Model of supply chain vulnerability for fresh produce

Cameron MacKenzie, Assistant Professor, Defense Resources Management Institute, Naval Postgraduate School

Aruna Apte, Associate Professor, Graduate School of Business and Public Policy, Naval Postgraduate School
Fresh produce contamination

Salmonella

E. Coli

Listeria Contamination
• Uniqueness of fresh produce supply chains (perishability of product, multitude of growers)

• Factors that influence fresh produce supply chain disruptions
  – Traceability, transparency, testability, time, trust, and training (Roth et al., 2008)
  – Traceability, product type, communication, topological structure, exposure to contamination (Apte, 2010)

• Disruption management models: actions taken during and after disruption


• Build a model that quantifies the effects of a contamination in fresh produce supply chain
• Translate qualitative factors that influence vulnerability into a mathematical model
• Quantify benefits of disruption management strategies for contamination of fresh produce
At demand node

Where is contamination node (CN)?

CN is distribution node

Can produce be rerouted?

Is safety stock useable?

Disruption mitigated

Disruption not mitigated

CN is producing node

Is safety stock useable?

Can production be increased?

Disruption mitigated

Disruption not mitigated
• Lost sales compared to sales without contamination

• Sum of three components
  – While searching for source of contamination
  – While relying on safety stock
  – After safety stock depleted
• Assume entire supply chain is closed while finding source of contamination

\[ T_1 Q \]

• Traceability may depend on
  – High-tech growers
  – Supply chain visibility
  – Prior probability of node being contaminated
Demand after contamination

- Demand for product may drop because of contamination
- New demand after contamination $D^*$
- Depends on
  - Essentialness of product
  - Communication to consumers
  - Trust level
Safety stock may be used to mitigate disruption

\[
\left( \min \left\{ (t_s - T_1)^+, \left( \frac{S}{D^* - Q^*} \right), T_2 \right\} \right) (Q - D^*)
\]

- Time to find source of contamination
- Amount of safety stock
- Amount produced before contamination
- Time until safety stock perishes
- Amount delivered after contamination
- Time until contaminated node reopens
- Demand after contamination
After safety stock depleted

If contaminated node is distribution node

\[
T_2 - \min \left\{ (t_s - T_1)^+, \left( \frac{S}{D^* - Q^*} \right) \right\}^+ (Q - Q^*)
\]

Time until contaminated node reopens
Time to find source of contamination
Amount of safety stock
Amount produced before contamination

Time until safety stock perishes
Demand after contamination
Amount delivered after contamination
After safety stock depleted

If contaminated node is producing node

\[
\left( T_2 - \min \left\{ \left( t_s - T_1 \right)^+, \left( \frac{S}{D^* - Q^*} \right) \right\} \right)^+ (Q - Q^{**})
\]

- Time until contaminated node reopens
- Time to find source of contamination
- Amount of safety stock
- Amount produced before contamination
- Amount delivered after contamination without additional production
- Amount delivered after contamination with additional production
- Time until safety stock perishes
- Demand after contamination
Safety stock and demand

Contaminated node is distribution node

\[ s = \text{safety stock} \]

\[ (t_s - T_1)(D^* - Q^*) \]

\[ D^* = \text{Amount demanded during disruption} \]

Contaminated node is producing node

\[ s = \text{safety stock} \]

\[ (t_s - T_1)(D^* - Q^*) \]

\[ D^* = \text{Amount demanded during disruption} \]
Topology of supply chain

\[ T_1 Q + T_2 (Q - Q^*) - s \]

- Red: Large proportion captured by alternate
- Blue: Small proportion captured by alternate

Production lost vs. Number of alternate distribution nodes

\[ T_1 Q + T_2 (Q - D^*) \]
• Model different elements in a supply chain that affect vulnerability
  – Traceability: length of time supply chain is closed
  – Communication and essentialness of product: demand during disruption
  – Topology: ability of supply chain to reroute production

• Can help supply chain managers quantify benefits of different disruption management strategies
  – Optimal value of safety stock
  – Communication to keep demand high
  – Useful for risk management: cost and uncertainty

Email: camacken@nps.edu
Traceability and prior probability

\[ T_1 = \text{Time to find contaminated node} \]

- Low-tech growers
- High-tech growers

Probability that a node is contaminated given that contaminated product is found at a demand node