Agenda

- Introduction to Freight Transportation
- Levels of Transportation Networks
  - Physical
  - Operational
  - Service
- Impact of Transportation on Planning
Case Study: Shoes from China

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

- Shoes are manufactured, labeled, and packed at plant
- ~4.5M shoes shipped per year from this plant
- 6,000 to 6,500 shoes shipped per container (~700-750 FEUs / year)
- Value of pair of shoes ~$35

Map showing Shenzhen, China and Kansas City, US removed due to copyright restrictions.
Pallets vs Slipsheets

48 x 40 in. pallet is most popular in US (27% of all pallets—no other size over 5%)
1200 x 800 mm "Euro-Pallet" is the standard pallet in Europe
Containers

- **Characteristics**
  - Airtight, Stackable, Lockable

- **International ISO Sizes (8.5’ x 8’)**
  - TEU (20 ft)
    - Volume 33 M³
    - Total Payload 24.8 kkg
  - FEU (40 ft)
    - Volume 67 M³
    - Total Payload 28.8 kkg

- **Domestic US (~9’ x 8.25’)**
  - 53 ft long
    - Volume 111 M³
    - Total Payload 20.5 kkg

Images removed due to copyright restrictions.
Inland Transport @ Origin

3 Port Options
- Shekou (30k)
  - Truck
- Yantian (20k)
  - Rail
  - Truck
- Hong Kong (32k)
  - Rail
  - Truck
  - Barge

In Hong Kong
- 9 container terminals

Figure by MIT OCW.
Ocean Shipping Options

- 40 shipping lines visit these ports each with many options

Examples:

- **APL – APX-Atlantic Pacific Express Service**
  - Origins: Hong Kong (Sat) -> Kaohsiung, Pusan, Kobe, Tokyo
  - Stops: Miami (25 days), Savannah (27), Charleston (28), New York (30)

- **CSCL – American Asia Southloop**
  - Origins: Yantian (Sat) -> Hong Kong, Pusan
  - Stops: Port of Los Angeles (16.5 days)
Inland Transportation in US

Figure by MIT OCW.
Maher Terminal

- Express Rail II NS RR
  - Double stack thru:
  - Harrisburg, Pittsburgh, Cleveland, Ft. Wayne, to Kansas City
- CSX RR (5-10 days)
  - Double stack thru:
  - Philadelphia, Baltimore, Washington, Pittsburgh, Stark, Indianapolis, to Kansas City
- Truckload (2.5 – 3 days)
  - NJ Turnpike to I-78W, I-81S, I-76/70 to Kansas City

Figure by MIT OCW.
Truck & Intermodal Operations

Photographs removed due to copyright restrictions.

Over the Road Truck
Power Unit & 53’
Trailer

Container on Flat Car
(COFC) Double Stack

Trailer on Flat Car (TOFC)
Air Freight

Photographs removed due to copyright restrictions.
Transport Options

So how do I ship shoes from Shenzhen to Kansas City?

What factors influence my decision?

Consider different types of networks
- Physical
- Operational
- Strategic
Transportation Networks

Example: Two clients ship product to Rotterdam. There are rail and truck options to multiple ports with various ocean carrier options.

Legend:
- Truck
- Rail
- Ocean

Figure by MIT OCW.
Transportation Networks

Example: Two clients ship product to Rotterdam. There are rail and truck options to multiple ports with various ocean carrier options.

Legend:
- Truck
- Rail
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Figure by MIT OCW.
Three Layers of Networks

Physical Network: The actual path that the product takes from origin to destination. Basis for all costs and distance calculations – typically only found once.

Operational Network: The route the shipment takes in terms of decision points. Each arc is a specific mode with costs, distance, etc. Each node is a decision point.

Strategic Network: A series of paths through the network from origin to destination. Each represents a complete option and has end to end cost, distance, and service characteristics.
The Physical Network

**Guideway**
- Free (air, ocean, rivers)
- Publicly built (roads)
- Privately built (rails, pipelines)

**Terminals**
- Publicly built (ports, airports)
- Privately built (trucking terminals, rail yards, private parts of ports and airports)

**Controls**
- Public (roads, air space, rivers)
- Private (rail, pipelines)

The physical network is the primary differentiator between transportation systems in established versus remote locations.
Operational Network

Four Primary Components

- Loading/Unloading
- Local-Routing (Vehicle Routing)
- Line-Haul
- Sorting

Node & Arc view of network
Each Node is a decision point
Strategic Network

- Path view of the Network
- Used in establishing overall service standards for logistics system
- Summarizes movement in common financial and performance terms – used for trade-offs

Shenzhen → KC

Air: 3 days, $??/pair

All Water Route: 35 days, $0.65/pair

Land Bridge: 28 days, $0.75/pair
Transportation Impact on TC

\[ TC(Q) = vD + A \left( \frac{D}{Q} \right) + r\nu \left( \frac{Q}{2} + k\sigma_L \right) + B_{SO} \left( \frac{D}{Q} \right) \Pr[SO] \]

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
Simple Transportation Cost Functions

Pure Variable Cost / Unit

- Modify unit cost (v) for Purchase Cost

Pure Fixed Cost / Shipment

- Modify fixed order cost (A) for Ordering Cost

Mixed Variable & Fixed Cost

- Modify both A and v
More Complex Cost Functions

Variable Cost / Unit with a Minimum

Incremental Discounts

Note that approach will be similar to quantity discount analysis in deterministic EOQ
Lead Time & Lead Time Variability

<table>
<thead>
<tr>
<th>Source</th>
<th>$\chi_L$</th>
<th>$\sigma_L$</th>
</tr>
</thead>
<tbody>
<tr>
<td>3PL</td>
<td>55</td>
<td>45</td>
</tr>
<tr>
<td>US</td>
<td>25</td>
<td>25</td>
</tr>
<tr>
<td>Pac Rim</td>
<td>85</td>
<td>35</td>
</tr>
<tr>
<td>EU</td>
<td>75</td>
<td>40</td>
</tr>
</tbody>
</table>

What is impact of longer lead times?
What is impact of lead time variability?
What are the sources of the lead time & variability?

Major Packaged Consumer Goods Manufacturer

Total Lead Time = 56 days

Avg (std dev)

Production Time 15 (12)
Inland Transport 2 (2)
Load & Delay @ Port 2 (1)
Ocean Transport 26 (5)
Unload & Clear Port 5 (2)
Inland Transport 6 (3)
Lead Time Variability

Demand $\sim U(1,3)$
Lead Time 3 weeks

6 units

Demand $\sim U(1,3)$
Lead Time $\sim U(3,6)$

11 units
6 days

4 units

6 units
3 days

6 units

7 units
4 days
Lead Time Variability

This is essentially the random sum of random numbers
- $D \sim (x_D, \sigma_D)$ items demanded / time, iid
- $L \sim (x_L, \sigma_L)$ number of time periods

We want to find the characteristics of a new variable, $y$:

$$y = \sum_{i=1}^{L} d_i = d_1 + d_2 + d_3 + d_4 + \ldots + d_L$$

Note that any observation of demand, $d_i$, consists of both a deterministic and a stochastic component:

$$d_i = E[D] + \tilde{d}$$

$\text{where } E[\tilde{d}] = 0 \text{ and } \sigma_D^2 = 0 + \sigma_{\tilde{d}}^2$
Lead Time Variability

First, let’s find the expected value, $E[y]$

$$E[y] = E[d_1 + d_2 + d_3 + ... d_L]$$

$$= E\left[ (E[d_1] + E[d_2] + E[d_3] + ... E[d_L]) + (\tilde{d}_1 + \tilde{d}_2 + \tilde{d}_3 + ... \tilde{d}_L) \right]$$

$$= E\left[ LE[D] \right] + E\left[ \tilde{d}_1 + \tilde{d}_2 + \tilde{d}_3 + ... \tilde{d}_L \right]$$

$$= E[D]E[L] + 0$$

$$E[y] = E[D]E[L]$$
Lead Time Variability

What is the impact of lead time variability?

Assumptions

- Lead Time and Demand are independent RVs
- \( D_{\text{Leadtime}} = \text{Demand over lead time} \)
- \( \sigma_{\text{Leadtime}} = \text{Standard deviation of demand over } t \)

Questions we can answer:
1. What is the impact of lead time variability on safety stock?
2. What is the trade-off between length of lead time and variability?
Transportation Options

When is it better to use a cheaper more variable transport mode?

- Air – higher $v$, smaller $\sigma$
- Rail – lower $v$, larger $\sigma$

$$\Delta \text{TRC} = \text{TRC}_a - \text{TRC}_r$$

where,

$$\text{TRC}_a = \sqrt{2A_aDv_ar + k_a\sigma_{L,a}v_ar + Dv_a}$$

$$\text{TRC}_r = \sqrt{2A_rDv_rr + k_r\sigma_{L,r}v_rr + Dv_r}$$

Pick mode with smaller TRC
Transport vs. Inventory Costs

Multiple Modes

\[ c_v + rvt_m \]

Transport Cost per Shipment

\[ c_f \]

Shipment Size

Mode 1

Mode 2

Mode 3
Consider a simple Production to Consumption Network

Primary Tradeoffs: **Moving** vs. **Holding**
## Mode Comparison Matrix

<table>
<thead>
<tr>
<th></th>
<th>Truck</th>
<th>Rail</th>
<th>Air</th>
<th>Water</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Operational Cost</strong></td>
<td>Moderate</td>
<td>Low</td>
<td>High</td>
<td>Low</td>
</tr>
<tr>
<td><strong>Market Coverage</strong></td>
<td>Pt to Pt</td>
<td>Terminal to Terminal</td>
<td>Terminal to Terminal</td>
<td>Terminal to Terminal</td>
</tr>
<tr>
<td><strong>Degree of competition</strong></td>
<td>Many</td>
<td>Few</td>
<td>Moderate</td>
<td>Few</td>
</tr>
<tr>
<td><strong>Traffic Type</strong></td>
<td>All Types</td>
<td>Low to Mod Value, Mod to High density</td>
<td>High value, Low density</td>
<td>Low value, High density</td>
</tr>
<tr>
<td><strong>Length of haul</strong></td>
<td>Short – Long</td>
<td>Medium – Long</td>
<td>Long</td>
<td>Med - Long</td>
</tr>
<tr>
<td><strong>Capacity (tons)</strong></td>
<td>10 – 25</td>
<td>50 – 12,000</td>
<td>5 – 12</td>
<td>1,000 – 6,000</td>
</tr>
</tbody>
</table>
# Mode Comparison Matrix

<table>
<thead>
<tr>
<th></th>
<th>Truck</th>
<th>Rail</th>
<th>Air</th>
<th>Water</th>
<th>Pipeline</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>BTU/ Ton-Mile</strong></td>
<td>2,800</td>
<td>670</td>
<td>42,000</td>
<td>680</td>
<td>490</td>
</tr>
<tr>
<td><strong>Cents / Ton-Mile</strong></td>
<td>7.50</td>
<td>1.40</td>
<td>21.90</td>
<td>0.30</td>
<td>0.27</td>
</tr>
<tr>
<td><strong>Avg Length of Haul</strong></td>
<td>300</td>
<td>500</td>
<td>1000</td>
<td>1000</td>
<td>300</td>
</tr>
<tr>
<td><strong>Avg Speed (MPH)</strong></td>
<td>40</td>
<td>20</td>
<td>400</td>
<td>10</td>
<td>5</td>
</tr>
</tbody>
</table>
Lead Time Variability

This is essentially the random sum of random numbers

- $D \sim (x_D, \sigma_D)$ items demanded / time, iid
- $L \sim (x_L, \sigma_L)$ number of time periods

We want to find the characteristics of a new variable, $y$:

$$y = \sum_{i=1}^{L} d_i = d_1 + d_2 + d_3 + d_4 + \ldots + d_L$$

Note that any observation of demand, $d_i$, consists of both a deterministic and a stochastic component:

$$d_i = E[D] + \tilde{d}$$

where $E[\tilde{d}] = 0$ and $\sigma^2_D = 0 + \sigma^2_{\tilde{d}}$
Lead Time Variability

First, let’s find the expected value, $E[y]$

$$E[y] = E[d_1 + d_2 + d_3 + ... d_L]$$

$$= E\left( E[d_1] + E[d_2] + E[d_3] + ... E[d_L] \right) + \left( \tilde{d}_1 + \tilde{d}_2 + \tilde{d}_3 + ... \tilde{d}_L \right)$$

$$= E[LE[D]] + E[\tilde{d}_1 + \tilde{d}_2 + \tilde{d}_3 + ... \tilde{d}_L]$$

$$= E[D]E[L] + 0$$

$$E[y] = E[D]E[L]$$
Lead Time Variability

Finding \( V[y] \)

\[
y = E[d_1] + E[d_2] + E[d_3] + \ldots E[d_L] + (\tilde{d}_1 + \tilde{d}_2 + \tilde{d}_3 + \ldots \tilde{d}_L)
\]

\[
= L E[D] + (\tilde{d}_1 + \tilde{d}_2 + \tilde{d}_3 + \ldots \tilde{d}_L)
\]

Both terms are independent random variables – note that \( E[D] \) is a constant, and \( V[aX] = a^2 V[x] \) and that \( V[X+Y] = V[X] + V[Y] \), so that

\[
\sigma^2_y = (E[D])^2 \sigma^2_L + V[(\tilde{d}_1 + \tilde{d}_2 + \tilde{d}_3 + \ldots \tilde{d}_L)]
\]

Substituting \( \lambda = \tilde{d}_1 + \tilde{d}_2 + \tilde{d}_3 + \ldots \tilde{d}_L \) We get \( \sigma^2_y = (E[D])^2 \sigma^2_L + \sigma^2_\lambda \)

By definition, we know that \( \sigma^2_X = E[X^2] - (E[X])^2 \)

Which gives us \( \sigma^2_\lambda = E[\lambda^2] - (E[\lambda])^2 = E[\lambda^2] - 0 = E[\lambda^2] \)
Lead Time Variability

Substitute in so that, \[ \sigma^2_\lambda = E\left[ \lambda^2 \right] = E\left[ \left( \tilde{d}_1 + \tilde{d}_2 + \tilde{d}_3 + ... \tilde{d}_L \right)^2 \right] \]

Recalling that, \( (x_1 + x_2 + x_3 + ... + x_n)^2 = x_1^2 + x_2^2 + x_3^2 + ... + x_n^2 + 2 \sum_{i=1}^{n} \sum_{j=i+1}^{n} x_i x_j \)

We get that, \[ \sigma^2_\lambda = E\left[ \lambda^2 \right] = E\left[ \tilde{d}_1^2 + \tilde{d}_2^2 + \tilde{d}_3^2 + ... \tilde{d}_L^2 + 2 \sum_{i=1}^{L} \sum_{j=i+1}^{L} \tilde{d}_i \tilde{d}_j \right] \]
\[ = E\left[ \tilde{d}_1^2 + \tilde{d}_2^2 + \tilde{d}_3^2 + ... \tilde{d}_L^2 \right] + 2 E\left[ \sum_{i=1}^{L} \sum_{j=i+1}^{L} \tilde{d}_i \tilde{d}_j \right] \]

Recalling that if random variables X and Y are independent, then \( E[XY] = E[X]E[Y] \), and the \( E(d^\sim) = 0 \), the second term goes to 0, thus,

\[ \sigma^2_\lambda = E\left[ \lambda^2 \right] = E\left[ \tilde{d}_1^2 + \tilde{d}_2^2 + \tilde{d}_3^2 + ... \tilde{d}_L^2 \right] \]
\[ = E\left[ \mu_1 + \mu_2 + \mu_3 + ... \mu_L \right] \quad \text{where } \mu_i = \tilde{d}_i^2 \]
\[ = E\left[ L \right] E\left[ \mu \right] = E\left[ L \right] E\left[ \tilde{d}_i^2 \right] \]

Which, again, is a random sum of random numbers!
(I substituted in the \( \mu \) to make it read easier)
Lead Time Variability

Starting with, \[ \sigma^2_{\lambda} = E[L] E[\tilde{d}_i^2] \]

We recall that for any random variable \( X \), \[ \sigma^2_X = E[X^2] - E[X]^2 \quad \text{or} \quad E[X^2] = \sigma^2_X + E[X]^2 \]

We get, \[ E[\tilde{d}^2] = \sigma^2_\tilde{d} + E[\tilde{d}]^2 = \sigma^2_\tilde{d} + 0 = \sigma^2_D \]

So that, \[ \sigma^2_{\lambda} = E[L] E[\tilde{d}_i^2] = E[L] \sigma^2_D \]

Combining terms, \[ \sigma^2_y = \left( E[D] \right)^2 \sigma^2_L + \sigma^2_{\lambda} \]
\[ \sigma^2_y = \left( E[D] \right)^2 \sigma^2_L + E[L] \sigma^2_D \]
Questions?