Managing Inventory in Global Supply Chains
Facing Port-of-Entry Disruption Risks
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Initial comments

- Prevention, identification, response, recovery from major disruptions
- Security
- Ancillary benefits
  - More generally, major disruptions
  - Productivity (economic strength, private sector perspective)
  - Pilferage
- Use of information technology – real-time supply chain control, based on real-time data for the next level of productivity, resilience (downside risk mitigation), and stability
Importance of trade for economic strength

Growth in Trade as a Percentage of US GDP

- 1990, 13%
- 2000, 26%
- 2020, 35%
Supply chain resiliency
Uncertainty & major disruption

- **Uncertainty** – dealing explicitly with stochastic effects, e.g., variability in demand, supply, congestion, driver availability
- **Major disruption** – a loss of nodes &/or links in the global freight transportation network
- **Resiliency in supply chains** – preventing, gracefully reacting to, and quickly recovering from major disruptions
- **Comment**: lean supply chains are notoriously fragile
- **Policy implication** – the balance in investment between prevention & quick recovery
- **R&D challenge** – for models of sequential decision making (e.g., route finding, MDP), a weighted sum of a multiplicative criterion and an additive criterion produces violations of the Principle of Optimality (dynamic programming); games
Supply Chain Disruptions

1997
- Toyota Brake Plant Fire
- UPS Labor Strike

1998
- GM Labor Strike

1999
- Nokia - Ericsson Supplier Fire
- Taiwan Earthquake

2000
- Ford-Firestone Tire Recall

2001
- Sarbanes-Oxley Act
- Longshoreman Strike & West Coast Ports Lockout

2002
- Business Failures: Enron, Arthur Andersen, Worldcom, Global Crossing, K-Mart, etc.

2003
- NASA Columbia Disaster
- Iraq War
- SARS Outbreak
Industry Portfolio of Risks

Financial Risks:
- Interest Rate Fluctuations
- Currency & Foreign Exchange Rate Fluctuations
- Financial Markets Instability
- Economic Recession
- Currency Inconvertibility

Hazard Risks:
- Asbestos Exposure
- Mold Exposure
- Cargo Losses
- Geopolitical Risks
- Severe Hot / Cold Weather
- Earthquake
- Flooding
- Terrorism / Sabotage
- Wildfire
- Disease / Epidemic
- Tornadoes
- Animal / Insect Infestation
- Blizzard / Ice Storms
- Hail Damage
- Hurricane / Typhoon

Strategic Risks:
- Shareholder Activism
- Adverse Changes in Industry Regulations
- Credit Default
- Equip., Facilities, Business Acquisitions & Divestitures
- Asset Valuation
- Uncompetitive Cost Structure
- Revenue Management
- Inadequate / Inaccurate Financial Controls & Reporting
- Debt & Credit Rating

Enterprise Risks:
- 3rd Party Liability
- General Liability
- Product Liability
- Property Damage
- Loss of Key Facility
- Building Collapse
- Boiler or Machinery Explosion
- Bldg. or Equip. Fire
- Workers Compensation
- Building Subsidence & Sinkholes
- Lightning Strikes
- Addiction
- Building Subsidence
- Land, Water, Atmospheric Pollution
- Toxic or Disease Outbreaks
- Heavy Rain / Thunderstorms
- Environmental Spills
- Terrorism / Sabotage
- Loss of Key Personnel
- IT System Failures
- New or Foreign Competitors
- Public Boycott
- Advertising
- Corporate Culture
- Pricing & Incentive Wars
- Customer Relations
- "Gotta Have Products"
- Supplier Relations
- Planning
- “Buy Now, Pay Later”
- Distributors
- Unplanned Expenses
- Material Fire
- Operators
- Inadequate Mgmt. Oversight
- Ineffective Planning
- Utility Failures
- Health Care & Pension Costs
- Technology Decisions
- Product Development Process

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Inventory Control with Risk of Major Supply Chain Disruptions

Brian M. Lewis, Alan Erera, Chelsea C. White III
Outline

- Motivation and Introduction
- Part 1: An Inventory Control Model with Border Closures
- Part 2: An Inventory Control Model with Border Closures and Congestion
Supply chain security has evolved: from cargo theft to WMD and border closures

Increased focus on supply chain security post-9/11: C-TPAT, CSI, 24-hour rule

Research motivated by possibility of port of entry closures
  - September 11 terrorist attacks
    * US-Canadian border delays: minutes to 12 hours
    * US air traffic grounded
  - 2003 BAH Port Security Wargame
    * Simulated terrorist attack with “dirty bomb” in containers
    * All US ports closed for 8 days, Backlog takes 92 days to clear
  - 2002 10-day labor lockout at 29 Western US seaports
    * Congestion and delays lasted for months
Motivation and introduction

Questions:

– How can we model major supply chain disruptions (e.g. border closures and congestion) within an inventory control framework?
– What does an optimal inventory policy look like?
– How are an optimal policy and the long-run average cost affected by the system parameters?
– What managerial and policy insights does the model provide?
Part 1: An Inventory Control Model with Border Closures

DIAMONSD/DyDAn/LPS Workshop, 17 November 2008
Problem statement

- Border system
  - Modeled by a DTMC
  - State space, $S = \{ \text{“O”= Open, “C”= Closed} \}
  - Exogenous system

![Diagram showing transition probabilities between states O (Open) and C (Closed).]
Problem statement

- Outstanding order vector, \( z = \{z_{kt}\} \)
  - \( k \in \{0,1,2,\ldots, L-1\} \): orders that have been outstanding for exactly \( k \) days
  - \( L \): orders that have been outstanding for at least \( L \) days
  - \( g \): orders that have arrived
- Order movement function

\[
M(k|O) = \begin{cases} 
  k + 1 & \text{if } 0 \leq k < L, \\
  \gamma & \text{if } k = L.
\end{cases}
\]

\[
M(k|C) = \begin{cases} 
  k + 1 & \text{if } 0 \leq k < L, \\
  L & \text{if } k = L.
\end{cases}
\]

- Order crossover is prevented
**Problem statement**

- Long-run average cost criterion - no discounting future costs
- Costs – purchase, holding, penalty
- Demand - bounded, non-negative, integer-valued, iid
- Specialize Song and Zipkin (1996) model
  - Stationary state-dependent, basestock policies optimal (denoted, $y$)
    - Reduced sufficient state information: $(i_t, x_t)$
  - Ordering decision rule at time $t$ is

$$
\delta(i_t, x_t) = \begin{cases} 
  y(i_t) - x_t & \text{if } x_t < y(i_t), \\
  0 & \text{if } x_t \geq y(i_t).
\end{cases}
$$
Theoretical results

- For the border closure model without congestion, $y^*(O) = y^*(C) = \hat{y}^*$.
- The optimal state-invariant order-up-to level ($\hat{y}^*$) is non-decreasing in the cost ratio $\left(\frac{p}{p+h}\right)$.
- The optimal state-invariant order-up-to level ($\hat{y}^*$) is non-decreasing in the penalty cost ($p$) and non-increasing in holding cost ($h$).
- The optimal state-invariant order-up-to level ($\hat{y}^*$) is non-decreasing in the minimum leadtime ($L$).
## Numerical Study

### Daily review

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Purchase Cost, $c$</td>
<td>$150,000</td>
</tr>
<tr>
<td>Holding Cost, $h$</td>
<td>$100, $500</td>
</tr>
<tr>
<td>Penalty Cost, $p$</td>
<td>$1,000, $2,000</td>
</tr>
<tr>
<td>Minimum Leadtime, $L$</td>
<td>1, 7, 15</td>
</tr>
<tr>
<td>Transition Probability, $p_{OC}$</td>
<td>0.001, 0.003, 0.01, 0.02, 0.05, 0.1, 0.2,...,0.8, 0.9, 0.95</td>
</tr>
<tr>
<td>Transition Probability, $p_{CO}$</td>
<td>0.05, 0.1, 0.2,...,0.8, 0.9, 0.95</td>
</tr>
<tr>
<td>Demand Distribution</td>
<td>Poisson(Mean=0.5), Poisson(Mean=1)</td>
</tr>
</tbody>
</table>
Impact of the transition probabilities:

$L=15$, $h=100$, $p=1000$, $D \sim \text{Poisson}(0.5)$
Impact of the transition probabilities

Observations:
- Order-up-to level and long-run average cost are non-decreasing in $p_{OC}$ and non-increasing in $p_{CO}$.
- The expected duration of a closure ($1/p_{CO}$) more negatively affects a firm's productivity than the probability of a closure ($p_{OC}$).
- Implications for the cooperation between business and government in disruption management and contingency planning.
Part 2: An Inventory Control Model with Border Closures and Congestion

Demand

Placed Orders

International Border

Foreign Supplier

Filled Orders (L>0 days)

Domestic Manufacturer

Observe State: Border Status, Queue Length, Inventory Position

Border Workload Queue

Part 2: An Inventory Control Model with Border Closures and Congestion
Results

- For the border closure model with congestion, the optimal order-up-to levels \( y^*(i,n) \) are dependent on border state \( i \) and border workload queue length \( n \).
- Order-up-to level and long-run average cost are non-decreasing in \( p_{OC} \) and non-increasing in \( p_{CO} \).
- The expected duration of a border closure \( 1/p_{CO} \) more negatively affects a firm's productivity than the probability of a border closure \( p_{OC} \).
- Order-up-to level and long-run average cost are more sensitive to the transition probabilities than in the model without congestion.
Perishable Product Transportation with Costly Observation

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Problem

- How to most effectively transport perishable freight from origin to destination
- Common practice: try to control temperature in transit. If goods perish, then discard at the destination.
- Question: how valuable would it be to check freight at intermediate locations between origin and destination and abort transport once it is determined freight is spoiled?
- Example: Transport temperature sensitive freight from Japan to LA/LB to Atlanta.
Temperatures in an air freight shipment with the instruction to maintain temperatures between 2 °C and 8 °C (Heap, 2006)
Economic impact of food spoilage

- 19% of food consumed in U.S. is grown in other countries
- Up to 20% of food is discarded due to spoilage (FDA)
- U.S. food industry annually discards $35 billion worth of spoiled goods (Forbes Magazine, April 24, 2006)
- 25% of all vaccine products reach their destination in a degraded state (Black, 2003, quoting WHO)
Problem Statement

Problem Setting

Origin

\[ W: \text{wholesale purchase cost} \]

Intermediate Inspection Points

\[ c(n,n+1): \text{transportation cost from } n \text{ to } (n+1) \]

Destination

\[ Rs: \text{reward for state } s \]

Origin 1 ... n n+1 ... N

States

- \((S+1)\) states: 0 (fresh), \(I\), ..., \(S\) (spoiled)

Decisions

- \(R\): return to the origin
- \(NI\): no inspection at \((n+1)\)
- \(I\): perform inspection at \((n+1)\)
- \(M\): inspection cost

\[ C(n) = c(n,n-1) + \beta c(n-1,n-2) + \cdots + \beta^{n-1} c(0,1) \]

DS: disposal cost for state \(s\)

\[ P: \text{State transition probability matrix from location } n \text{ to } (n+1) \]
Conclusion

- **Value of information**: Investigated the value of having the choice to inspect freight quality at intermediate locations in transit.

- **Business implications**:
  - Better inform decision to invest in IT infrastructure
  - Better understanding of how to set price; what profit to expect
  - Operationally, when to optimally inspect

- **Basic knowledge creation**:
  - Structure of optimal reward functions & optimal policies
  - Bound on value of information
  - Real time algorithmic development

- **Future research**: use of inspection information for:
  - Expedite decisions in inventory systems
  - Security
Thank you
Extra slides
Real-time supply chain control, based on real-time data
Where do the data come from?

- Inventory levels
- Production rates
- Vehicle, vessel, or trailer
  - Position
  - Speed
  - Direction
  - Temperature
  - Oil or air pressure
- Driver alertness
- Traffic congestion
- Weather
- Freight status & visibility
Real time control, based on real time data

- The next level of supply chain efficiency, resilience, stability
- What’s the value of real-time data? Is it worth the IT infrastructure investment?
- Operationally, how to extract the value (optimally, sub-optimally) of real-time data?
- Dealing with data corruption: sensors, transmission, processing
- What is impact of data processing delay on information value?
- Are we sure that improved system observation will improve system performance?