Transportation Management
Fundamental Concepts

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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.

Source: Chiu MLOG 2005

Pallets vs Slipsheets

Images of pallets removed due to copyright restrictions.

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 M^3
    - Total Payload 24.8 kkg
  - FEU (40 ft)
    - Volume 67 M^3
    - Total Payload 28.8 kkg
- Domestic US (~9′ x 8.25′)
  - 53 ft long
    - Volume 111 M^3
    - Total Payload 20.5 kkg

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Inland Transport @ Origin

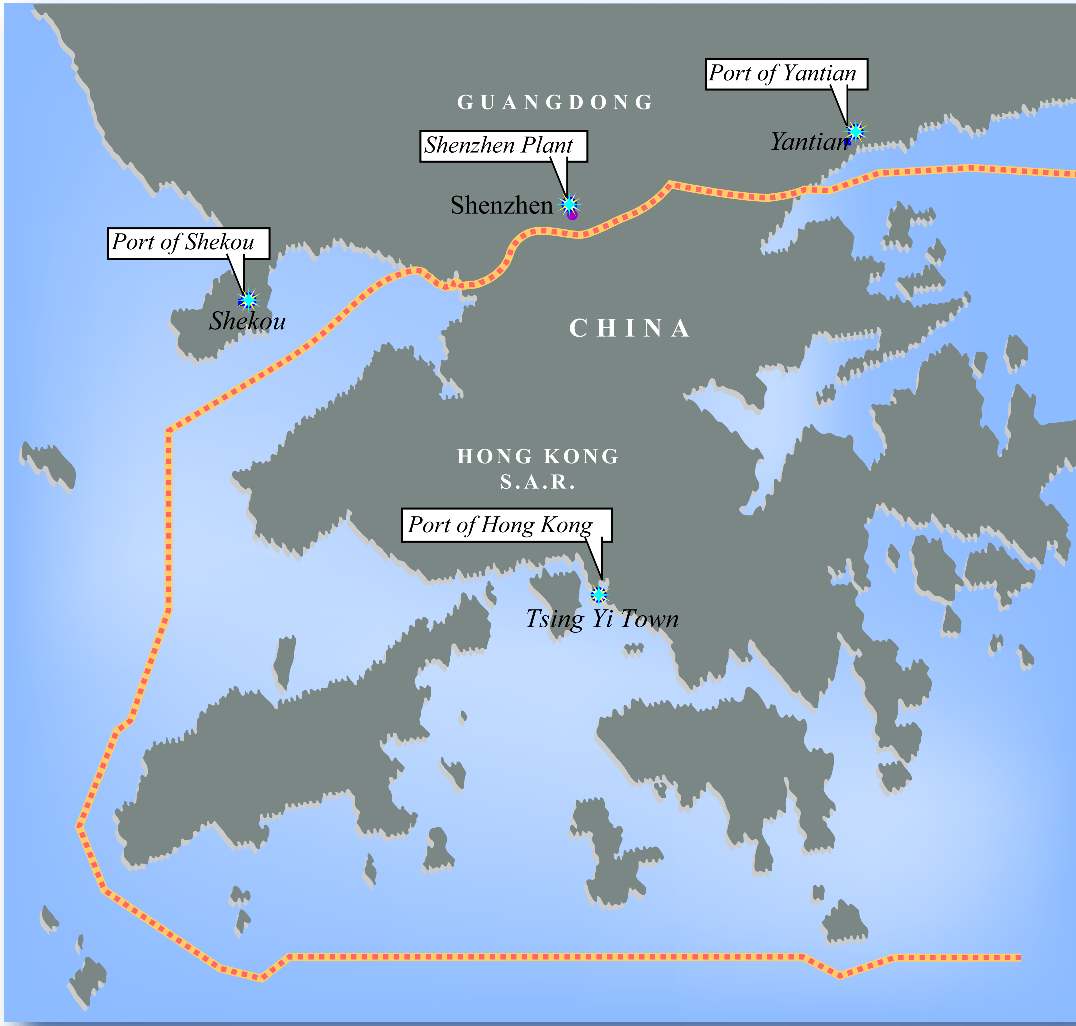


Figure by MIT OCW.

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

Ocean Shipping Options

- 40 shipping lines visit these ports each w/ 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)

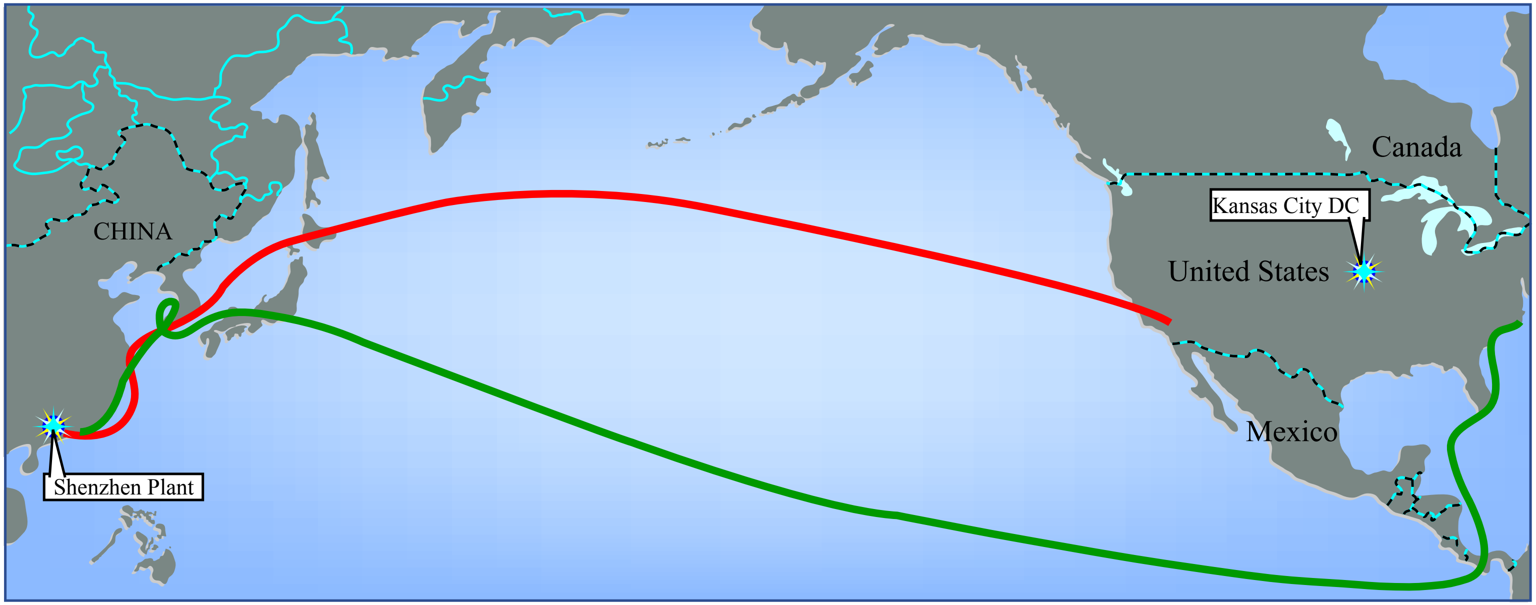


Figure by MIT OCW.

Inland Transportation in US

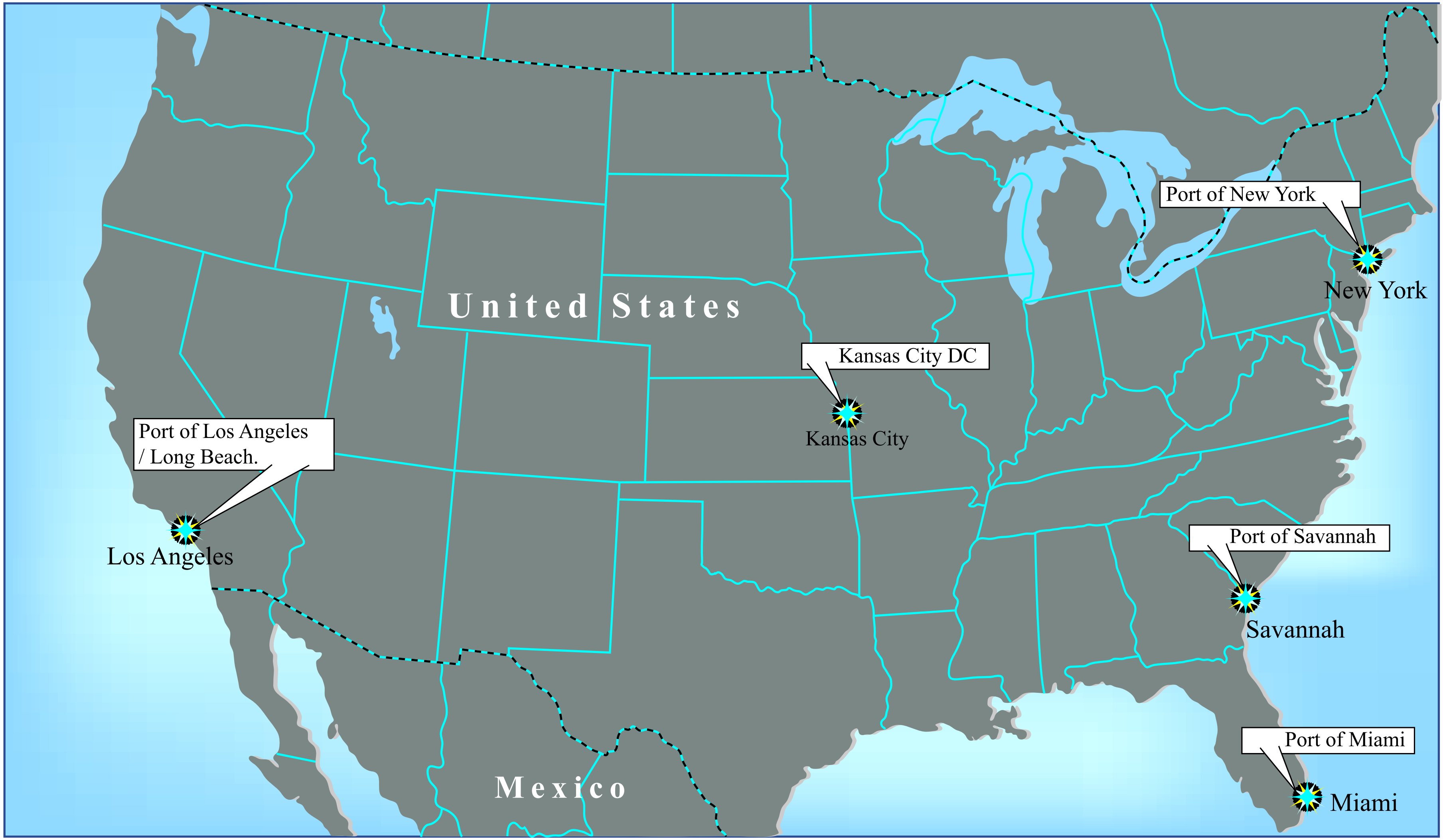


Figure by MIT OCW.

Port of New York / New Jersey

- 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

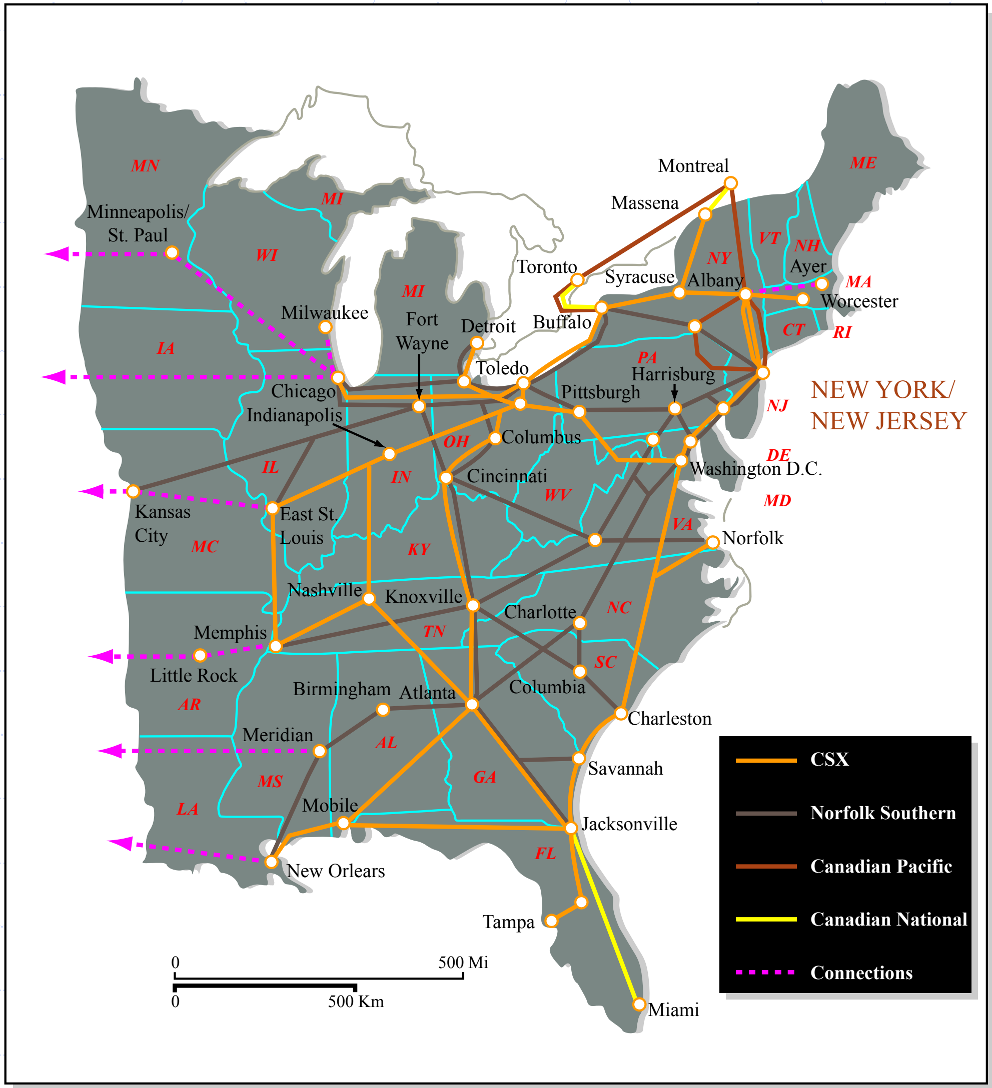


Figure by MIT OCW.

Truck & Intermodal Operations

Over the Road Truck Power Unit & 53' Trailer

Photographs removed due to copyright restrictions.

Container on Flat Car (COFC) Double Stack

Trailer on Flat Car (TOFC)

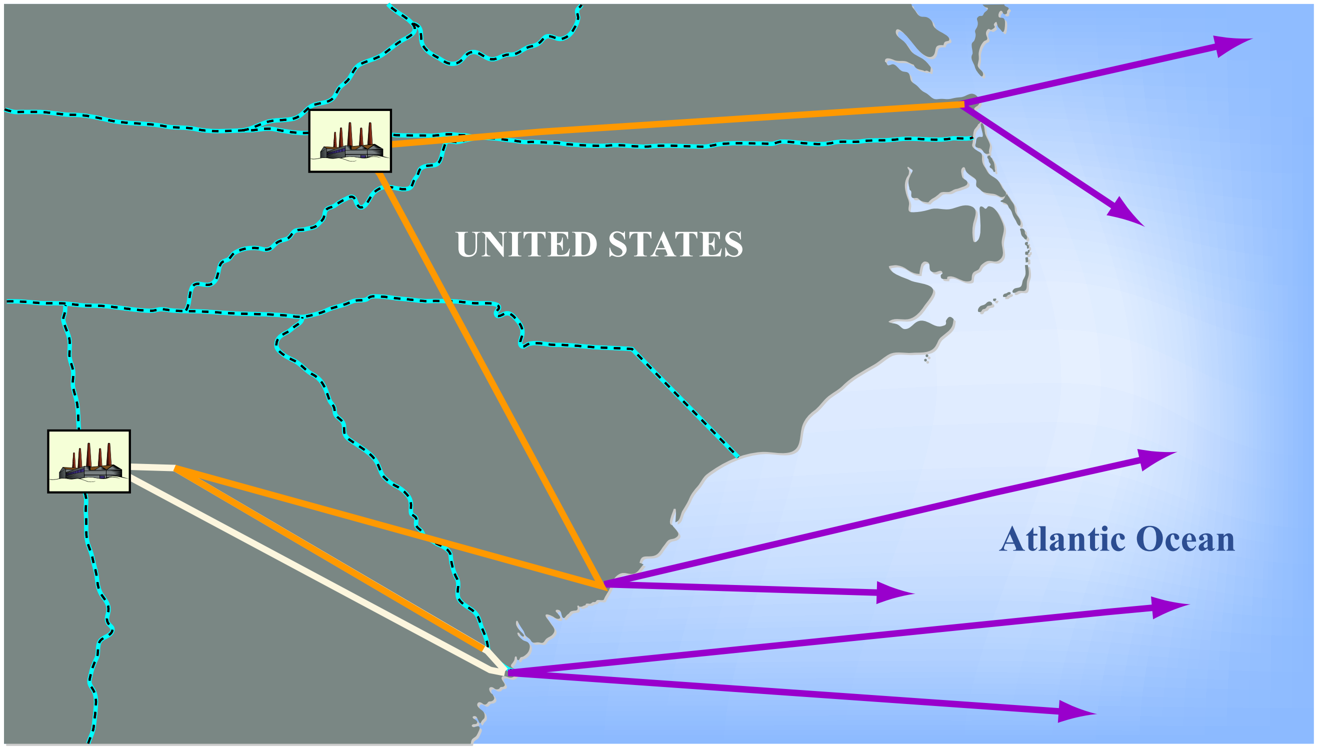
Air Freight

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

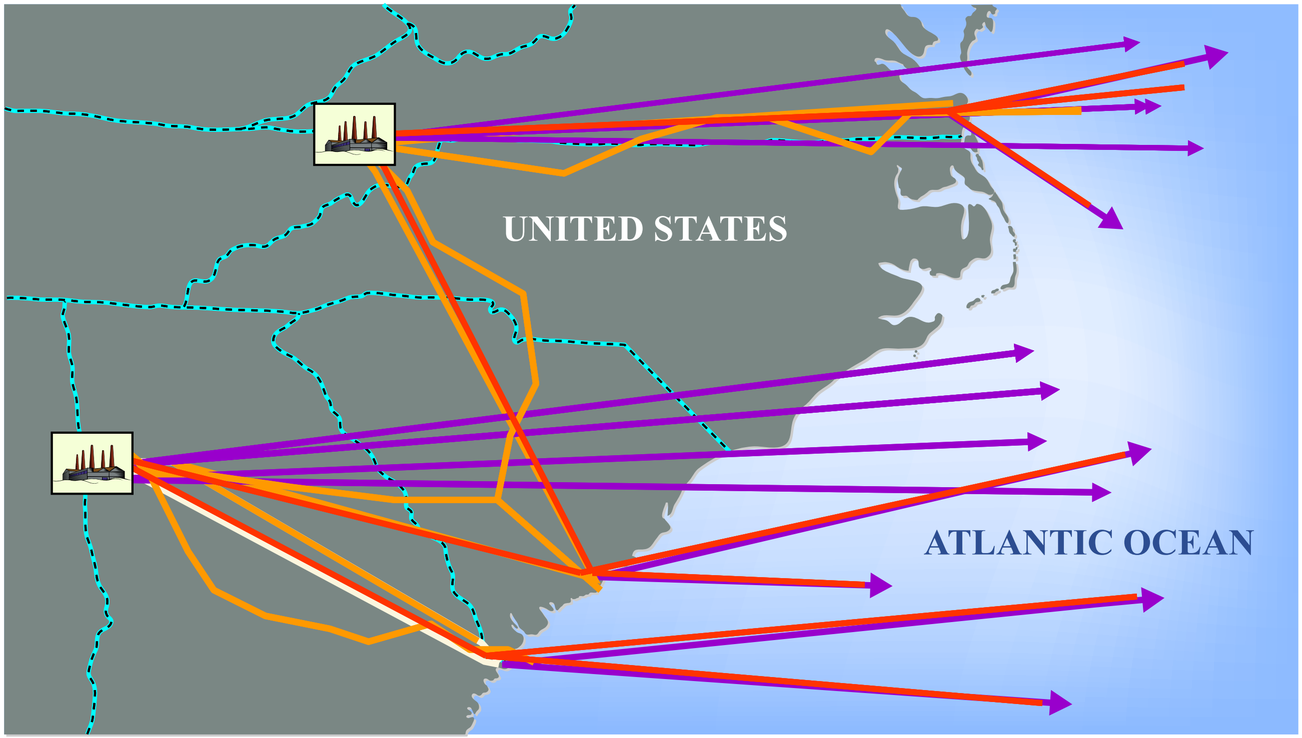
Transportation Networks



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

Figure by MIT OCW.

Transportation Networks



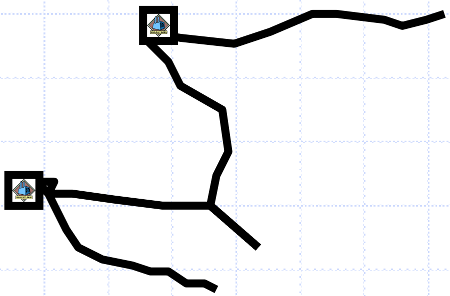
Example: Two clients ship product to Rotterdam. There are rail and truck options to multiple ports with various ocean carrier options.

Legend:
- ***Truck***
- ***Rail***
- ***Ocean***

Physical —— Operational Strategic

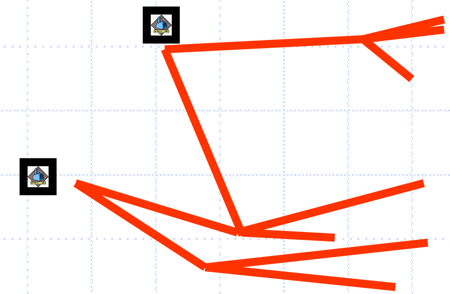
Figure by MIT OCW.

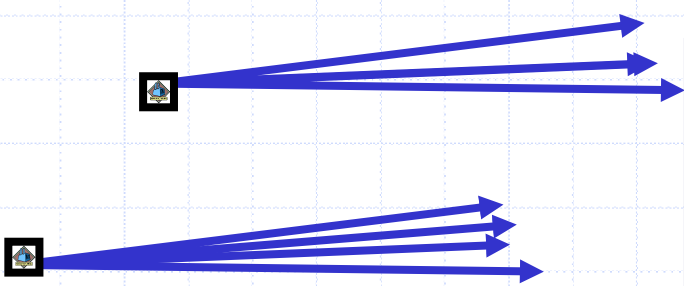
Three Layers of Networks



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.

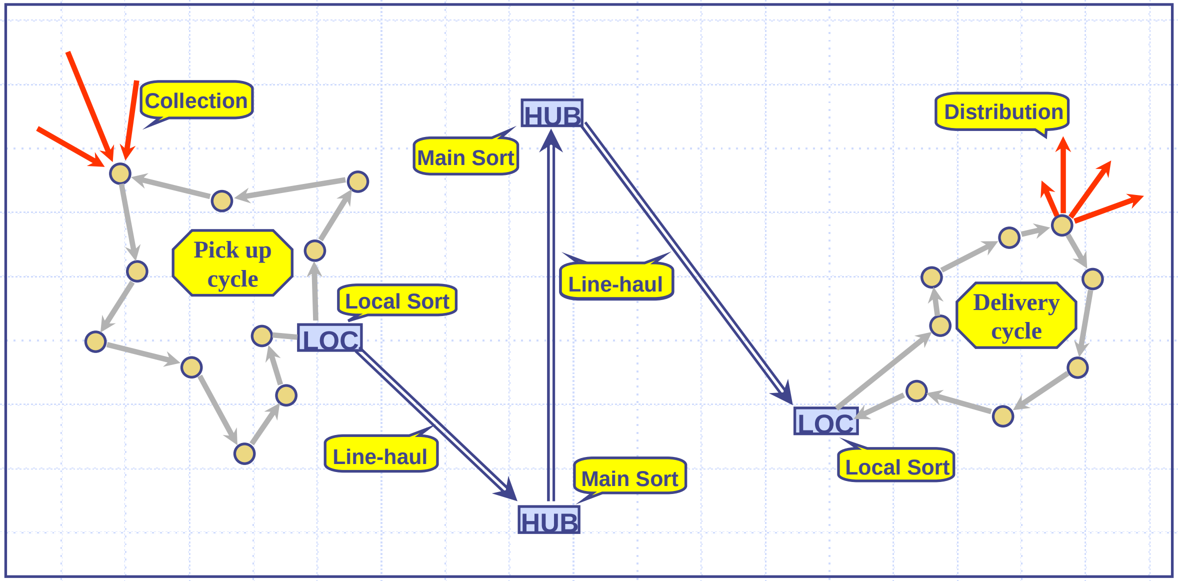
The Physical Network

- 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

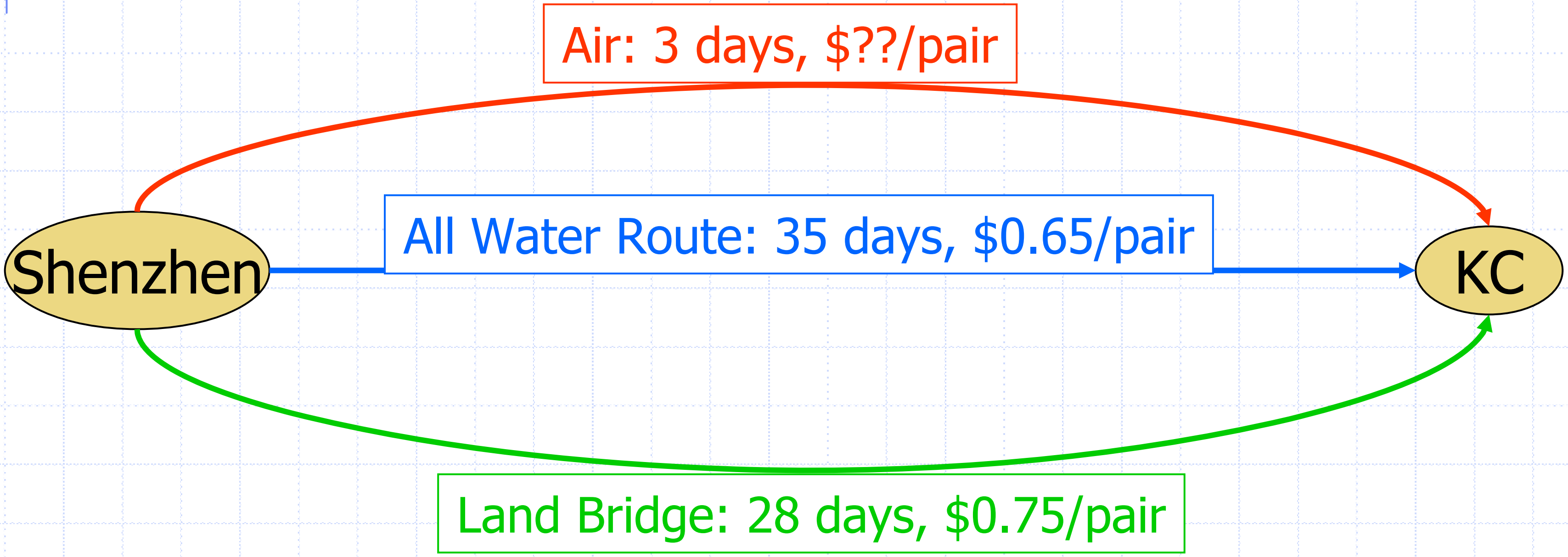
- Four Primary Components
  - Loading/Unloading
  - Local-Routing (Vehicle Routing)
  - Line-Haul
  - Sorting



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



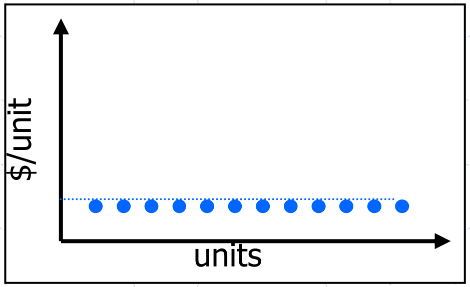
Transportation Impact on TC

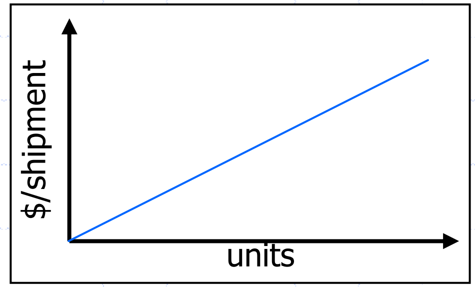
$$TC(Q) = vD + A\left(\frac{D}{Q}\right) + rv\left(\frac{Q}{2} + k\sigma_L\right) + B_{SO}\left(\frac{D}{Q}\right)\Pr[SO]$$

- 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

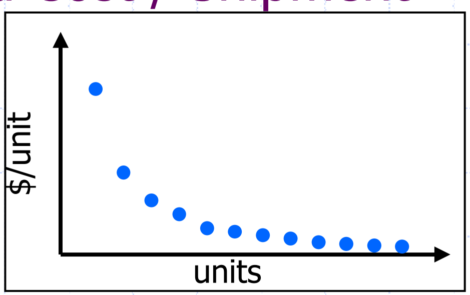
Pure Variable Cost / Unit

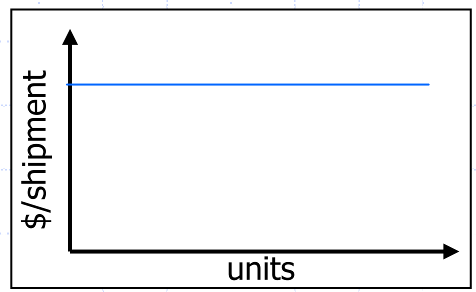




Modify unit cost (v) for Purchase Cost

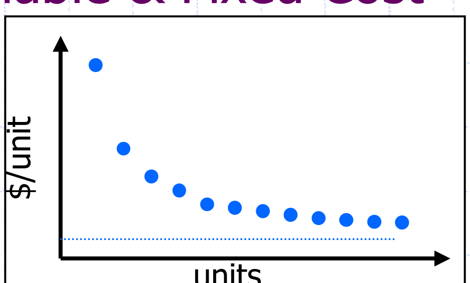
Pure Fixed Cost / Shipment

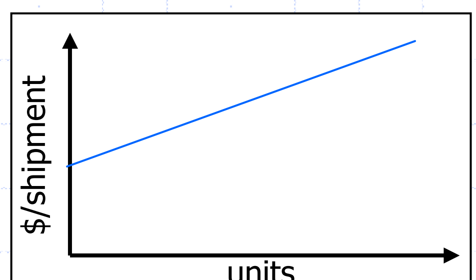




Modify fixed order cost (A) for Ordering Cost

Mixed Variable & Fixed Cost

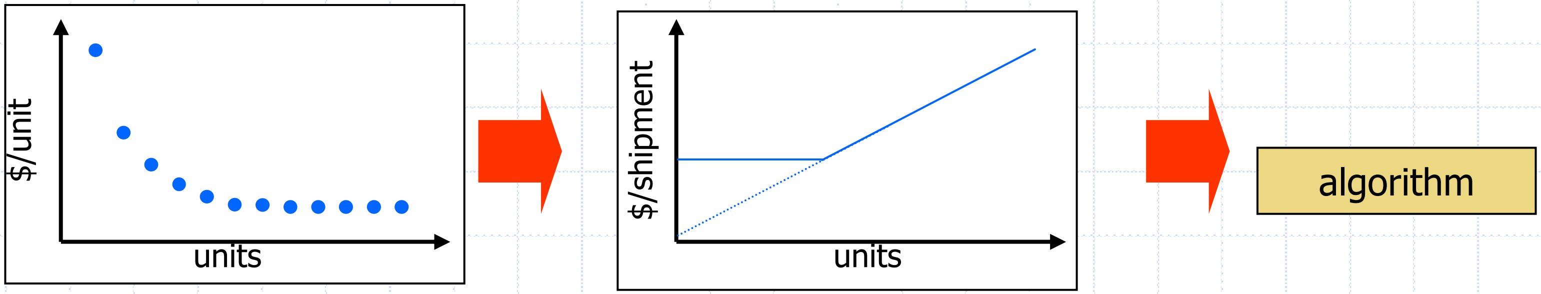




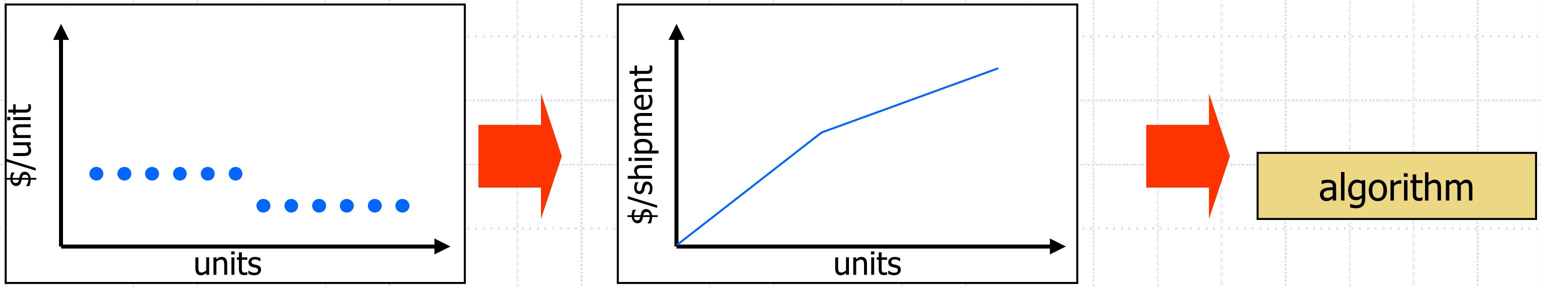
Modify both A and v

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

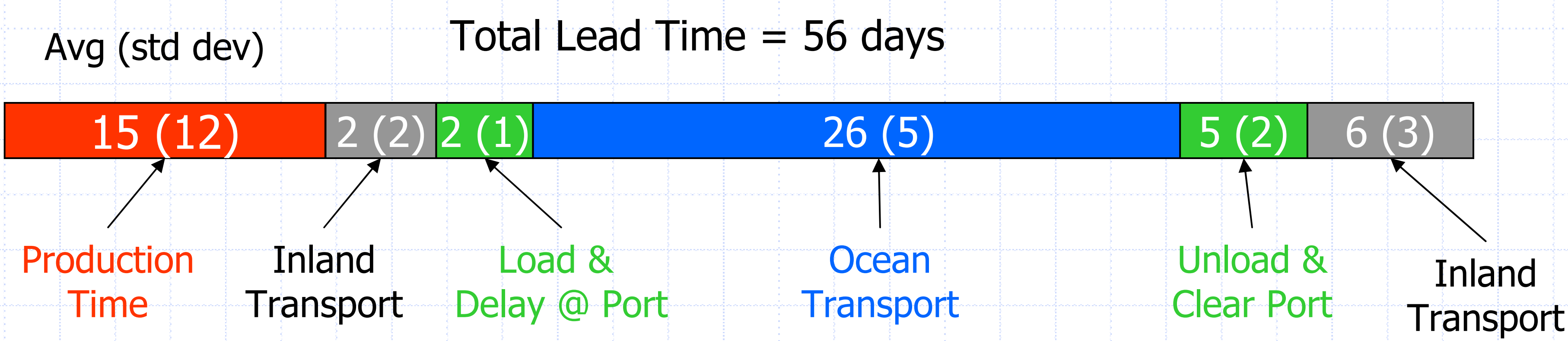
Source	x_L	σ_L
3PL	55	45
US	25	25
Pac Rim	85	35
EU	75	40

Major Packaged Consumer Goods Manufacturer

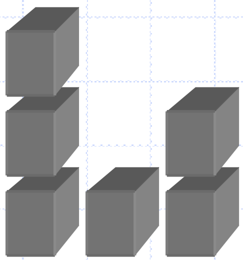
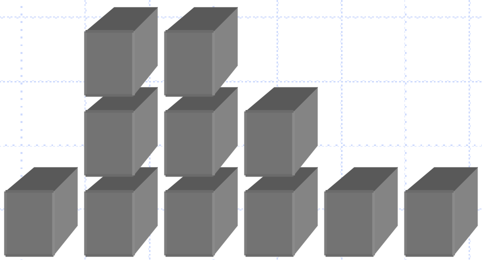
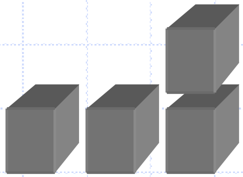
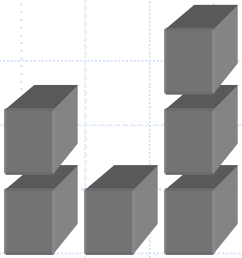
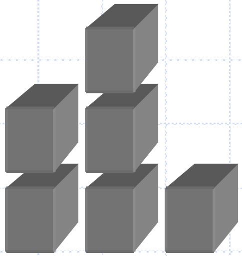
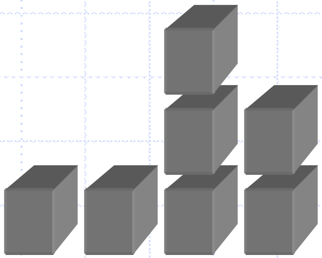
What is impact of longer lead times?

What is impact of lead time variability?

What are the sources of the lead time & variability?



Lead Time Variability

Demand ~U(1,3) Lead Time 3 weeks		Demand ~U(1,3) Lead Time ~U(3,6)	
	6 units		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:

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

$$where \quad E[\tilde{d}] = 0 \quad and \quad \sigma_D^2 = 0 + \sigma_{\tilde{d}}^2$$

Lead Time Variability

- First, let's find the expected value, E[y]

$$E[y] = E[d_1 + d_2 + d_3 + \ldots d_L]$$
$$= E\left[\left(E[d_1] + E[d_2] + E[d_3] + \ldots E[d_L]\right) \quad + \quad \left(\tilde{d}_1 + \tilde{d}_2 + \tilde{d}_3 + \ldots \tilde{d}_L\right)\right]$$
$$= E\left[LE[D]\right] + E\left[\tilde{d}_1 + \tilde{d}_2 + \tilde{d}_3 + \ldots \tilde{d}_L\right]$$
$$= E[D]E[L] + 0$$
$$E[y] = E[D]E[L]$$

Lead Time Variability

- What is the impact of lead time variability?
- Assumptions
  - Lead Time and Demand are independent RVs
  - $D_{Leadtime}$ =Demand over lead time
  - $\sigma_{Leadtime}$= Standard deviation of demand over L

$$E(D_{Leadtime}) = E(L)E(D)$$

$$\sigma_{Leadtime} = \sqrt{E(L)\sigma_D^2 + \left(E(D)\right)^2 \sigma_L^2}$$

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 σ
  - Rail – lower v, larger σ

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

where,

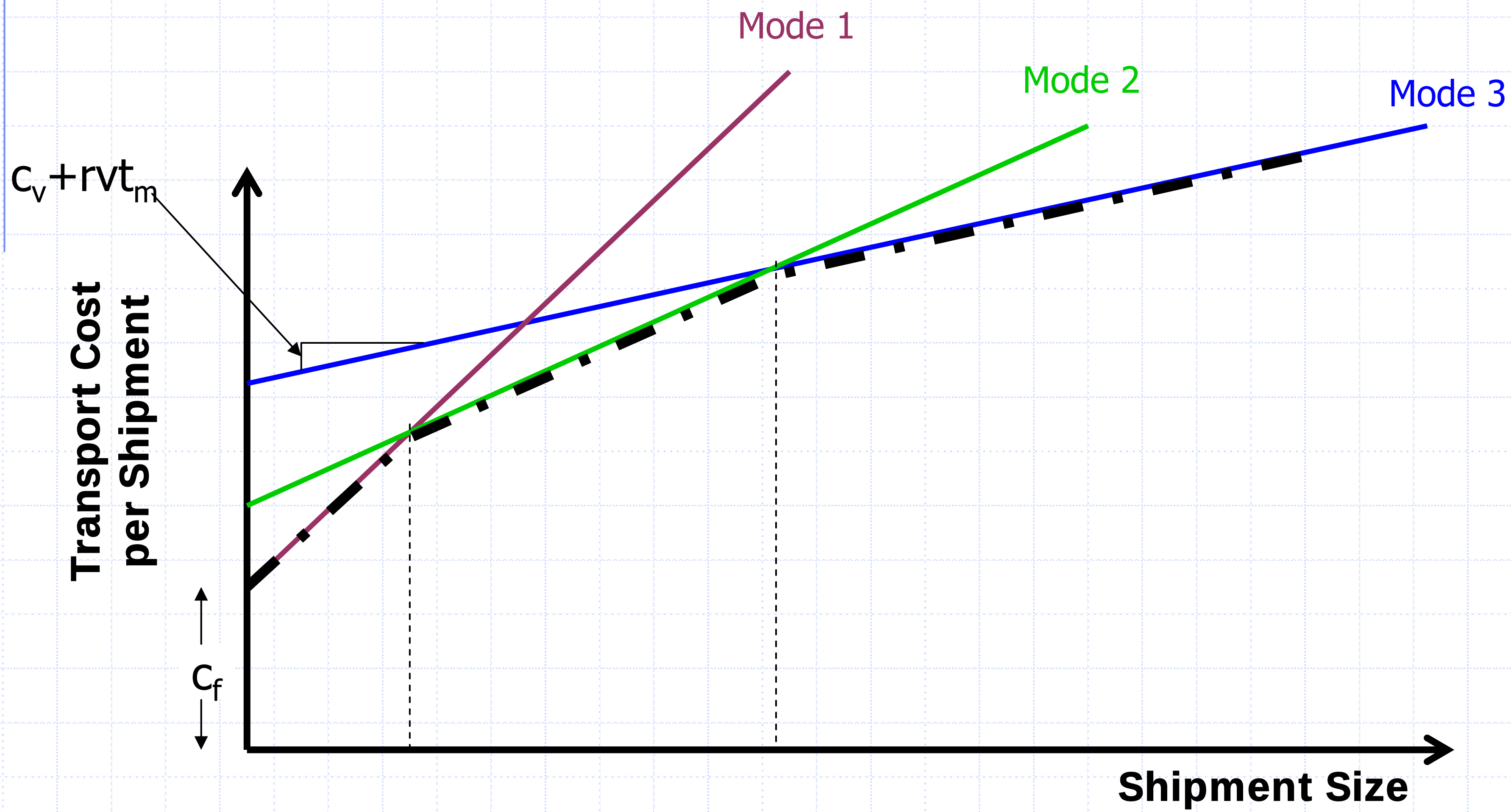
$$\text{TRC}_a = \sqrt{2A_a D v_a r} + k_a \sigma_{L,a} v_a r + D v_a$$

$$\text{TRC}_r = \sqrt{2A_r D v_r r} + k_r \sigma_{L,r} v_r r + D v_r$$

- Pick mode with smaller TRC

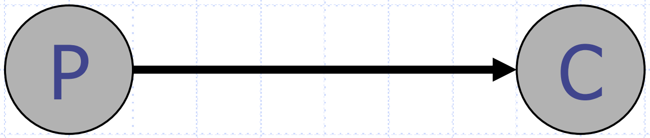
Transport vs. Inventory Costs

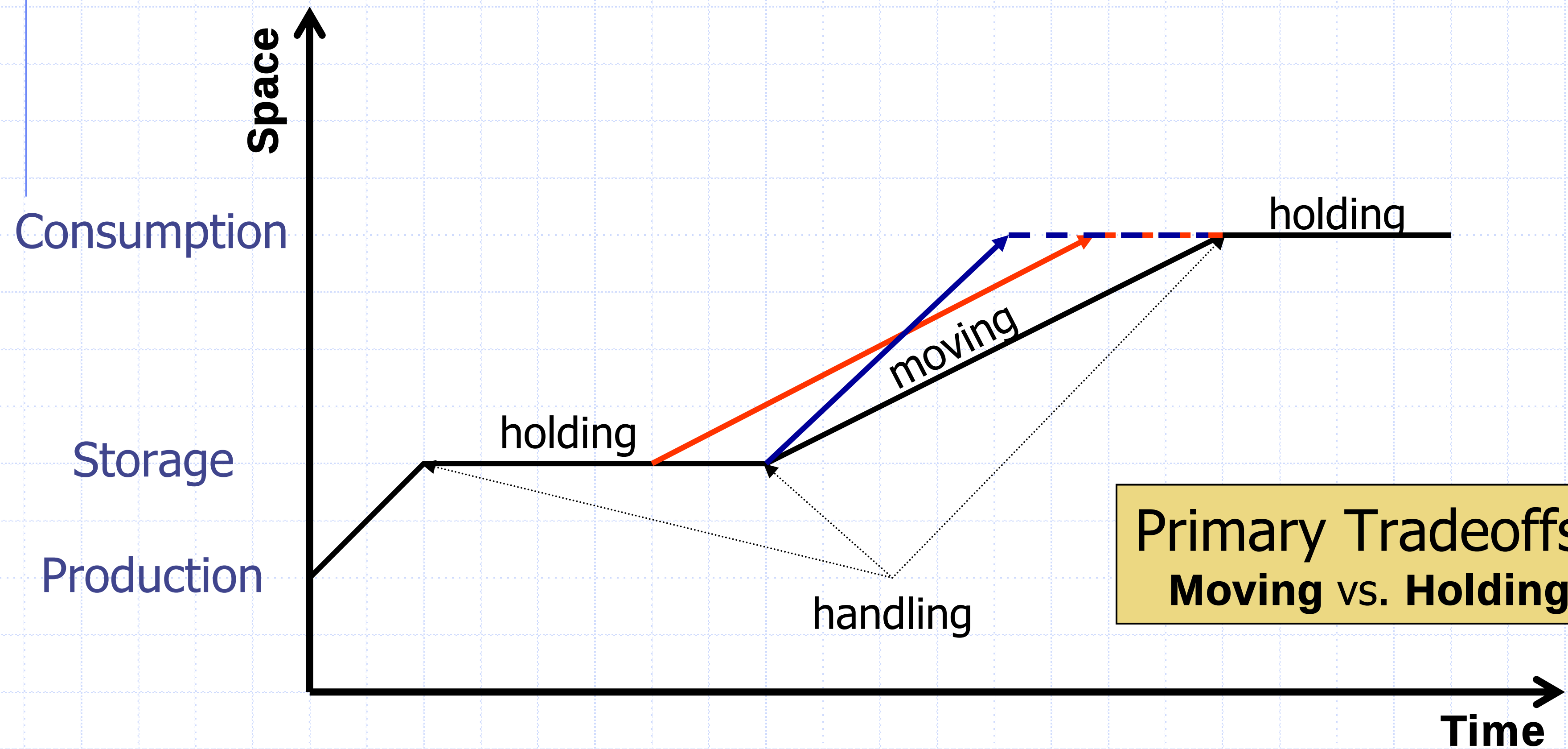
- Multiple Modes



Time Space Diagram

Consider a simple Production to Consumption Network





Primary Tradeoffs:
Moving vs. **Holding**

Mode Comparison Matrix

	Truck	Rail	Air	Water
Operational Cost	Moderate	Low	High	Low
Market Coverage	Pt to Pt	Terminal to Terminal	Terminal to Terminal	Terminal to Terminal
Degree of competition	Many	Few	Moderate	Few
Traffic Type	All Types	Low to Mod Value, Mod to High density	High value, Low density	Low value, High density
Length of haul	Short – Long	Medium – Long	Long	Med - Long
Capacity (tons)	10 – 25	50 – 12,000	5 – 12	1,000 – 6,000

Mode Comparison Matrix

	Truck	Rail	Air	Water
Speed	Moderate	Slow	Fast	Slow
Availability	High	Moderate	Moderate	Low
Consistency (delivery time)	High	Moderate	Moderate	Low
Loss & Damage	Low	High	Low	Moderate
Flexibility	High	Low	Moderate	Low

	Truck	Rail	Air	Water	Pipeline
BTU/ Ton-Mile	2,800	670	42,000	680	490
Cents / Ton-Mile	7.50	1.40	21.90	0.30	0.27
Avg Length of Haul	300	500	1000	1000	300
Avg Speed (MPH)	40	20	400	10	5

Lead Time Variability

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Lead Time Variability

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

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

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

$$E[y] = E[D]E[L]$$

Lead Time Variability

Finding V[y]

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

$$= L\,E[D] + \left(\tilde{d}_1 + \tilde{d}_2 + \tilde{d}_3 + \dots \tilde{d}_L\right)$$

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

$$\sigma_y^2 = \left(E[D]\right)^2 \sigma_L^2 + V\left[\left(\tilde{d}_1 + \tilde{d}_2 + \tilde{d}_3 + \dots \tilde{d}_L\right)\right]$$

Substituting $\lambda = \tilde{d}_1 + \tilde{d}_2 + \tilde{d}_3 + \dots \tilde{d}_L$ We get $\sigma_y^2 = \left(E[D]\right)^2 \sigma_L^2 + \sigma_\lambda^2$

By definition, we know that $\sigma_X^2 = E\left[X^2\right] - \left(E[X]\right)^2$

Which gives us $\sigma_\lambda^2 = E\left[\lambda^2\right] - \left(E[\lambda]\right)^2 = E\left[\lambda^2\right] - 0 = E\left[\lambda^2\right]$

Lead Time Variability

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

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

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

$$= E\left[\tilde{d}_1{}^2 + \tilde{d}_2{}^2 + \tilde{d}_3{}^2 + \ldots \tilde{d}_L{}^2\right] + 2E\left[\sum_{i=1}^{L}\sum_{j=i+1}^{L} \tilde{d}_i \tilde{d}_j\right]$$

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

$$\sigma_\lambda^2 = E\left[\lambda^2\right] = E\left[\tilde{d}_1{}^2 + \tilde{d}_2{}^2 + \tilde{d}_3{}^2 + \ldots \tilde{d}_L{}^2\right]$$

$$= E\left[\mu_1 + \mu_2 + \mu_3 + \ldots \mu_L\right] \qquad where\ \mu_i = \tilde{d}_i^2$$

$$= E[L]E[\mu] = E[L]E\left[\tilde{d}_i^2\right]$$

Which, again, is a random sum of random numbers!

(I substituted in the μ to make it read easier)

Lead Time Variability

Starting with, $\sigma_\lambda^2 = E[L]E\left[\tilde{d}_i^{\,2}\right]$

We recall that for any random variable X, $\sigma_X^2 = E\left[X^2\right] - E[X]^2 \quad or \quad E\left[X^2\right] = \sigma_X^2 + E[X]^2$

We get, $E\left[\tilde{d}^{\,2}\right] = \sigma_{\tilde{d}}^2 + E\left[\tilde{d}\right]^2 = \sigma_{\tilde{d}}^2 + 0 = \sigma_D^2$

So that, $\sigma_\lambda^2 = E[L]E\left[\tilde{d}_i^{\,2}\right] = E[L]\sigma_D^2$

Combining terms,

$$\sigma_y^2 = \left(E[D]\right)^2 \sigma_L^2 + \sigma_\lambda^2$$

$$\sigma_y^2 = \left(E[D]\right)^2 \sigma_L^2 + E[L]\sigma_D^2$$

Questions?