Responding to Shipment Delays: The Roles of Operational Flexibility & Lead-time Visibility

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Shipments Delays

- Complex Logistics of Global Sourcing
- Port Congestion due to High Trade Volumes
- New Security Measures for Custom Clearance
- External Causes (Weather, Labor Strikes etc)
How do Firms Respond?

- Higher Inventory Levels
- Expediting Shipments
- Back-up Sourcing

Role of Information Technology
Literature (Supply Uncertainty)

- Song and Zipkin (1996), Chen and Yu (2005)
  - Stochastic Lead-time, Information Sharing

- Anupindi and Akella (1994)
  - Yield and Lead-time uncertainty, Dual Sourcing

- Tomlin (2005), Tomlin and Snyder (2006)
  - Mitigation & Contingency Strategies for Supply Chain Disruptions
Basic Model

Supplier → Potential Delay → Firm Location

Lead time $\mathcal{L}$

\[ \Pr(\mathcal{L} = l) = \Theta \]
\[ \Pr(\mathcal{L} = L) = 1 - \Theta \]

$L > l$

Periodic Review Inventory Policy: Review Period Length $T$

Stochastic Demand $D_{(t_1,t_2)}$
Response Strategies: Two Dimensions

- Operational Flexibility
  - Additional Resources for Faster Replenishment

- Lead-time Visibility
  - Information on Lead-time in Advance
Operational Flexibility

- **Zero Operational Flexibility**
  - No additional resources.

- **Logistics Flexibility**
  - Expedite Orders using Faster Transportation Mode

- **Sourcing Flexibility**
  - Order with a Faster and Expensive Alternative Supplier
Lead-time Visibility

$\mathcal{L}$: Time at which the realization of lead-time is learned

$L_i$: Time at which the realization of lead-time is learned

$\mathcal{L} = l$

$\mathcal{L} = L$
Zero Operational Flexibility

\[ L_i > 0 \quad \text{No Lead-time Visibility} \]

\[ L_i = 0 \quad \text{Full Lead-time Visibility: Place Orders with Full Information} \]
No Lead-time Visibility (Base Case ZN)

Cost = \Theta \int_0^L G(S,D_{(0,t)}) \, dt + \bar{\Theta} \int_0^L G(S - D_{(-T,0)}, D_{(0,t)}) \, dt + \int_{L}^{l+T} G(S,D_{(0,t)}) \, dt

where

\[ G(S,D_{(0,t)}) = \mathbb{E} \left[ h(S-D_{(0,t)})^+ + p(D_{(0,t)} - S)^+ \right] \]
No Lead-time Visibility (Base Case ZN)

Cost = $\Theta G_{(l,l+T]}(S) + \bar{\Theta} G_{(L,L+T]}(S)$

where $G_{(t_1,t_2]}(S) = \int_{t_1}^{t_2} G(S, D_{(0,t]}) dt$
**Full Lead-time Visibility (Strategy ZF)**

\[ L_i = 0 \]

Lead-time Dependent Base-stock Policy is Optimal
(Song and Zipkin 1996)

Order-up-to \( S_{L_i}^{zf} \)
Order-up-to \( S_{l_i}^{zf} \)

\[ L \]
\[ T \]
\[ \Theta \]
Logistics Flexibility

Led-time $l_e$

Unit cost $c_e$

Potential Delay

Lead time $\mathcal{L}$

Supplier

Firm Location

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Logistics Flexibility: Time Line

Ordering Decision

Expediting Decision
Logistics Flexibility
No Lead-time Visibility (Strategy LN)

\[ T_e < L_i \]

Ordering Decision

Expediting Decision

Both Decisions are made without Lead-time Information
No Lead-time Visibility (Strategy LN)

Single Period Cost

\[ G_{(T_e+l_e;l)}(x + q) + \Theta G_{(l;L]}(x + Q) \]
\[ + \bar{\Theta} G_{(l;L]}(x + q) + G_{(L,T+T_e+l_e]}(x + Q) \]
No Lead-time Visibility (Strategy LN)

- Optimal Policy

Order-up-to $S^{ln}$

Expedit-up-to $z_u$

$S^{ln}$

$T_e$

$T$
Logistics Flexibility

Partial Lead-time Visibility (Strategy LP)

\[ L = L \]

\[ 0 < L_i \leq T_e \]

Ordering Decision Made without Lead-time Information

Expediting Decision Made with Lead-time Information

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Partial Lead-time Visibility (Strategy LP)

No Shipment Delay
Not Optimal to Expedite

Shipment Delay
Optimal to Expedite

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Partial Lead-time Visibility (Strategy LP)

- Optimal Policy

Order-up-to $S^{lp}$

Do Not Expedite
Expedit-up-to $z_i$

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Logistics Flexibility

Full Lead-time Visibility (Strategy LF)

\[ T_e \quad l_e \]

\[ L = l \]

\[ L = L \]

\[ L_i = 0 \]

Ordering Decision

Expediting Decision

Both Decisions are made with Lead-time Information

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Full Lead-time Visibility (Strategy LF)

- Optimal Policy

Do Not Expedite
Expedit-up-to $z_i$

Order-up-to $S_L^{lf}$
Order-up-to $S_l^{lf}$

$S_L^{lf}$
$S_l^{lf}$

$z_i$

$T_e$

$T$

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Sourcing Flexibility

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Sourcing Flexibility: Time Line

Simplifying Assumption:
Ordering Decision with Alternative Supplier at time $T_a$

Ordering Decision with Regular Supplier
Ordering Decision with Alternative Supplier
Sourcing Flexibility

- Three Models with
  - No Lead-time Visibility (Strategy $SN$)
  - Partial Lead-time Visibility (Strategy $SP$)
  - Full Lead-time Visibility (Strategy $SF$)

- Optimal Policies are Not Base-Stock Policies

- Solutions with Dynamic Programs
Numerical Comparison

Cost Saving with Strategy $M$

$B^M = \frac{C^{ZN} - C^M}{C^{ZN}} \times 100$

Optimal Cost with Strategy $M$

Optimal Cost with Base Case $ZN$

(Zero Flexibility & No Lead-time Visibility)

$M \in \{ZF, LN, LP, LF, SN, SP, SF\}$
Effect of Delay Probability (Logistics Flexibility)

Saving %

- Full Visibility
- Partial Visibility
- No Visibility
- 0 Flexibility
- & Full Visibility

Probability of Shipment Delay

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Effect of Delay Probability (Sourcing Flexibility)

- Full Visibility
- Partial Visibility
- No Visibility
- 0 Flexibility
- & Full Visibility

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Effect of Delay Time (Logistics Flexibility)

![Graph showing the effect of delay time on logistics flexibility with different visibility levels: Full Visibility (BLF), Partial Visibility (BLP), No Visibility (BZF), 0 Flexibility (B LN) & Full Visibility (BLN). The x-axis represents delay time (L), and the y-axis represents saving percentage.]
Effect of Delay Time (Sourcing Flexibility)

![Graph showing the effect of delay time on saving percentage for different visibility levels.]

- Full Visibility
- Partial Visibility
- No Visibility
- 0 Flexibility
- & Full Visibility

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Effect of Expediting Cost (Logistics Flexibility)

![Graph showing the effect of expediting cost with different visibility levels: Full Visibility, Partial Visibility, No Visibility, 0 Flexibility, and Full Visibility & Full Visibility.]

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Effect of Alternative Sourcing Cost (Sourcing Flexibility)

- Full Visibility
- Partial Visibility
- No Visibility
- 0 Flexibility & Full Visibility

Diagram showing the effect of sourcing cost on saving percentage, with curves labeled $B_{SN}$, $B_{SF}$, $B_{SP}$, and $B_{ZF}$.
Effect of Demand Rate (Logistics Flexibility)

\[ B^{LF} \]

\[ B^{LP} \]

\[ B^{ZF} \]

\[ B^{LN} \]

Full Visibility
Partial Visibility
No Visibility
0 Flexibility
& Full Visibility

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Effect of Demand Rate (Sourcing Flexibility)

$B^{SF}$

$B^{SP}$

$B^{SN}$

$B^{ZF}$

Full Visibility
Partial Visibility
No Visibility
0 Flexibility
& Full Visibility

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Observations

- Flexibility protects from long lead-times
- Lead-time visibility protects from uncertainty in lead-times
- Operational flexibility and lead-time visibility are complementary
- Partial lead-time visibility captures most of the gains with full visibility
Impact of Other Factors

- More general delays
  - Complex optimal ordering policies
  - Robust heuristics

- Fixed costs of Ordering/Freight Mode
  - Reduced Flexibility (Jain, Groenevelt and Rudi)
  - Scope for negotiation on Fixed vs Variable costs
Impact of other factors

- Capacity constraints on freight modes
  - Real options.. How to value it?
  - Market for freight modes

- Information availability
  - Cost of providing information
  - Incentive to share timely information on delays
Contribution

- Model to identify impact of operational flexibility and lead-time visibility on
  - Optimal policies
  - Costs

- Justification for investments in
  - Logistics and sourcing flexibility
  - Information system