Lead Time Variability & Mode Selection
Agenda

• Connections to Inventory Planning
• Transit Time Reliability
• Handling Lead Time Variability
• Mode Selection
Transportation Impact on Inventory
Impact on Inventory

\[ TC(Q) = cD + c_t \left( \frac{D}{Q} \right) + c_e \left( \frac{Q}{2} + k\sigma_{DL} + LD \right) + B_{SO} \left( \frac{D}{Q} \right) \Pr[SO] \]

- **How does transportation impact our total costs?**
  - Cost of transportation
    - Value & Structure
  - Lead Time
    - Value & Variability & Schedule
  - Capacity
    - Limits on Q
  - Miscellaneous Factors
    - Special Cases
Transportation Cost Functions

Pure Variable Cost / Unit

Pure Fixed Cost / Shipment

Mixed Variable & Fixed Cost

Modify fixed order cost ($c_t$) for Ordering Cost

Modify both $c_t$ and $c$
Complex Cost Functions

Variable Cost / Unit with a Minimum

Incremental Discounts

Note that approach will be similar to quantity discount analysis in deterministic EOQ
Shipping Shoes from Shenzhen II
- The Next Chapter
Shipping Shoes II

How should I ship my shoes from Shenzhen to Kansas City?

- **General Information**
  - Shoes are manufactured, labeled, and packed at plant
  - Demand ~N(4.5M, 0.54M) annual demand
  - 3,000 shoe boxes fit into one TEU
  - Average cost ~$35 per pair
  - Cost of product in container $105,000
  - Average sales price ~$75 per pair
  - Order for shipment cost $5000 per order
  - Holding costs are 15%
  - Assume 50 weeks/year, 350 days/year
  - Assume CSL 95%

- **Transportation Options**
  - **Inland Origin:** Shenzhen to Ports ($/container)
    - Yantian ($35, 2 day)
    - Hong Kong ($30, 5 days)
  - **Port to Port:** China to US ($/container)
    - CSCL (AAC) Yantian to POLA ($1100, 20 days)
    - CSCL (AAS) Hong Kong to POLA ($1025, 13 days)
    - APL Hong Kong to New York ($1200, 29 days)
  - **Destination Port:** US Ports ($/container)
    - POLA (5 days)
    - New York / New Jersey (3 days)
  - **Inland Destination:** To Kansas City ($/container)
    - POLA to KC by BNSF ($1100, 11 days)
    - PANYNJ to KC by NS ($800, 5 days)
    - PANYNJ to KC by HJBT Truckload ($1150, 2 days)

Which option provides the lowest logistics cost?
Shipping Shoes

(1) Y-LA-KC $2235, 38 d
(2) HK-LA-KC $2155, 34 d
(3) HK-NY-rr-KC $2030, 42 d
(4) HK-NY-tl-KC $2380, 39 d
Shipping Shoes Part 2.

\[ TC(Q) = c_D + c_i \left( \frac{D}{Q} \right) + c_e \left( \frac{Q}{2} + k\sigma_{DL} + LD \right) \]

- Lowest total cost path is (2) at $2155/container = $1.67/pair of shoes

<table>
<thead>
<tr>
<th>Path</th>
<th>L (days)</th>
<th>( c_{\text{trans}} ) ($/cnt)</th>
<th>( c ) ($/cnt)</th>
<th>( c_t ) ($/ord)</th>
<th>( c_e ) ($/cnt/yr)</th>
<th>D (cnt/yr)</th>
<th>Q (cnt/ord)</th>
<th>( \sigma_{DL} ) (cnt)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>38</td>
<td>$2,235</td>
<td>$107,235</td>
<td>$5,000</td>
<td>$16,085</td>
<td>1,500</td>
<td>30</td>
<td>59.3</td>
</tr>
<tr>
<td>2</td>
<td>34</td>
<td>$2,155</td>
<td>$107,155</td>
<td>$5,000</td>
<td>$16,073</td>
<td>1,500</td>
<td>30</td>
<td>56.1</td>
</tr>
<tr>
<td>3</td>
<td>42</td>
<td>$2,030</td>
<td>$107,030</td>
<td>$5,000</td>
<td>$16,055</td>
<td>1,500</td>
<td>30</td>
<td>62.4</td>
</tr>
<tr>
<td>4</td>
<td>39</td>
<td>$2,380</td>
<td>$107,380</td>
<td>$5,000</td>
<td>$16,107</td>
<td>1,500</td>
<td>30</td>
<td>60.1</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Path</th>
<th>Purchase Cost ($M)</th>
<th>Ordering Cost ($K)</th>
<th>Cycle Stock Cost ($K)</th>
<th>Safety Stock Cost ($M)</th>
<th>Pipeline Inventory ($M)</th>
<th>Total Cost ($M)</th>
<th>Logistics Cost Per Shoe</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>$160.8</td>
<td>$250</td>
<td>$241</td>
<td>$1.57</td>
<td>$2.62</td>
<td>$165.5</td>
<td>$1.77</td>
</tr>
<tr>
<td>2</td>
<td>$160.7</td>
<td>$250</td>
<td>$241</td>
<td>$1.48</td>
<td>$2.34</td>
<td>$165.0</td>
<td>$1.67</td>
</tr>
<tr>
<td>3</td>
<td>$160.5</td>
<td>$250</td>
<td>$241</td>
<td>$1.65</td>
<td>$2.89</td>
<td>$165.5</td>
<td>$1.78</td>
</tr>
<tr>
<td>4</td>
<td>$161.1</td>
<td>$250</td>
<td>$242</td>
<td>$1.59</td>
<td>$2.69</td>
<td>$165.9</td>
<td>$1.86</td>
</tr>
</tbody>
</table>
Transit Time Reliability
Lead / Transit Time Reliability

• Key Questions:
  ■ What is the definition of reliability within a firm?
  ■ What are the sources of unreliability/variability?
  ■ How can the current situation be improved?

• Two Dimensions of Reliability
  ■ Credibility
    ■ Did the carrier reserve slots as agreed to? (Rejections / Bumping)
    ■ Did the carrier stop at all ports agreed to? (Skipping)
    ■ Did the carrier load all containers committed? (Cut & Run)
  ■ Schedule Consistency
    ■ How close was the carrier’s performance to their quoted schedule?
    ■ How consistent was the carrier’s actual transit time?

Definitions of Schedule Consistency

- **Compare actual transit time to the contract.**
  - Contract transit time (CTT)
  - CTT + 2 days
  - Frequency
  - Reliability = % less than [CTT+2]

- **Compare actual transit time to the published ship schedule.**
  - Scheduled Arrival Days (SAD)
  - SAD + 2 days
  - Frequency
  - Reliability = % less than [SAD+2]

- **Compare actual transit time to the average of the last 6 months.**
  - Ave of Last 6 Months (AL6M)
  - AL6M+1StdDev
  - Frequency
  - Reliability = % less than [AL6M+1StdDev]

- **Measure the “tightness” of the distribution of transit times.**
  - Mode of actual transit times
  - Frequency
  - Reliability = % within 2 days of the mode

Three Observations from Practice

Observation 1: Contract reliability in procurement and operations do not always match

Three Observations from Practice

Observation 2: Contract reliability differs dramatically across different route segments

While accurate estimates of the port-to-port transit times exist, there is only limited information on port dwell times.
### Three Observations from Practice

**Observation 3:** Most transit variability occurs in inland transportation and at the ports.

<table>
<thead>
<tr>
<th>Destination</th>
<th>Origin Landside Transit</th>
<th>Origin Port Dwell</th>
<th>Ocean Transit</th>
<th>Destination Port Dwell</th>
<th>Destination Landside Transit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Asia to North America</td>
<td>1.2</td>
<td>0.9</td>
<td>0.4</td>
<td>1.0</td>
<td>0.8</td>
</tr>
<tr>
<td>South America to North America</td>
<td>1.3</td>
<td>0.8</td>
<td>0.2</td>
<td>0.8</td>
<td>0.9</td>
</tr>
<tr>
<td>Europe to North America</td>
<td>0.7</td>
<td>0.7</td>
<td>0.3</td>
<td>0.7</td>
<td>0.7</td>
</tr>
<tr>
<td>North America to Europe</td>
<td>0.8</td>
<td>0.9</td>
<td>0.5</td>
<td>0.8</td>
<td>1.3</td>
</tr>
</tbody>
</table>

Coefficient of Variation of Time for Each Segment when CV = \(\sigma/\mu\).
Lead Time Variability
Sample of Transit Time Distribution

- **Origin-to-Port**
- **Port-to-Port**
- **Port-to-Destination**

Sample of 245 container moves
Common trade lane

**Frequency %**

**Transit Time (Days)**
Lead Time Variability Impact

Weekly Demand $\sim U(1,3)$

Lead Time 3 weeks

- 6 units
- 4 units
- 6 units

Weekly Demand $\sim U(1,3)$

Lead Time $\sim U(3,6)$ weeks

- 11 units
- 6 weeks
- 6 units
- 3 weeks
- 7 units
- 4 weeks

This is an example of Random Sums of Random Variables
Random Sums of Random Variables

- Let
  - \( N \) = is a random variable assuming positive integer values 1, 2, 3, ...
  - \( X_i \) = independent random variables so that \( E[X_i] = E[X] \)
  - \( S \) = sum of \( X_i \) from \( i = 1 \) to \( N \)

- Then
  \[
  E[S] = E\left[ \sum_{i=1}^{N} X_i \right] = E[N]E[X]
  \]
  \[
  Var[S] = Var\left[ \sum_{i=1}^{N} X_i \right] = E[N]Var[X] + (E[X])^2 Var[N]
  \]

- Simple Example
  - \( N \) has a mean of 28 and a standard deviation of 7
  - \( X \) has a mean of 180 and standard deviation of 68

- What is the mean, variance, and standard deviation of \( S \)?
  - \( E[S] = \mu_s = (28)(180) = 5040 \)
  - \( Var[S] = \sigma_s^2 = (28)(68)^2 + (180)^2(7)^2 = 129472 + 1587600 = 1,717,072 \)
  - \( StdDev[S] = \sigma_s = \sqrt{(1,717,072)} = 1310 \)

Lead Time Variability

- Sometimes referred to as Hadley-Whitin equation
  - Lead Time and Demand are independent RVs
  - \( \mu_D \) = Expected demand (items) during one time period
  - \( \sigma_D \) = Standard deviation of demand (items) during one time period
  - \( \mu_L \) = Expected number of time periods for lead time
  - \( \sigma_L \) = Standard deviation of time periods for lead time
  - \( \mu_{DL} \) = Expected demand (items) over lead time
  - \( \sigma_{DL} \) = Standard deviation of demand (items) over lead time

\[
\mu_{DL} = \mu_L \mu_D \quad \sigma_{DL} = \sqrt{\mu_L \sigma_D^2 + (\mu_D)^2 \sigma_L^2}
\]

- Transportation Example
  - Suppose that lead time is 12 days on average with a standard deviation of 3 days. The daily demand for an item is 100 units with a standard deviation of 22.
  - What is my expected demand over lead time as well as standard deviation of demand over lead time.
    - \( \mu_{DL} = (12)(100) = 1200 \)
    - \( \sigma_{DL} = \sqrt{(12)(22)^2 + (100)^2(3)^2} = \sqrt{5808 + 90000} = 309.5 \sim 310 \)

I can now find set an inventory performance metric using this demand distribution!
Shipping Shoes from Shenzhen III
– The Final Chapter
Shipping Shoes III

How should I ship my shoes from Shenzhen to Kansas City?

- **General Information**
  - Shoes are manufactured, labeled, and packed at plant
  - Demand $\sim N(4.5M, 0.54M)$ annual demand
  - 3,000 shoe boxes fit into one TEU
  - Average cost $\sim$ $35$ per pair
  - Cost of product in container $105,000$
  - Average sales price $\sim$ $75$ per pair
  - Order for shipment cost $5000$ per order
  - Holding costs are 15%
  - Assume 50 weeks/year, 350 days/year
  - Assume CSL 95%

- **Transportation Options**
  - **Inland Origin**: Shenzhen to Ports ($$/cnt, \mu, \sigma_L$)
    - Yantian ($35$, 2 days, 1 day)
    - Hong Kong ($30$, 5 days, 5 days)
  - **Port to Port**: China to US ($$/cnt, \mu, \sigma_L$)
    - CSCL (AAC) Yantian to POLA ($1100$, 20 days, 2 days)
    - CSCL (AAS) Hong Kong to POLA ($1025$, 13 days, 13 days)
    - APL Hong Kong to New York ($1200$, 29 days, 3 days)
  - **Destination Port**: US Ports ($$/cnt, \mu, \sigma_L$)
    - POLA ($0$, 5 days, 3 days)
    - New York / New Jersey ($0$, 3 days, 1 day)
  - **Inland Destination**: To Kansas City ($$/cnt, \mu, \sigma_L$)
    - POLA to KC by BNSF ($1100$, 11 days, 3 days)
    - PANYNJ to KC by NS ($800$, 5 days, 2 days)
    - PANYNJ to KC by HJBT Truckload ($1150$, 2 days, 1 days)

Which option provides the lowest logistics cost?
Shipping Shoes III

(1) Y-LA-KC $2235, 38 d, 4.8d
(2) HK-LA-KC $2155, 34 d, 14.6d
(3) HK-NY-rr-KC $2030, 42 d, 6.2d
(4) HK-NY-tl-KC $2380, 39 d, 6.0d

\[ \sigma_L = \sqrt{(1)^2 + (2)^2 + (3)^2 + (3)^2} = 4.796 \approx 4.8 \]
Shipping Shoes III

$$TC(Q) = c_D + c_e \left( \frac{D}{Q} \right) + c_e \left( \frac{Q}{2} + k \sigma_{DL} + LD \right)$$

<table>
<thead>
<tr>
<th>Path</th>
<th>$\mu_L$</th>
<th>$\sigma_L$</th>
<th>$\mu_D$</th>
<th>$\sigma_D$</th>
<th>$\mu_{DL}$</th>
<th>$\sigma_{DL}$</th>
<th>New SS ($\text{M}$)</th>
<th>Old SS ($\text{M}$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>38</td>
<td>4.80</td>
<td>4.29</td>
<td>9.62</td>
<td>162.86</td>
<td>62.78</td>
<td>$1.66$</td>
<td>$1.57$</td>
</tr>
<tr>
<td>2</td>
<td>34</td>
<td>14.60</td>
<td>4.29</td>
<td>9.62</td>
<td>145.71</td>
<td>84.04</td>
<td>$2.22$</td>
<td>$1.48$</td>
</tr>
<tr>
<td>3</td>
<td>42</td>
<td>6.20</td>
<td>4.29</td>
<td>9.62</td>
<td>180.00</td>
<td>67.78</td>
<td>$1.79$</td>
<td>$1.65$</td>
</tr>
<tr>
<td>4</td>
<td>39</td>
<td>6.00</td>
<td>4.29</td>
<td>9.62</td>
<td>167.14</td>
<td>65.36</td>
<td>$1.73$</td>
<td>$1.59$</td>
</tr>
</tbody>
</table>

$\mu_D = \frac{(1500 \text{ cnt/year})}{(350 \text{ days/year})}$

$\sigma_D = \frac{(180 \text{ cnt/year})}{\sqrt{(350 \text{ days/year})}}$

$$\mu_{DL} = \mu_L \mu_D$$

$$\sigma_{DL} = \sqrt{\mu_L \sigma_D^2 + (\mu_D)^2 \sigma_L^2}$$

(1) Y-LA-KC
(2) HK-LA-KC
(3) HK-NY-M-KC
(4) HK-NY-T-KC

Only safety stock changes!
Shipping Shoes III

\[ TC(Q) = cD + c_i \left( \frac{D}{Q} \right) + c_e \left( \frac{Q}{2} + k\sigma_{DL} + LD \right) \]

<table>
<thead>
<tr>
<th>Path</th>
<th>Purchase Cost ($M)</th>
<th>Ordering Cost ($K)</th>
<th>Cycle Stock Cost ($K)</th>
<th>Safety Stock Cost ($M)</th>
<th>Pipeline Inventory ($M)</th>
<th>Total Cost ($M)</th>
<th>Logistics Cost Per Shoe</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>$160.8</td>
<td>$250</td>
<td>$241</td>
<td>$1.66</td>
<td>$2.62</td>
<td>$165.6</td>
<td>$1.79</td>
</tr>
<tr>
<td>2</td>
<td>$160.7</td>
<td>$250</td>
<td>$241</td>
<td>$2.22</td>
<td>$2.34</td>
<td>$165.8</td>
<td>$1.83</td>
</tr>
<tr>
<td>3</td>
<td>$160.5</td>
<td>$250</td>
<td>$241</td>
<td>$1.79</td>
<td>$2.89</td>
<td>$165.7</td>
<td>$1.82</td>
</tr>
<tr>
<td>4</td>
<td>$161.1</td>
<td>$250</td>
<td>$242</td>
<td>$1.73</td>
<td>$2.69</td>
<td>$166.0</td>
<td>$1.89</td>
</tr>
</tbody>
</table>

Lowest total cost path is (1) at $2235 /container = $1.79 / pair of shoes

#3 - Lowest transportation cost route @ ~$0.68 $/shoe

#2 - Lowest logistics cost route @ ~$1.67 $/shoe, not considering variability of transit time

#1 - Lowest logistics cost route @ ~$1.79 $/shoe, considering variability of transit time
Mode Selection

• Criteria for selection between modes
  ■ Feasible choices:
    ▷ By geography
      ■ Global: Air versus Ocean
      ■ Surface: Trucking (TL, LTL, parcel) vs. Rail vs. Intermodal vs. Barge
    ▷ By required speed
      ■ >500 miles in 1 day – Air
      ■ <500 miles in 1 day – TL
    ▷ By shipment size (weight/density/cube, etc.)
      ■ High weight, cube items cannot be moved by air
      ■ Large oversized shipments might be restricted to rail or barge
    ▷ By other restrictions
      ■ Nuclear or hazardous materials (HazMat)
      ■ Product characteristics

■ Trade-offs within the set of feasible choices:
  ▷ Cost
  ▷ Time (mean transit time, variability of transit time, frequency)
  ▷ Capacity
  ▷ Loss and Damage
Mode Choice Example

• You are in charge of transportation planning for a manufacturer. One of the lanes you are managing brings raw material from a supplier into your plant. Your plant requires about ~N(3000, 750) pounds of the product per day. The product is valued at $20 per lb with 20% annual holding cost. You assume a CSL of 95% and 250 working days per year. You take ownership of the product at the origin.

• You have two options for this inbound movement.
  - **Truckload** – Transit time is 3 days on average with a standard deviation of 0.5 days and it costs $1800 per truckload (capacity of 40,000 lbs)
  - **Intermodal** – Transit time is 6 days on average with a standard deviation of 2 days and it costs $1400 per container (capacity of 40,000 lbs)

• Questions:
  - Your company’s policy is to always “weigh out” your shipments. That is, always ship in full truckload or container quantities. Following this policy, what mode should you select?
Solution: Mode Choice

\[ TC(Q) = cD + c_t \left( \frac{D}{Q} \right) + c_e \left( \frac{O}{2} + k\sigma_{DL} + LD \right) \]

<table>
<thead>
<tr>
<th></th>
<th>TL</th>
<th>IM</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lead Time ((\mu_L))</td>
<td>3</td>
<td>6</td>
</tr>
<tr>
<td>Std Dev Lead Time ((\sigma_L))</td>
<td>0.5</td>
<td>2</td>
</tr>
<tr>
<td>Cost ((c_t))</td>
<td>1800</td>
<td>1400</td>
</tr>
</tbody>
</table>

\[ \mu_{DL} = \mu_L \mu_D \]
\[ \sigma_{DL} = \sqrt{\mu_L \sigma_D^2 + (\mu_D)^2 \sigma_L^2} \]

<table>
<thead>
<tr>
<th></th>
<th>TL</th>
<th>IM</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average Demand over Lead Time ((\mu_{DL}))</td>
<td>9000</td>
<td>18000</td>
</tr>
<tr>
<td>Std Dev Demand over Lead Time ((\sigma_{DL}))</td>
<td>1984</td>
<td>6275</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>TL</th>
<th>IM</th>
</tr>
</thead>
<tbody>
<tr>
<td>Capacity ((Q))</td>
<td>40000</td>
<td>40000</td>
</tr>
<tr>
<td>Number of loads/year ((N = D/Q))</td>
<td>18.75</td>
<td>18.75</td>
</tr>
<tr>
<td>Annual Ordering Cost</td>
<td>$33,750</td>
<td>$26,250</td>
</tr>
<tr>
<td>Annual Cycle Stock Cost</td>
<td>$80,000</td>
<td>$80,000</td>
</tr>
<tr>
<td>Annual Safety Stock Cost</td>
<td>$13,017</td>
<td>$41,164</td>
</tr>
<tr>
<td>Annual Pipeline Inventory Cost</td>
<td>$36,000</td>
<td>$72,000</td>
</tr>
<tr>
<td><strong>Total Annual Logistics Cost</strong></td>
<td><strong>$162,767</strong></td>
<td><strong>$219,414</strong></td>
</tr>
</tbody>
</table>

Does the “weigh-out” policy make sense?

\[ c = $ 20 \text{ per lb} \]
\[ h = 20\% \text{ per year} \]
\[ c_e = 20(0.20) = 4 \$/\text{yr} \]
\[ \mu_D = 3000 \text{ lbs/day} \]
\[ \sigma_D = 750 \text{ lbs/day} \]
\[ k = 1.64 \]

Select TL for this lane. TL saves > $56k /yr, but note – transport costs are higher but are trumped by safety stock and pipeline inventory.
Solution: Mode Choice

\[ TC(Q) = cD + c_i \left( \frac{D}{Q} \right) + c_e \left( \frac{Q}{2} + k\sigma_{DL} + LD \right) \]

\[ Q^* = \sqrt{\frac{2c_tD}{c_e}} \]

<table>
<thead>
<tr>
<th></th>
<th>TL</th>
<th>IM</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lead Time ((\mu_L))</td>
<td>3</td>
<td>6</td>
</tr>
<tr>
<td>Std Dev Lead Time ((\sigma_L))</td>
<td>0.5</td>
<td>2</td>
</tr>
<tr>
<td>Cost ((c_i))</td>
<td>1800</td>
<td>1400</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>TL</th>
<th>IM</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average Demand over Lead Time ((\mu_{DL}))</td>
<td>9000</td>
<td>18000</td>
</tr>
<tr>
<td>Std Dev Demand over Lead Time ((\sigma_{DL}))</td>
<td>1984</td>
<td>6275</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>TL</th>
<th>IM</th>
</tr>
</thead>
<tbody>
<tr>
<td>Capacity (Q)</td>
<td>25981</td>
<td>22913</td>
</tr>
<tr>
<td>Number of loads/year ((N = D/Q))</td>
<td>28.87</td>
<td>32.73</td>
</tr>
<tr>
<td>Annual Ordering Cost</td>
<td>$51,962</td>
<td>$45,826</td>
</tr>
<tr>
<td>Annual Cycle Stock Cost</td>
<td>$51,962</td>
<td>$45,826</td>
</tr>
<tr>
<td>Annual Safety Stock Cost</td>
<td>$13,017</td>
<td>$41,164</td>
</tr>
<tr>
<td>Annual Pipeline Inventory Cost</td>
<td>$36,000</td>
<td>$72,000</td>
</tr>
<tr>
<td><strong>Total Annual Logistics Cost</strong></td>
<td><strong>$152,940</strong></td>
<td><strong>$204,815</strong></td>
</tr>
</tbody>
</table>

\(c = \$20\) per lb  
\(h = 20\%\) per year  
\(c_e = 20(0.20) = 4\) $/yr  
\(\mu_D = 3000\) lbs/day  
\(\sigma_D = 750\) lbs/day  
\(k = 1.64\)

Still use TL  
Shipping below max weight saves ~ $10k per year! Why?

When would IM make sense for this lane?

- Lower value (\(c \leq 0.73\) $/lb)
- Better service (\(\mu_L=5, \sigma_L=1\), & \(c \leq 2.67\) $/lb)
- Lower IM rate (\(c_t \leq 263\) $/load)
Key Points from Lesson
Key Points

\[ TC(Q) = c_D + c_t \left(\frac{D}{Q}\right) + c_e \left(\frac{Q}{2} + k\sigma_D + LD\right) \]

- Mode/route/carrier selection is a trade-off between
  - Transportation costs
  - Inventory costs (cycle, safety, pipeline)
  - Level of service
- Need to consider more than just direct transport cost
- Lead time impacts safety stock levels and variability impacts it even more so!
- Be careful about shape of distribution for demand over lead time.

\[
\begin{align*}
\mu_{DL} &= \mu_L \mu_D \\
\sigma_{DL} &= \sqrt{\mu_L \sigma_D^2 + (\mu_D)^2 \sigma_L^2}
\end{align*}
\]
Questions, Comments, Suggestions?
Use the Discussion!

“Wilson – pondering the Hadley-Whitin Equation”
Yankee Golden Retriever Rescued Dog
(www.ygr.org)

caplice@mit.edu