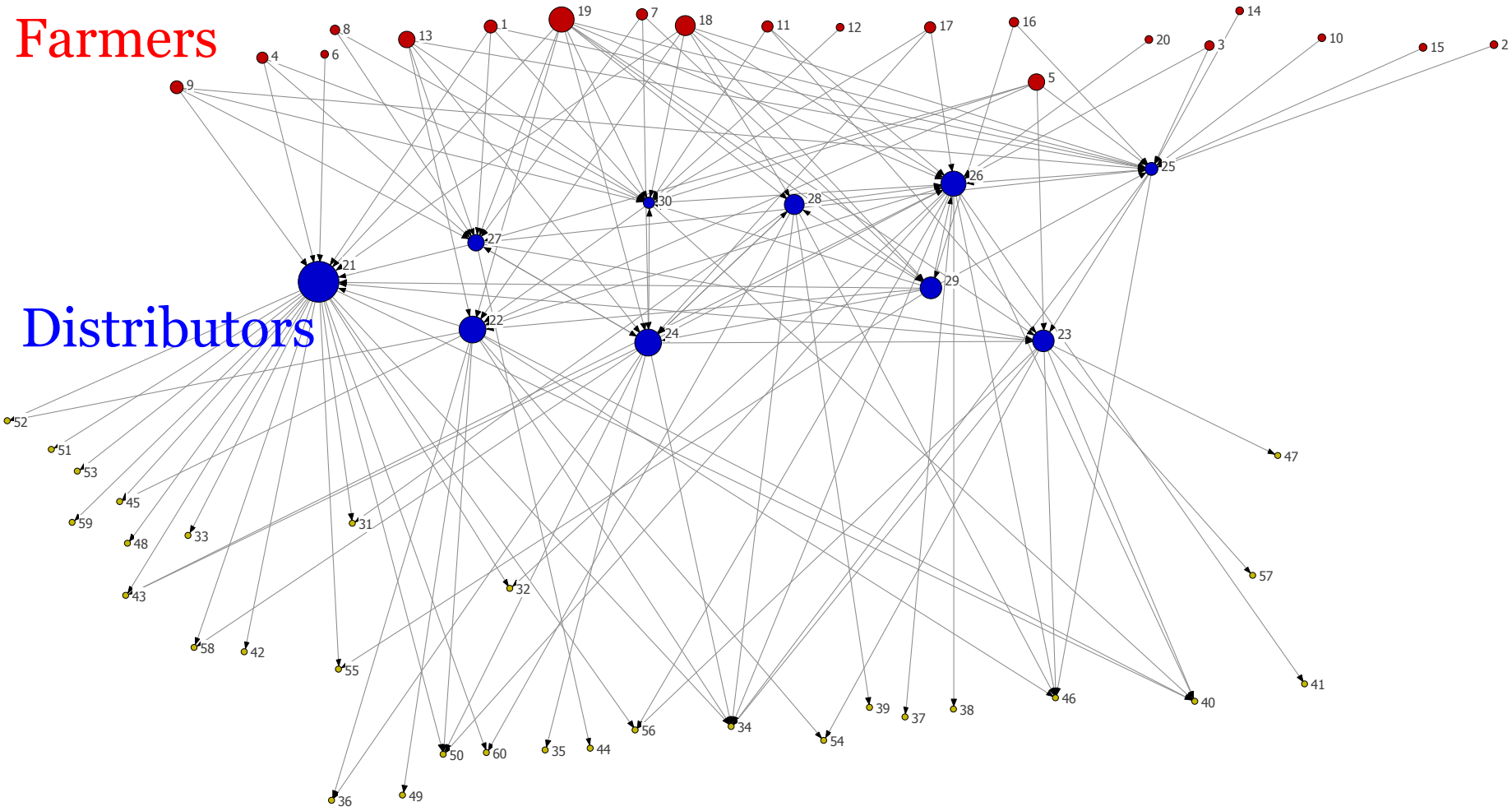
BAYESIAN UPDATING NETWORK APPROACH

Modeling Framework



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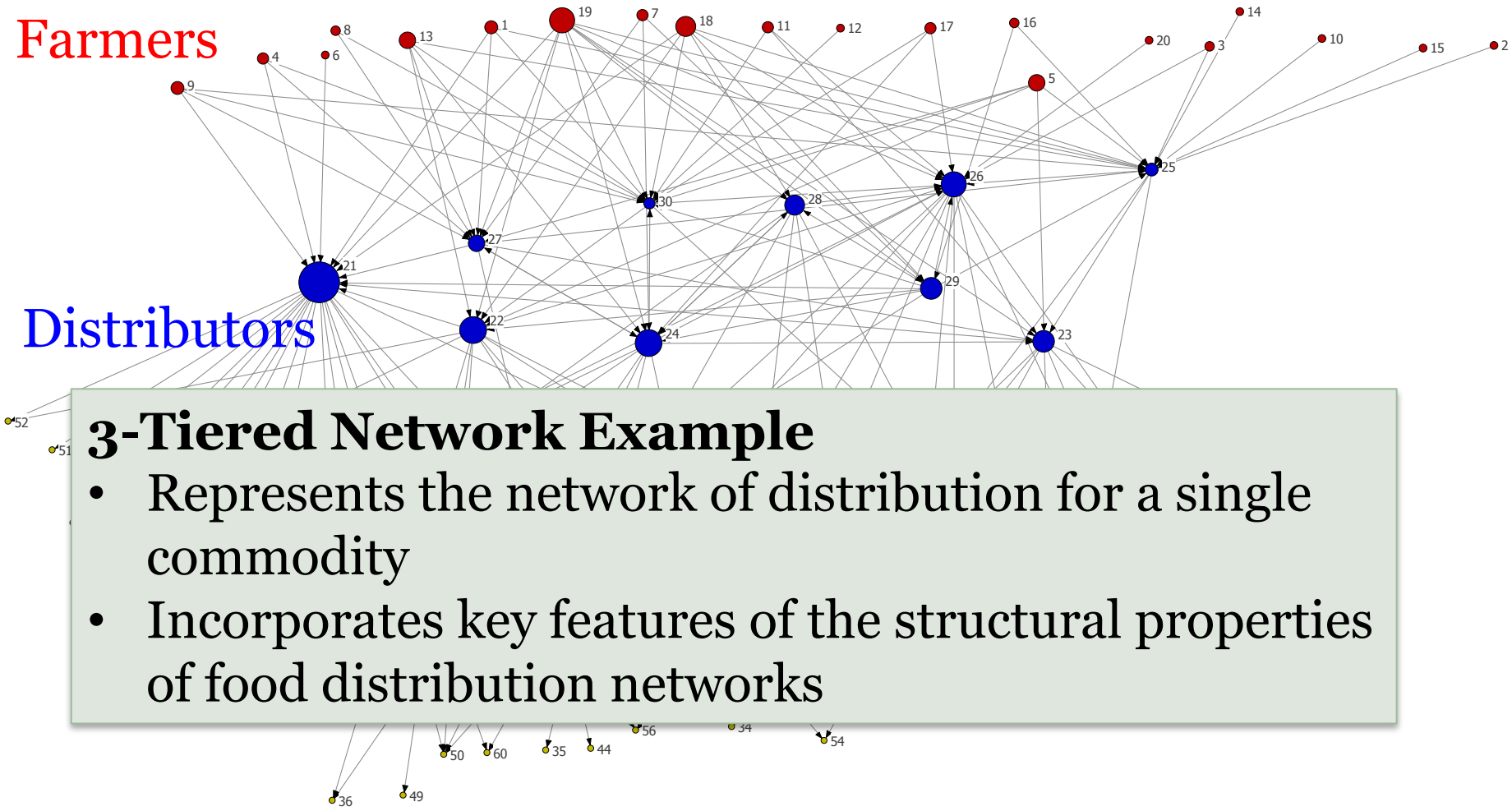
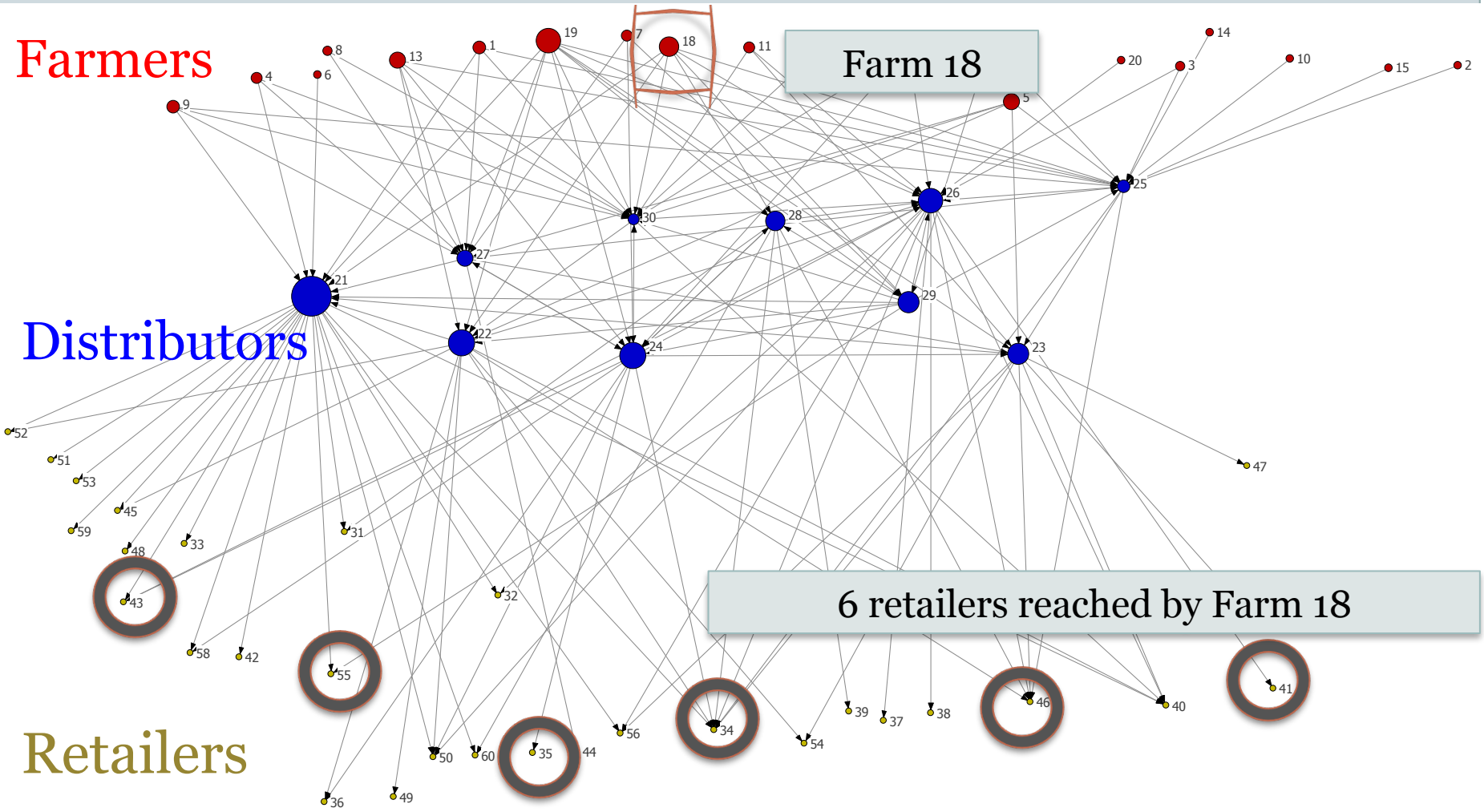


3-Tiered Network Example

- Represents the network of distribution for a single commodity
- Incorporates key features of the structural properties of food distribution networks

Modeling Framework



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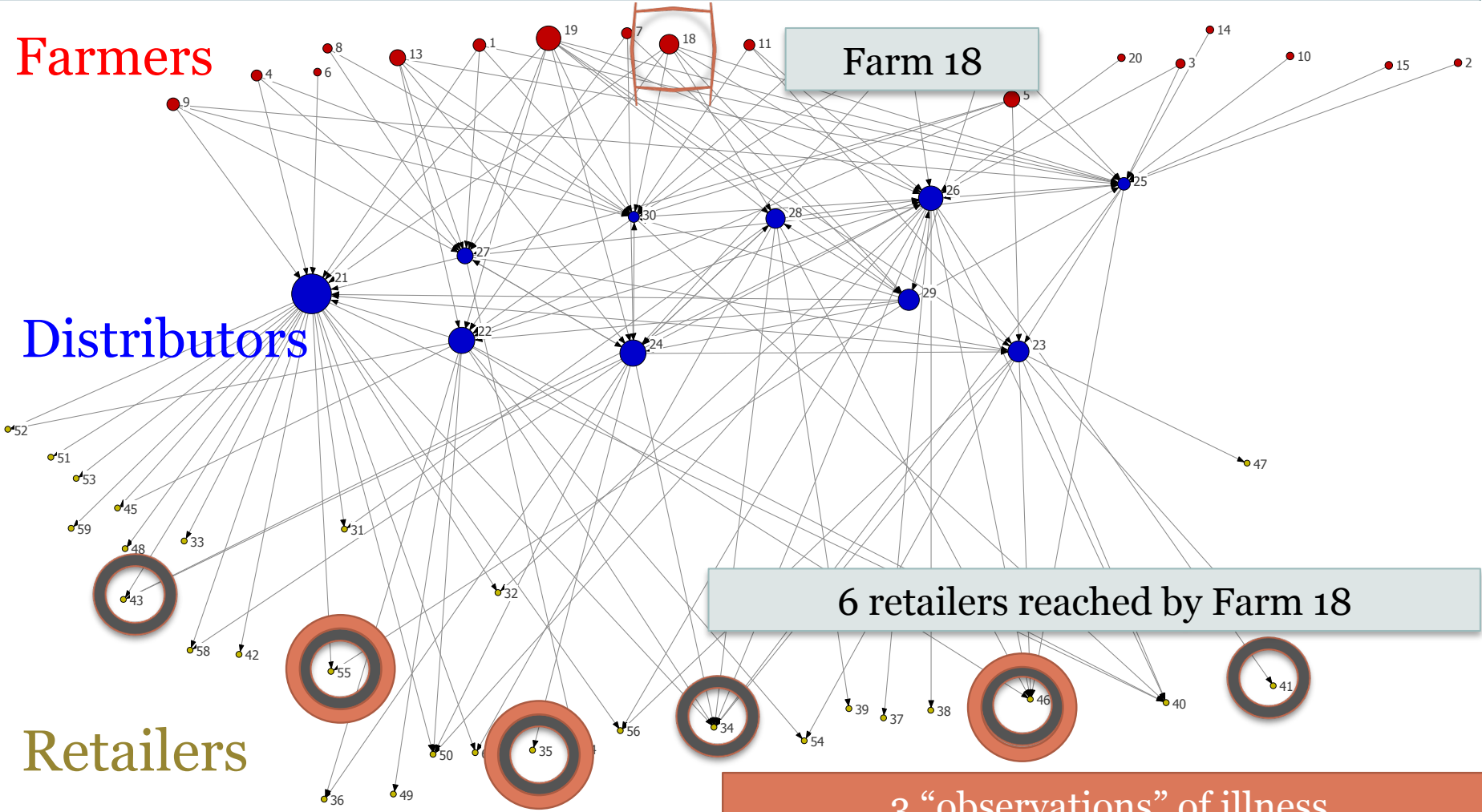

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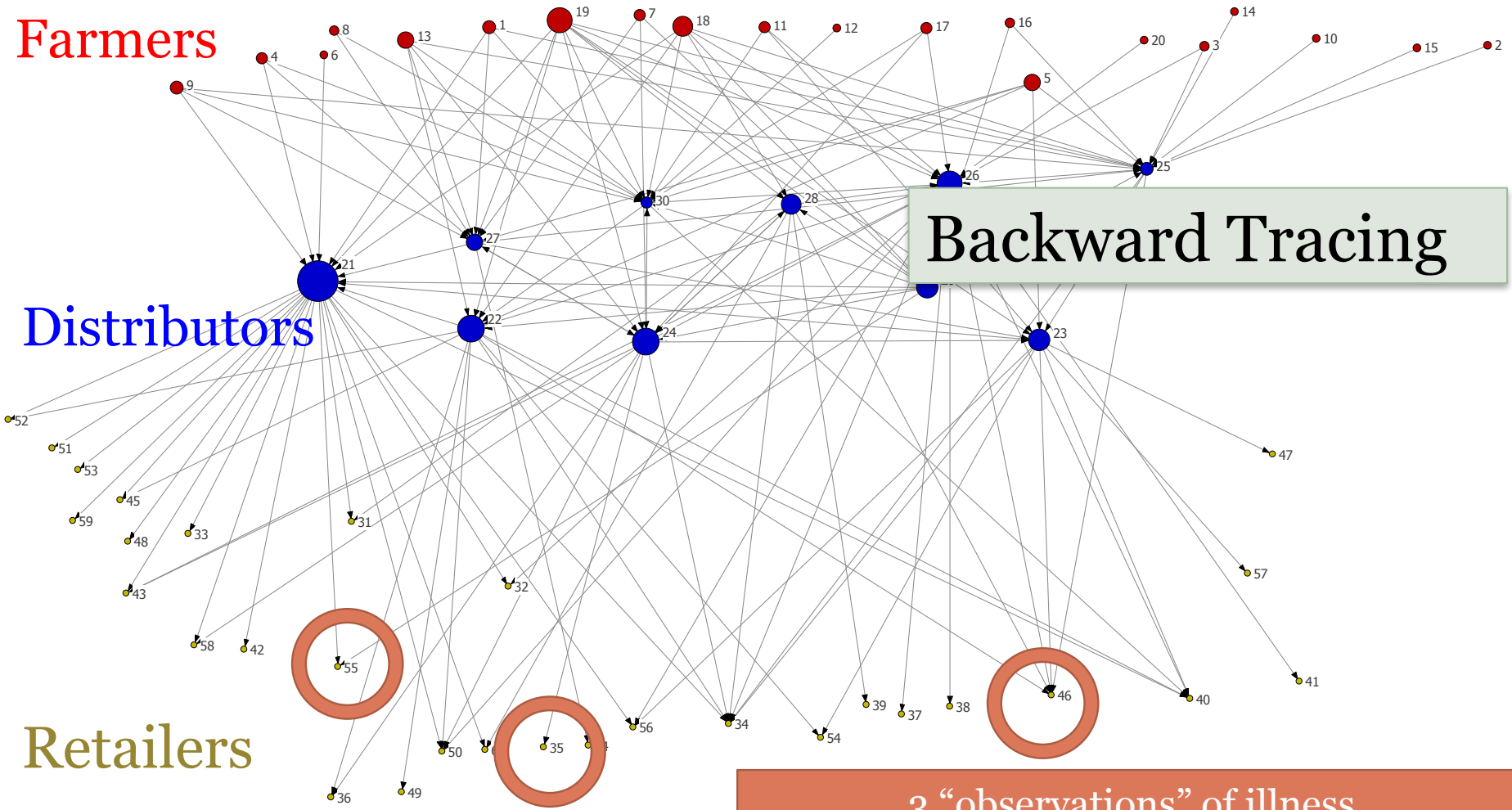
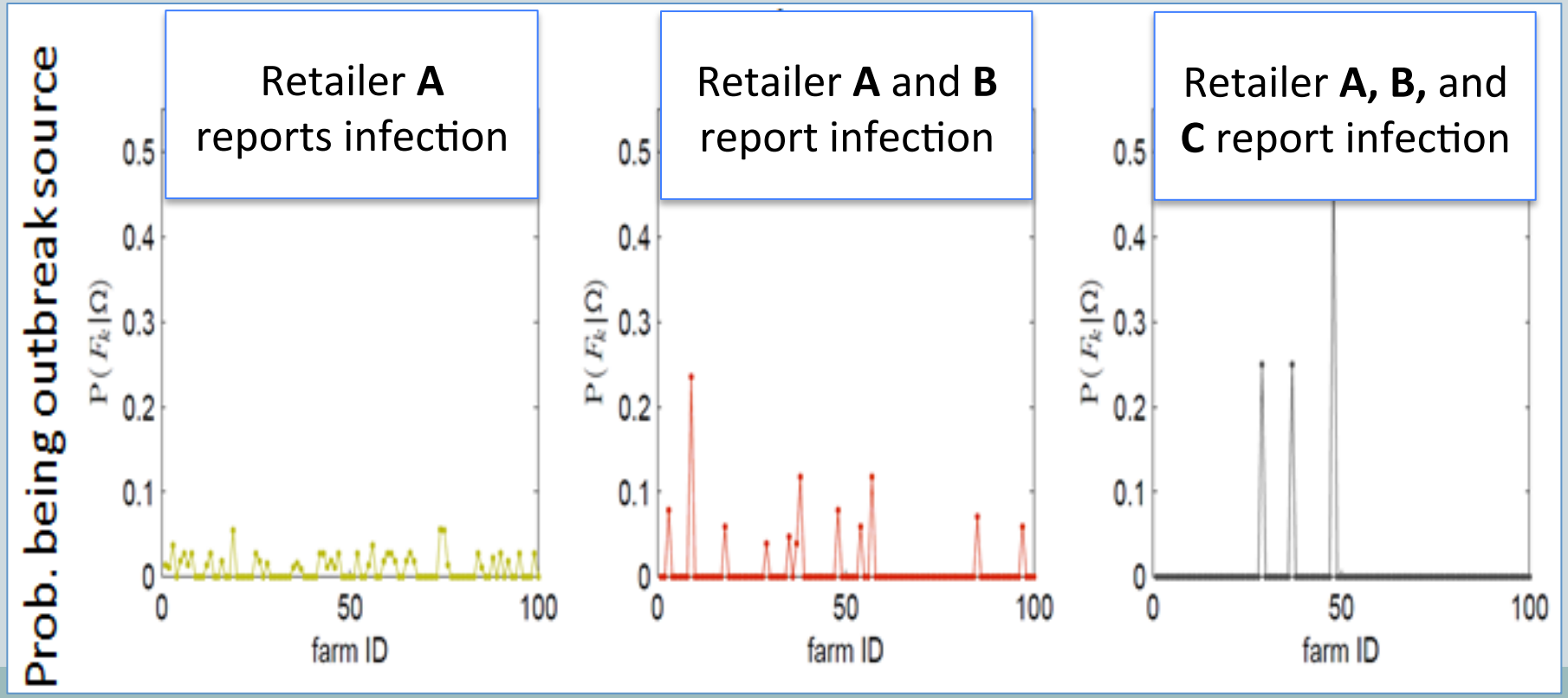


Probability of each farm being the outbreak source given R retailers reporting illness

Let $\boldsymbol{F_k}$ = Farm k is the outbreak source, k = 1,..., F
Let $\boldsymbol{\Omega}$ = set of retailers reporting infection
Find: P(F_k|$\boldsymbol{\Omega}$), where $\boldsymbol{\Omega_1}$= r_A , $\boldsymbol{\Omega_2}$= r_A, r_B, $\boldsymbol{\Omega_3}$= r_A, r_B, r_C



PhD Research:
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4. **Monte Carlo simulation on network models incorporating more of the true system complexity**

Research Purpose: Sensitivity analysis to explore realistic outbreak scenarios

1. Bayesian Prior Probabilities

Determine Bayesian subjective prior probability of each district being the outbreak source location by combining and weighing information of the following types (when available):

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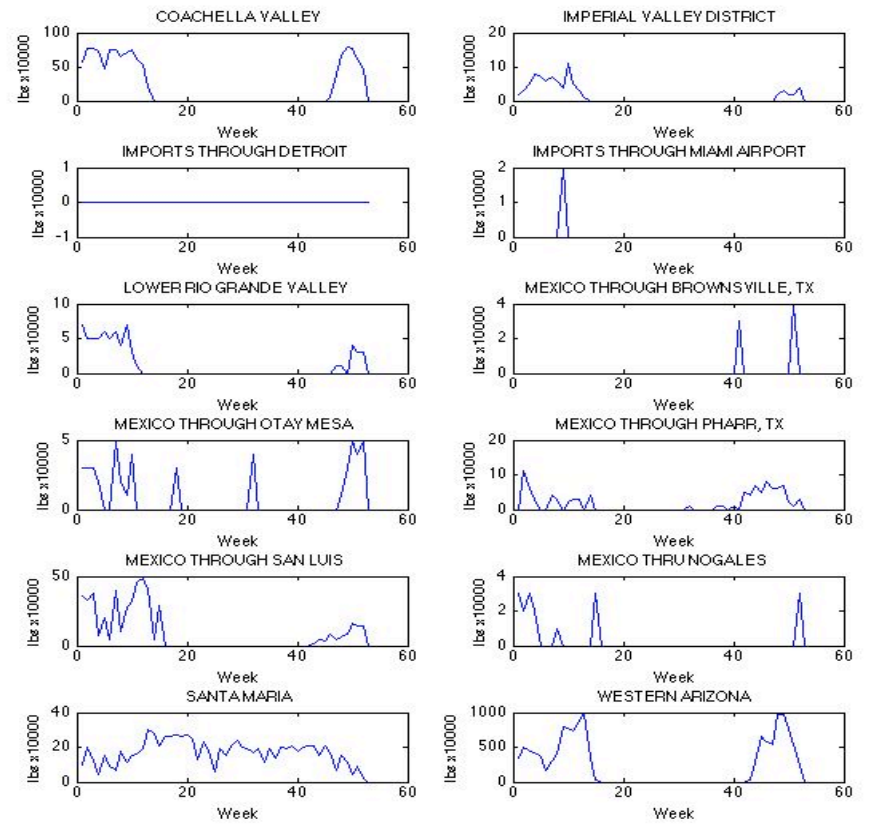
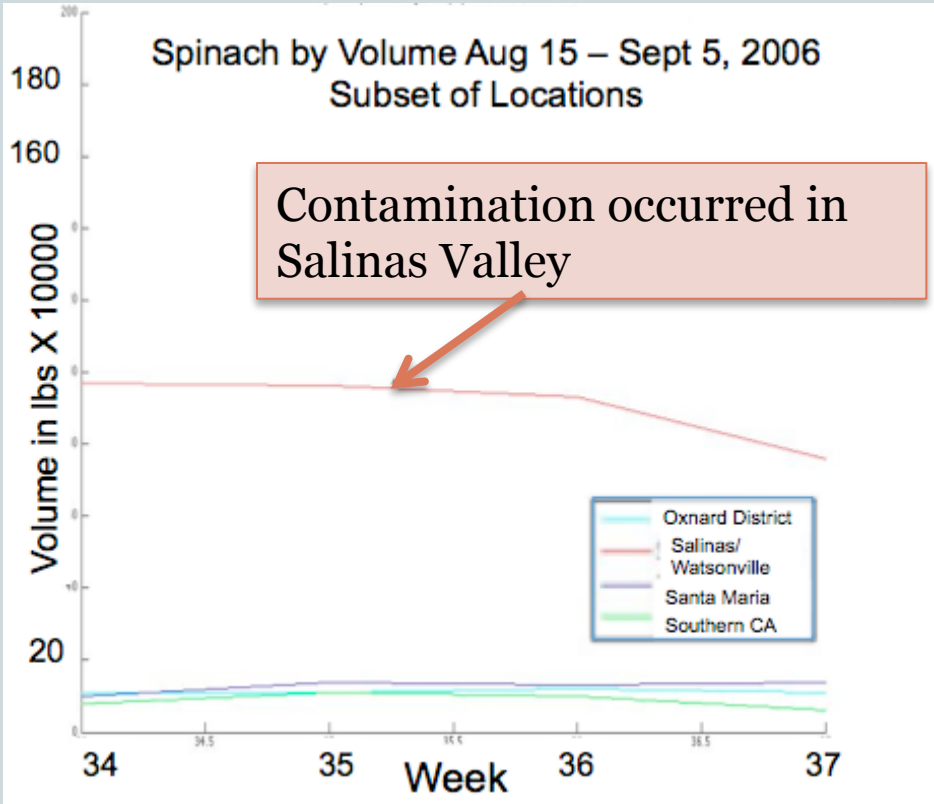
D) Current consumption – estimated from volume of product shipped per week from each possible district

1. Bayesian Prior Probabilities



Shipping records for movement of spinach from all (12) districts of origin during 2006 (from USDA Agricultural Marketing Service)



Movement of spinach for ***possible*** origin districts during August 15 – September 6th, 2006.

2. Analytical Models

Using simple, stylized network structures:

→ Develop closed-form expressions to explore the relationship between network parameters and traceback accuracy, e.g.:

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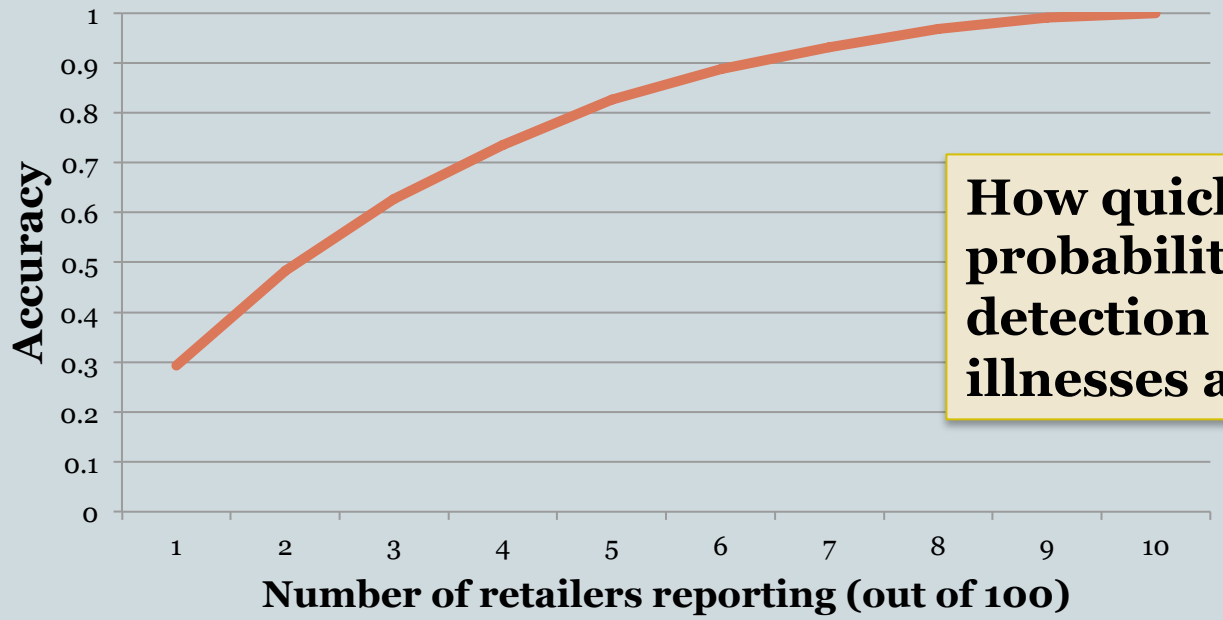


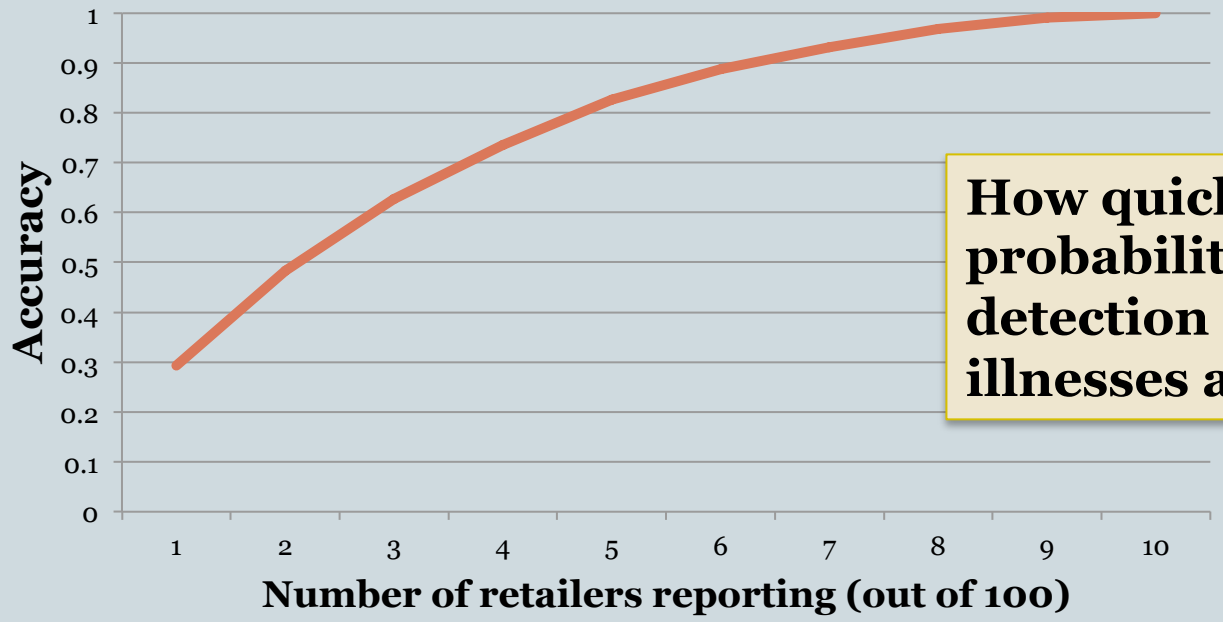
How quickly does the probability of correct source detection improve as new illnesses are reported?

2. Analytical Models

Using simple, stylized network structures:

→ Develop closed-form expressions to explore the relationship between network parameters and traceback accuracy, e.g.:

→ Relationships such as **tradeoffs** provide key insights to decision makers



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→ Analysis on networks with more complicated connectivity patterns

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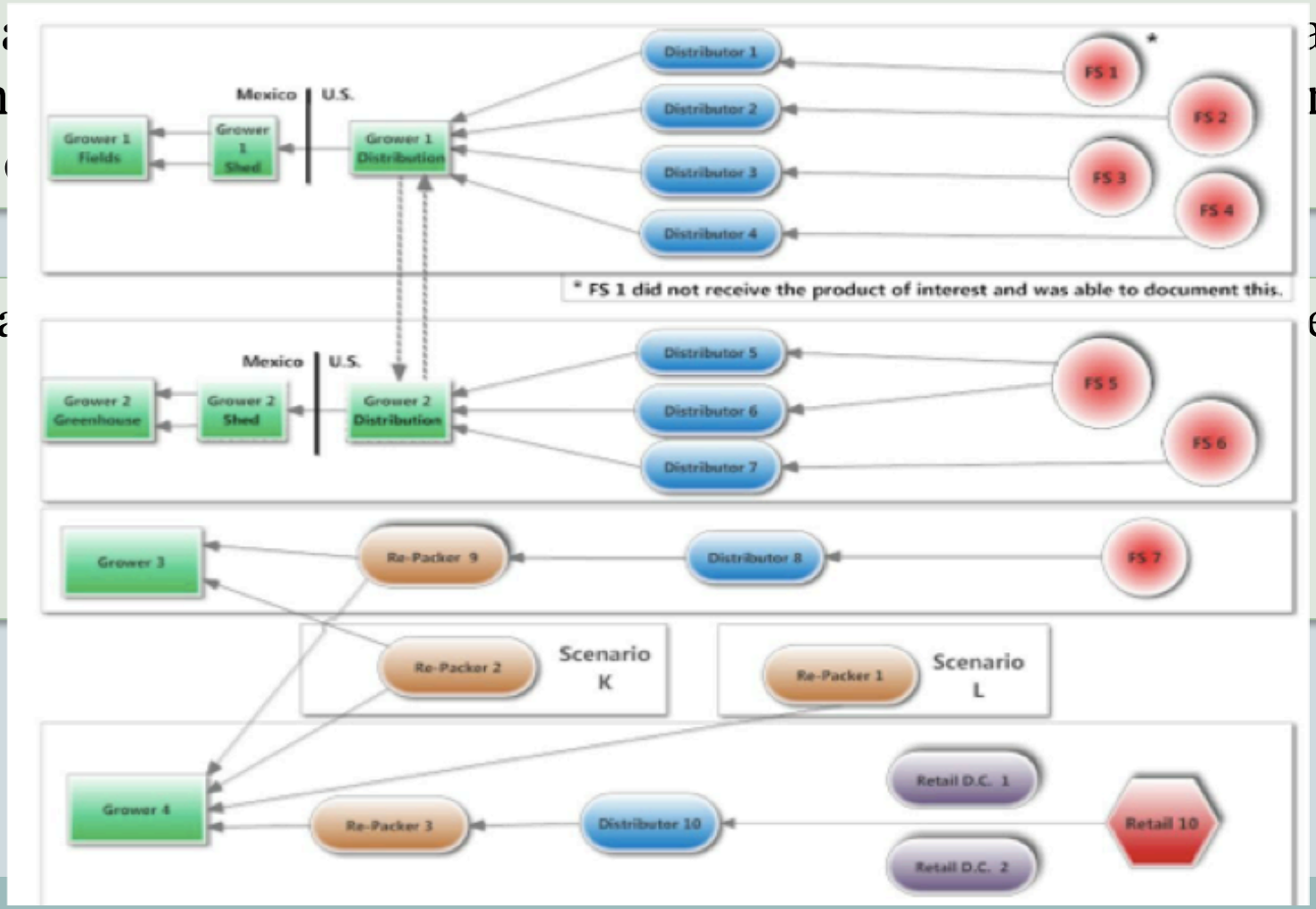
→ Ana…erns



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<u>This will be the backbone of the methodology we are developing for investigators to use during an investigation</u>

4. Simulation on Realistic Modeling Structures

Sensitivity Analysis: Use Monte Carlo simulation on network models incorporating more of the true system complexity

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Loosen restrictions even further

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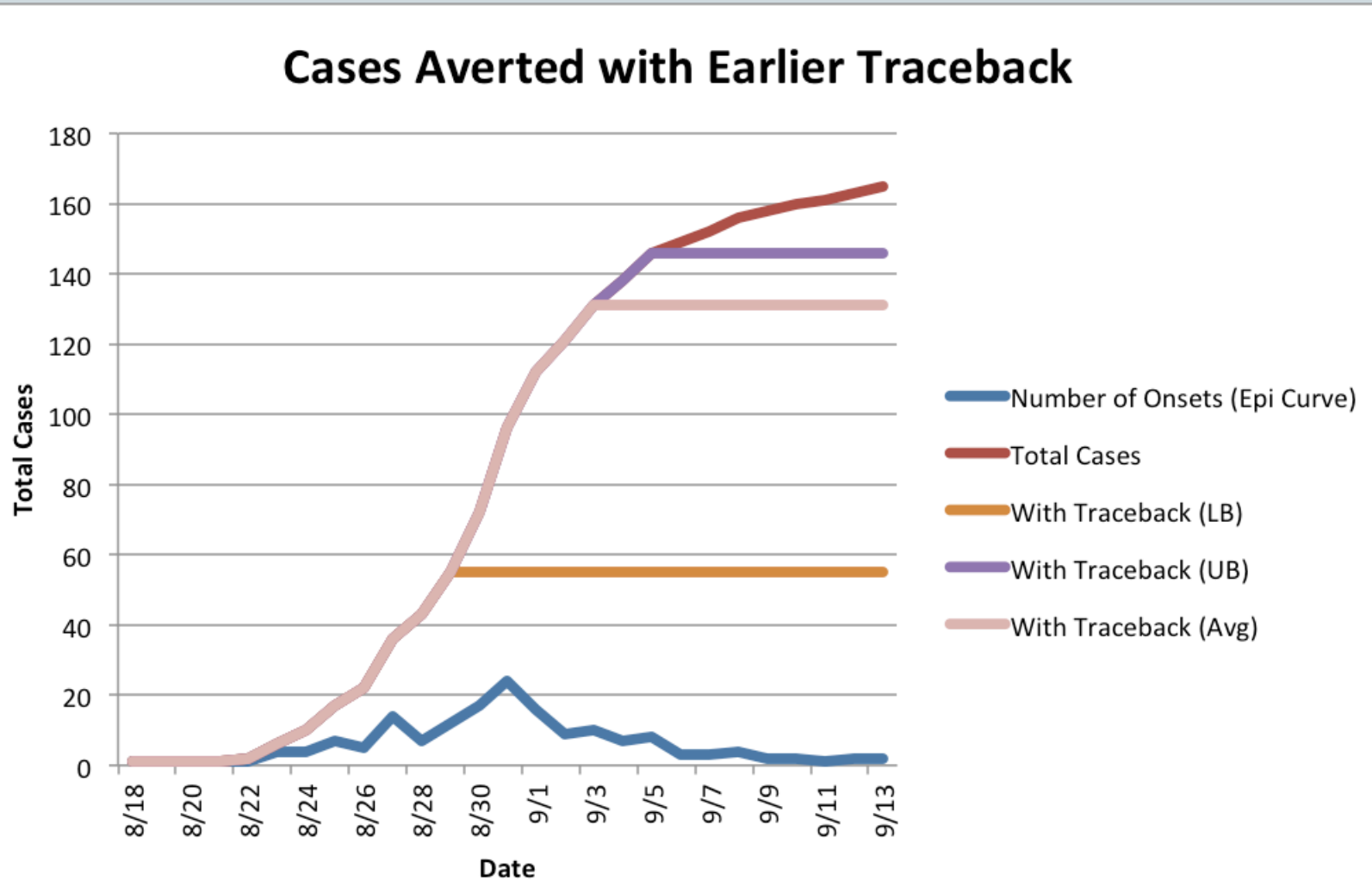
Make comparisons:

- Between hypothetical policy interventions
- **To concrete examples of past outbreaks**

→ Time reduced = illnesses averted

4. Simulation on Realistic Modeling Structures



Tactical Crisis Response Strategy

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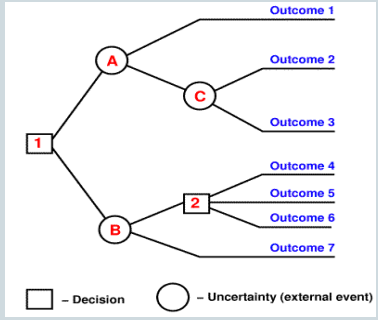
GUIDE INVESTIGATION:

- How to best allocate search effort
- Determine where additional data collection is warranted



Jennifer B. Nuzzo et al (2013). When Good Food Goes Bad: Strengthening the US Response to Foodborne Disease Outbreak. Final Report: UPMC.

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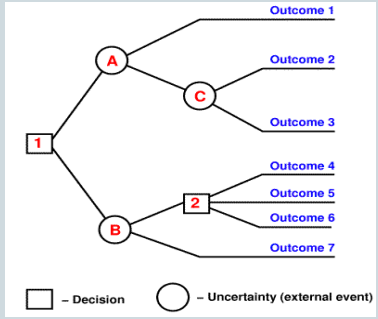

GUIDE CONTROL MEASURES:

- When to issue public service announcements

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Expected Contributions

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Academic and practical contribution is to improve accuracy and speed of tracebacks

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"Any measure that will help to determine where we should focus our attention and give leads on the investigation would have a lot of application and utility for public health. Messaging could be more targeted because we would be able to narrow down more quickly where the product is not coming from…This could really make a difference early on!"

–– S. McGarry, Foodborne Outbreak Coordinator at FDA Headquarters, Personal communication, December 20, 2012

Acknowledgements

Robert Wood Johnson Foundation

PUBLIC HEALTH | SERVICES & SYSTEMS RESEARCH
PRACTICE-BASED RESEARCH NETWORKS

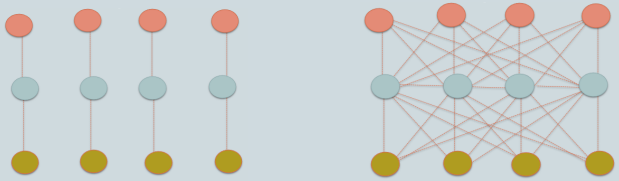
Thank you!

Questions?

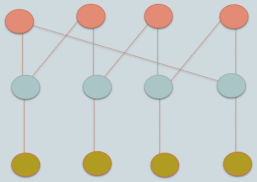
MIT ESD
Massachusetts Institute of Technology
Engineering Systems Division

Backup Slides

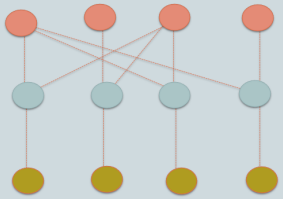
Analytical Model Example: Knowledge of network structure helps



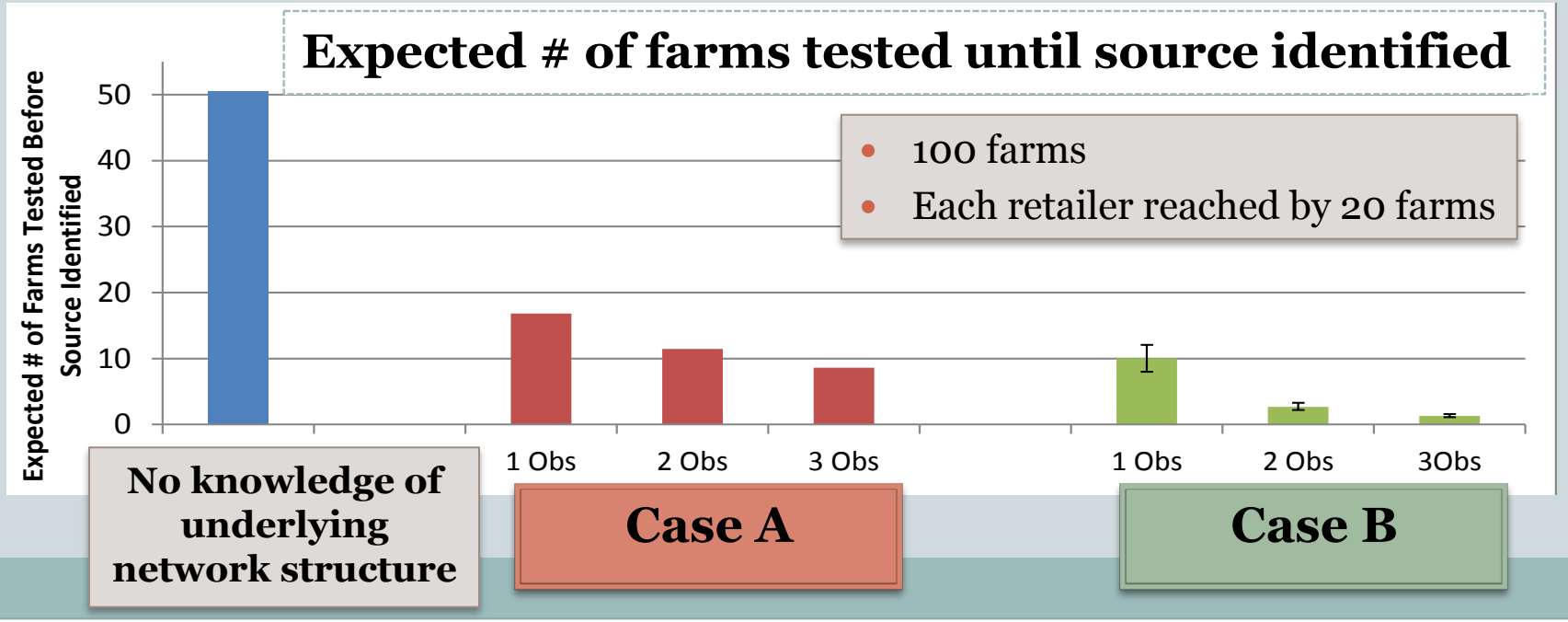
Limiting Cases



Case A: Network with lowest traceability



Case B: Random network structure



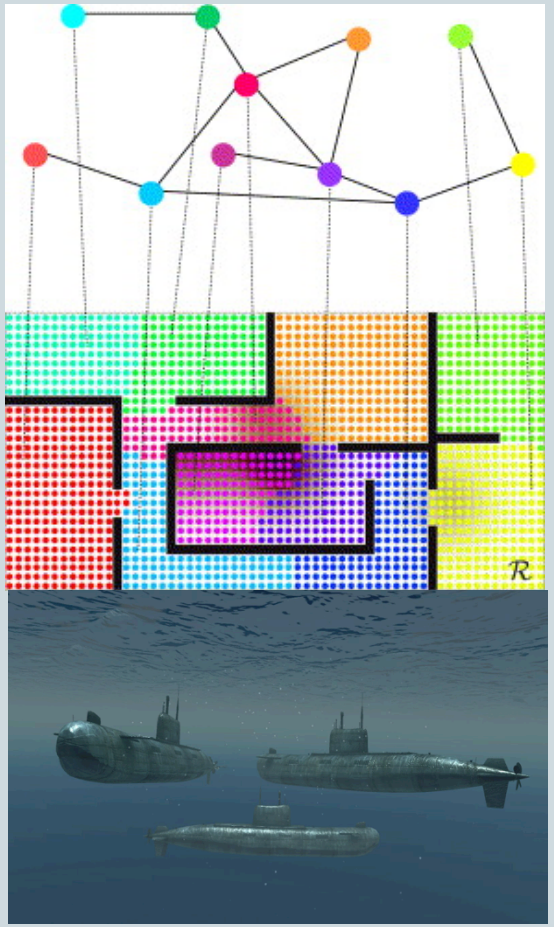
No knowledge of underlying network structure

Case A

Case B

Problem Framing: Optimal Search Theory

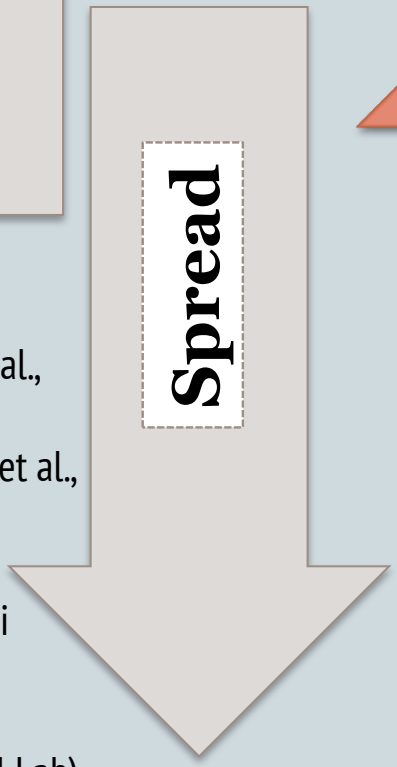
- Bernard Koopman's "Theory of Optimal Search" (Richardson, 1986).
- Anti-submarine warfare problem
  - Search over 3-D space
  - Prior probabilities
  - Bayesian updates
  - Allocated "search effort" a highly nonlinear function of the updated probabilities
- Turned around the war in the North Atlantic (Nunn, 1981).

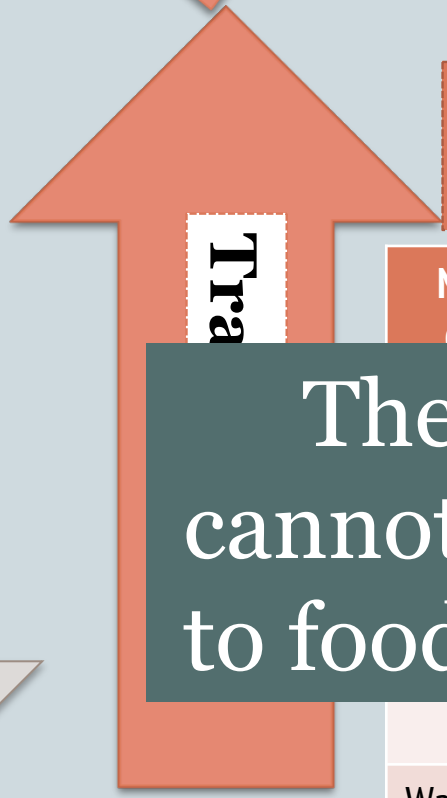


Literature Gap

Food safety and network literature

Wein and Liu, 2005;
Pinior et al., 2012;
Dupuy et al., 2005; Bertolini et al., 2006;
Fritz and Schiefer, 2009; Wang et al., 2009,
Ahumada and Villalobos, 2009;
Harlander and Sholl, 2007; Beni et al., 2011;
Hashemi et al. 2012,
Conrad et al., 2012 (Sandia Natl Lab)





Network literature only

Network domain	References
	Shah and Zaman, 2011
Water distribution	Tao et al., 2012; Preis and Ostfeld, 2007

These models cannot be extended to food distribution

Promise of Technology-Enabled Traceability

A1

Technology exists to have fully traceable food supply system

But along with logistical difficulties of tracing loose produce…
current lack of will to implement full traceability due to:

Mandated by Government

- No meaningful purposed legislation
- Unfavorable legislative environment
- Only can go in after "reasonable cause"

Adopted by Industry

- **Full compliance a distant reality**
- Not incentivized to create a system that tracks food once it has been sold and consumed
- Failure to supply adequate traceability systems for basic food safety control
- Firms find value in anonymity (Golan et al., 2004)

Model Building and Data Sources

A2

Build high-level models from ground up

Data Types	Data Sources
NODES: Locations of growing regions, locations of distribution centers, brokers, wholesalers, and retail warehouses	• Secondary data collection of shipping records and expert elicitation compiled by BTSafety, LLC, for their Consequence Management System • Expert elicitation with state agriculture and commerce departments, marketing associations/trade organizations, and cooperative extension centers
LINKS: Supply and demand data for traders	• National Agricultural Statistics Service (NASS) • Gravity models to fill in (Pinior et al., 2012)
WEIGHTS: Weekly shipment and border crossing information, commodity seasonality	• Agricultural Marketing Service • FDA pathogen-commodity risk models • Expert elicitation as above
OUTPUT: Location of reported cases	• Marler Clark Litigation Firm

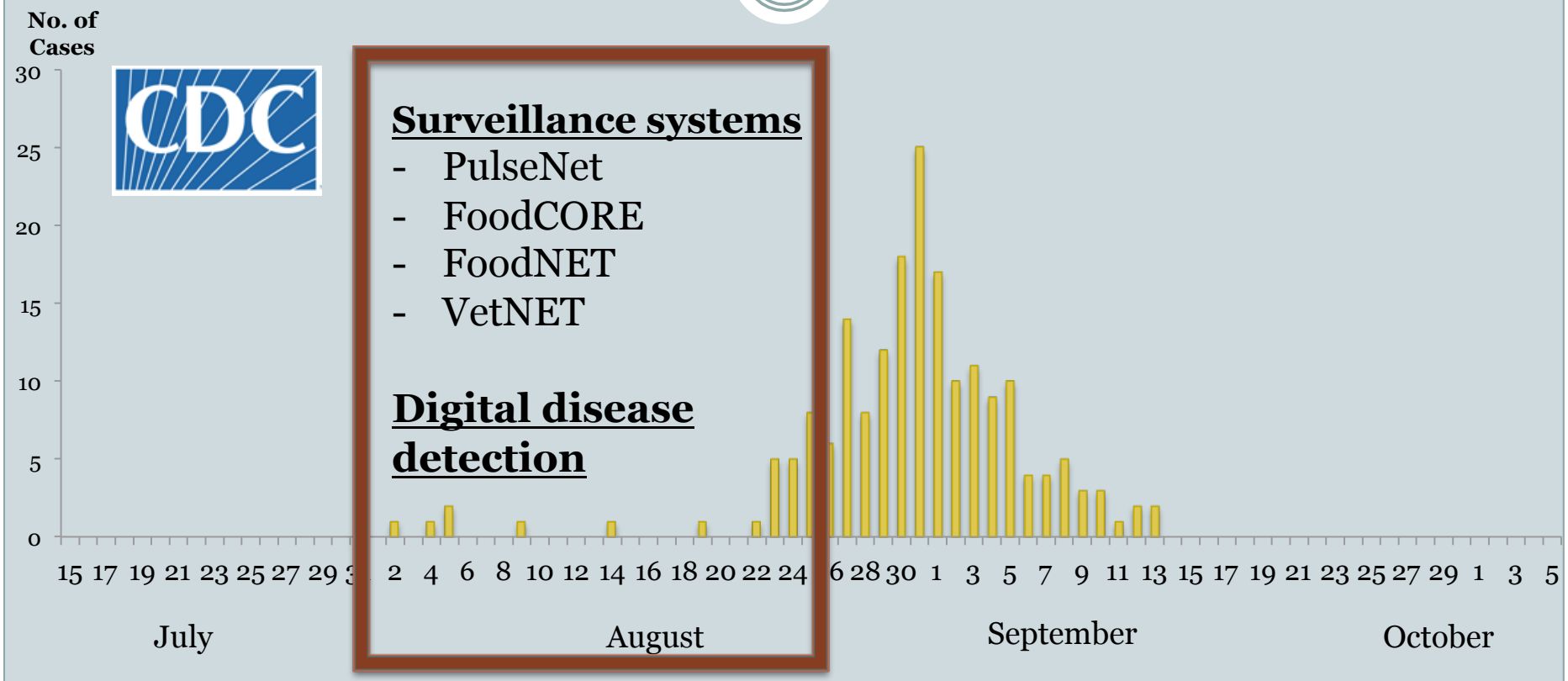
Outbreak Prevention

Working in prevention space:

- **Microbiologists**
- **Environmental biologists**
- **FDA prevention initiatives**

These measures do not provide the tactical support necessary for response to foodborne illness outbreaks that have occurred

Outbreak Surveillance



Centers for Disease Control and Prevention (CDC) (2006b). Timeline for Reporting of E. coli Cases. September 19, 2006. http://www.cdc.gov/ecoli/reportingtimeline.htm

Toner ES, Nuzzo JB, Watson M, et al. Biosurveillance where it happens: state and local capabilities and needs. *Biosecur Bioterror*. 2011 Dec;9(4):321-330.

Annual Impact of Foodborne Disease Outbreaks

Despite efforts at prevention
the impact of foodborne disease outbreaks remains high:

Every year in the US…

- 48 million illnesses
- 128,000 hospitalizations
- 3000 deaths
- $77 billion in healthcare costs
- **55 - 65% of identified foodborne illness outbreaks UNSOLVED**

- Osterholm, MT. Foodborne Disease in 2011 — The Rest of the Story. N Engl J Med 2011; 364:889-891, March 10, 2011.
- Scharff, R. (2009). Health-related costs from food borne illness in the United States. Retrieved from http://www.producesafetyproject.org
- Jennifer B. Nuzzo, Samuel B. Wollner, Ryan C. Morhard, Tara Kirk Sell, Anita J. Cicero, Thomas V. Inglesby. (2013). When Good Food Goes Bad: Strengthening the US Response to Foodborne Disease Outbreak. Final Report: Center for Biosecurity of UPMC.

Expected Contributions

1) A planning tool enabling public health and emergency preparedness officials to determine how to optimally allocate search effort in the event of an outbreak
   - Currently working with stakeholders to ensure a scientifically sound, *implementable* methodology

2) A set of recommendations on policy changes that can significantly facilitate faster tracebacks, e.g.
   - **Recordkeeping requirements** that could facilitate traceability
   - Actions to improve traceability:
     - Restructuring distribution pathways
     - Holding samples at each farm/distribution center