Military and Commercial Cargo Mission Needs

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Subject 16.886 Air Transportation System Architecting

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Introduction

- The cargo world attempts to solve a very complex mission (problem)
- This presentation outlines the elements of the problem but does not define a specific mission
- I have been trying to understand this subject for a few years now
  - I may only be a few weeks ahead of you (if that)!
- This presentation is non-linear
  - Requires integration by the student after the fact…
- Military and commercial needs are similar in structure
  - Widely different values
  - Military values very dependent on situation

General Problem

- Object of the game: Devise a goods creation and distribution system that creates greater value than it costs
  - Measure of merit varies
- Elements of the system include:
  - Creation of the goods (manufacturing, mining, farming)
  - Distribution
  - Customers

General Solution

- Provides overall production/transport architecture to maximize an economic measure
- This optimization results in the need for global distribution of goods
  - System seeks a balance between production and transport costs:
    - Low-cost or expert labor
    - Mass production
    - Product type consolidation (cars in Detroit, movies in LA)
    - Farmland
    - Proximity to market
    - Good transport system access
    - Etc
- Production and distribution are a linked system

Transport Problem

- The problem pertains to the distribution of non-human objects (not electronic information)
  - Humans are “self-loading cargo” and are a special case not addressed here
    - Chief difference between people and cargo is that people’s time is generally much more valuable than cargo’s
      - Transoceanic transport:
        - » Cargo: 99% ship, 1% air (by weight)
        - » People: 1% ship, 99% air (approximately)
      - As a result, cargo systems are much different than passenger systems
- Addressing the transport problem in isolation from production, the object is to obtain the lowest total cost of transport

Total Distribution Cost

- Object of logistics systems is to minimize Total Distribution Cost (TDC)
- TDC is the total cost of transporting goods
  - Sum of cost of transport and cost of holding inventory
- Cost of transport is fees paid to carriers (ship, truck, etc)
- Annual cost of inventory is typically a fraction of the value of the inventory
  - This fraction is called “Inventory Carrying Cost”
    - Typical fraction is 25%, but depends heavily on actual goods, timing
      - Diamonds have low ICC, food has high ICC
    - Consists of interest, depreciation, taxes, insurance, losses, warehouses

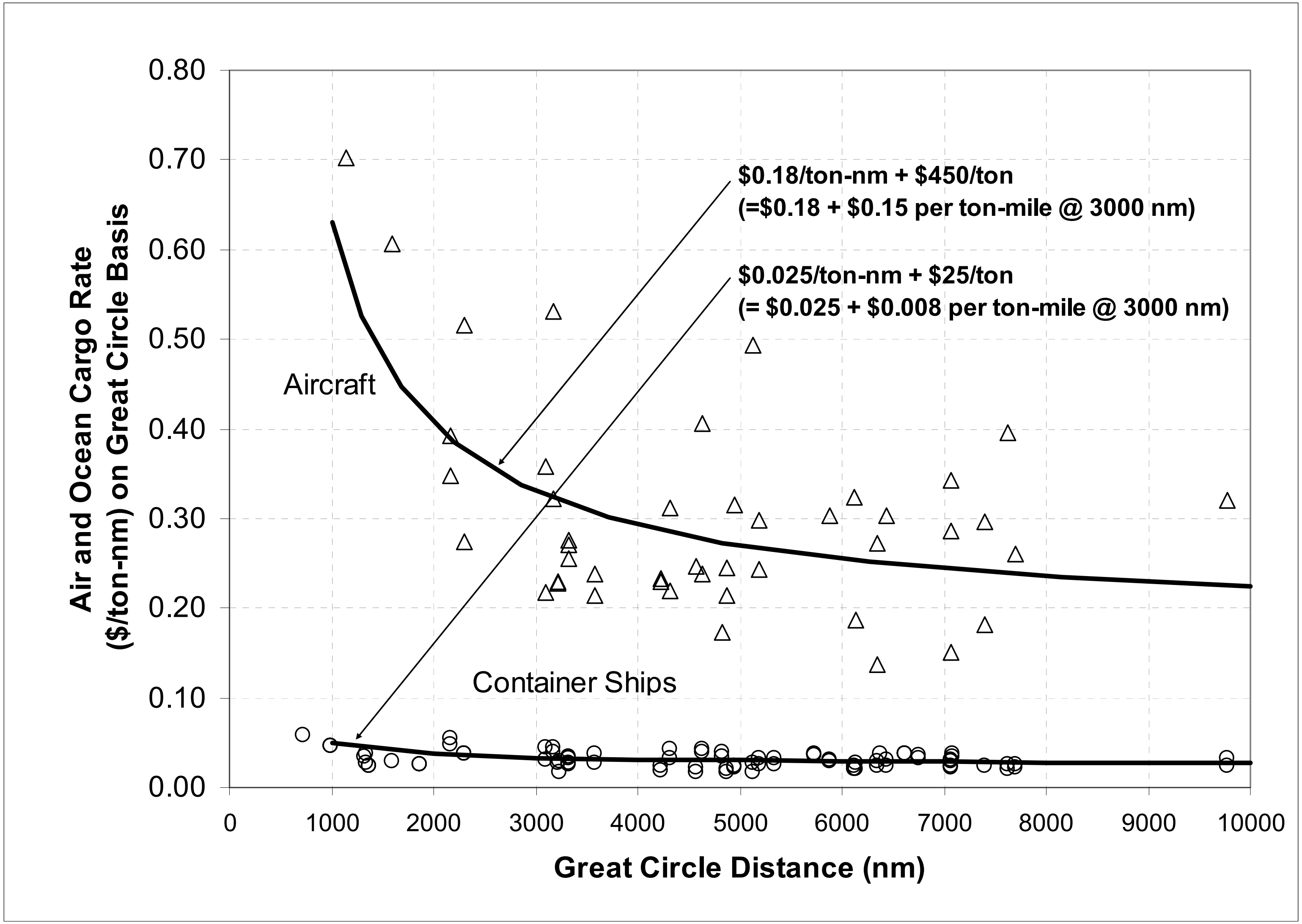
Depreciation

- Depreciation is the most powerful and variable factor in ICC
- Depreciation refers to loss of potential value over time
- Depreciation may not be linear at all
  - Seasonal variation
    - If you get the air conditioners in one month late they may be on the shelves for 10 months – very expensive
    - Lots of stuff is seasonal!
  - Spoilage
    - Food is worth less than nothing after it spoils
- Depreciation may pertain to loss of value in the larger system, not just the cargo proper
  - Airplane on ground, factory halted, troops die, etc
- Obsolescence and Hits
  - Rapid technical change can cause high depreciation
    - Michael Dell says his computers depreciate 1%/week!
  - Inability to deliver a hit product will result in a loss of sales
  - Military version of obsolescence and hits pertains to war
    - Value of time can be very, very great in wartime

Cost of Transport

- Cost of transport is split into two parts:
  - Direct operating cost
  - Indirect operating cost
- Direct operating cost pertains to vehicle operation
  - Fuel, crew, vehicle depreciation, maintenance, etc
- Indirect operating cost pertains to other costs
  - Sales, cargo handling, administration, profit, etc
- Sum of direct and indirect operating costs is “cargo rate”

2002 Cargo Rates



Comments on Cargo Rates

- Rates decline with range
  - Much of indirect operating cost is independent of range
    - Cargo handling, sales costs don't depend on range
      - So indirect cost per mile is less at greater ranges
- Ships are much less expensive than airplanes
  - Ships are very efficient: L/D ~400
  - Ships indirect costs are much less than airplane's
    - Large containers, mechanized loading
- Trend curves can be approximated by a simple formula
  - Rate = cost/ton-nm + cost/ton
    - Cost/nm can be thought of as DOC
    - Fixed cost can be thought of as IOC
- Scatter in rates due to two factors
  - Asymmetrical demand (east versus west for instance)
  - Airplane main deck pays full rate, belly cargo rides for ~IOC,

Total Distribution Cost

TDC = (cargo rate * tons * nautical miles) + (time * cargo value * ICC)

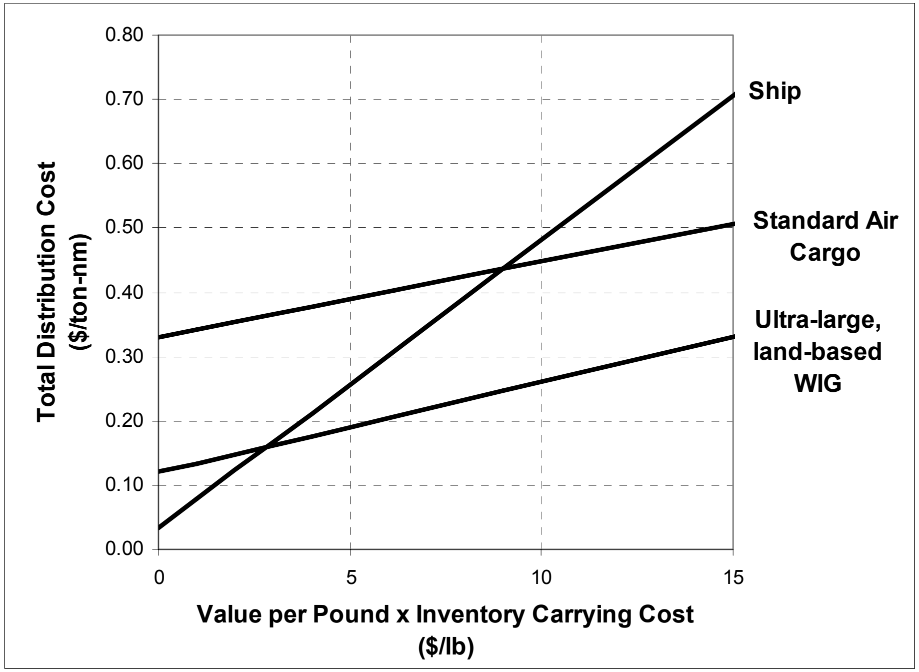
so

TDC/ton-nm = cargo rate + (1/speed * cargo value/pound * ICC * 0.2283)

Where units are $, tons, nautical miles, knots

Total Distribution Cost

- Plot shows relationship between value, ICC, TDC and speed
  - For three vehicle systems
- Y-intercept is cargo rate, slope is proportional to 1/speed
  - Note that speed is not vehicle speed alone, but entire supply chain speed. Very important!
- Line for WIG is speculative
- Fast, intermediate-cost vehicles can provide lower TDC for some types of goods



Check out this reference: B. K. Rawdon, Z. C. Hoisington, Air Vehicle Design for Mass-Market Cargo Transport, AIAA 2003-0555, 2003

Supply Chain

- The “supply chain” refers to all the steps in the transport process in which the goods are “out of service”
  - So ICC applies to all of the inventory in the supply chain
    - In transit
    - Waiting between transport modes
    - At the origin being built up
    - At the destination being broken down
    - In the store until sold
  - An alternate definition of supply chain may include all the time your money is “out of service”
    - Some companies pay for the goods before they are manufactured

Inventory

- Inventory is expensive
  - Typically 25% of value per year
- Inventory performs several functions:
  - Buffer between a relatively steady production and an intermittent transport
  - “Safety stock” to assure an acceptable level of service (acceptable likelihood of delivery)
    - A function of system schedule reliability
    - Also a function of variability and predictability of demand
  - Buffer to connect two asynchronous transport modes
  - Buffer to build inventory sufficient for efficient transport
    - Between transport modes
- There is room for improvement in reducing inventory
  - Perfect knowledge would be a good start

Inventory Drivers

- Frequency of service
  - More frequent service reduces inventory at origin and destination
  - Reduces period between asynchronous transport modes
- Reliability of service from a schedule standpoint
  - Vehicle may be late
  - Vehicle may not be available (full)
  - Reliable service permits reduced safety stock
    - Uncertain ship availability drives shippers crazy
- Variability of demand
- Predictability of demand
- Supply chain architecture

Variability

- Variability in demand influences supply chain architecture
- Variability is roughly proportional to the square root of the quantity involved.
  - Large quantities provide proportionally less variability
    - 10/100 versus 100/10,000 (10% versus 1%)
  - This favors reduced product differentiation, centralized distribution centers
    - However:
      - Customers prefer differentiated products
      - Centralized distribution centers have longer delivery distances
- Architecture must balance quantity, differentiation and distance
  - Compare warehouse store with corner hardware store
  - Compare mail-order with local store
  - Some organizations use different architecture within same system
    - High-value goods centralized, low value goods dispersed

Predictability of Demand

- Suppliers attempt to match supply to demand at optimum price
  - Some architectures force long lead times (time between order and delivery)
    - This reduces predictability since market or competition may change in the meantime
    - Note that lead times can be cumulative
      - Many products are the sum of numerous separate products, sometimes serial
- Market serves as feedback for production
  - Long lag time between production and market feedback reduces precision of control
    - Very expensive mistakes
    - Exacerbated by seasonal aspect – cannot fine-tune over the long run
- Some architectures improve responsiveness despite long supply chains
  - Restaurants: generalized, low-value inventory held until the last moment when custom product is created
  - Dell Computer: same as restaurant
  - Last minute allocation: Mass order on ships, allocated to specific regions or stores just before docking according to present demand

Vehicle Size

- In transport systems, bigger is usually more efficient
  - Ships:
    - Volume/wetted area; Reynolds number; Froude number
      - Faster and more efficient
    - More cargo per crew
  - Airplanes:
    - Volume/wetted area; Reynolds number
    - More cargo per crew
    - Structural penalty of large size (wing bending mostly) is offset by other benefits (compact fuselage)
- However, large size implies lower schedule frequency
  - Optimum system must balance transport cost reduction of larger vehicle with reduced inventory of smaller vehicle
    - Because airplanes generally carry goods with greater value or ICC, they will tend to be smaller than ships
  - As world traffic increases, vehicles tend to increase in size

Node Number

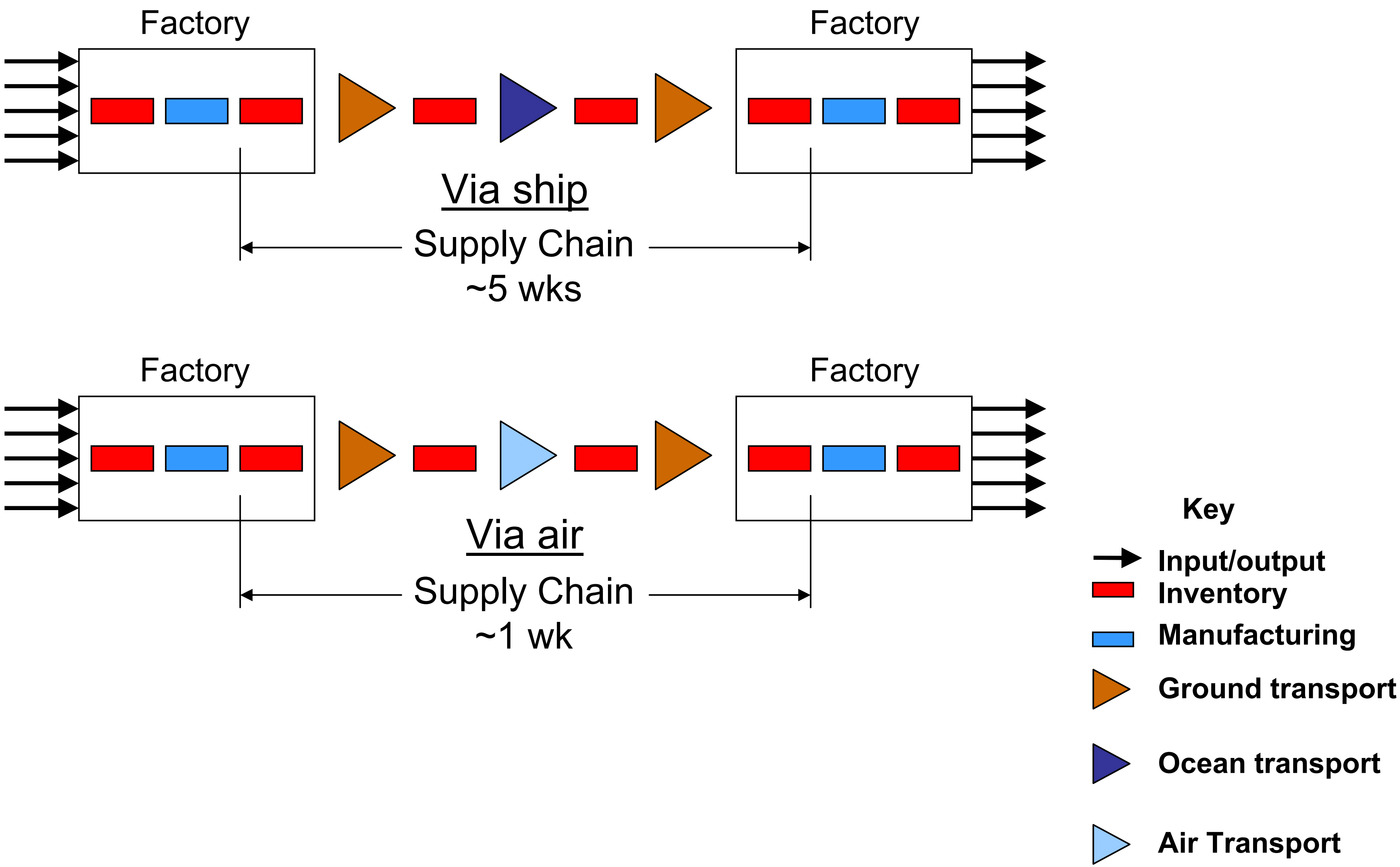
- Total Distribution Cost is influenced by the number of nodes (ports, distribution centers, stores, etc)
  - Fewer nodes result in more frequent service and/or larger vehicles
- In the case of ships, fewer ports means that the cargo must travel farther on more expensive trucks or trains
  - Number of ports must balance the value of frequent service and larger vehicles with the increased cost of surface transport
    - Casual observation indicates a tendency toward few, major ports
- In the case of airplanes, fewer airports means the cargo must travel farther in slower surface vehicles
  - Must balance value of frequency of service and vehicle size with slower delivery
  - Note that for airliners there are approximately one zillion airports worldwide
    - The number for cargo is much less because cost is more important than time
  - Route structure design can improve schedule frequency by combining loads
- In the case of distribution centers, fewer, larger centers are more efficient and require less safety stock (lower variability), but are farther from their customers
  - Cargo transport into distribution centers is typically less expensive that cargo going out
    - Packaging efficiency, variation due to quantity
- The size and/or number of nodes may increase over time as traffic increases

Supply Chain Speed

- Supply chain speed drives Total Distribution Cost (TDC)
  - More important for goods with high value per pound, high depreciation
- Supply chain speed driven by:
  - Vehicle speed
  - Supply chain architecture
  - Vehicle size
- Optimum supply chain architecture driven by:
  - Vehicle speed, size and cost
  - Value and ICC of goods
  - Distance between origin and destination

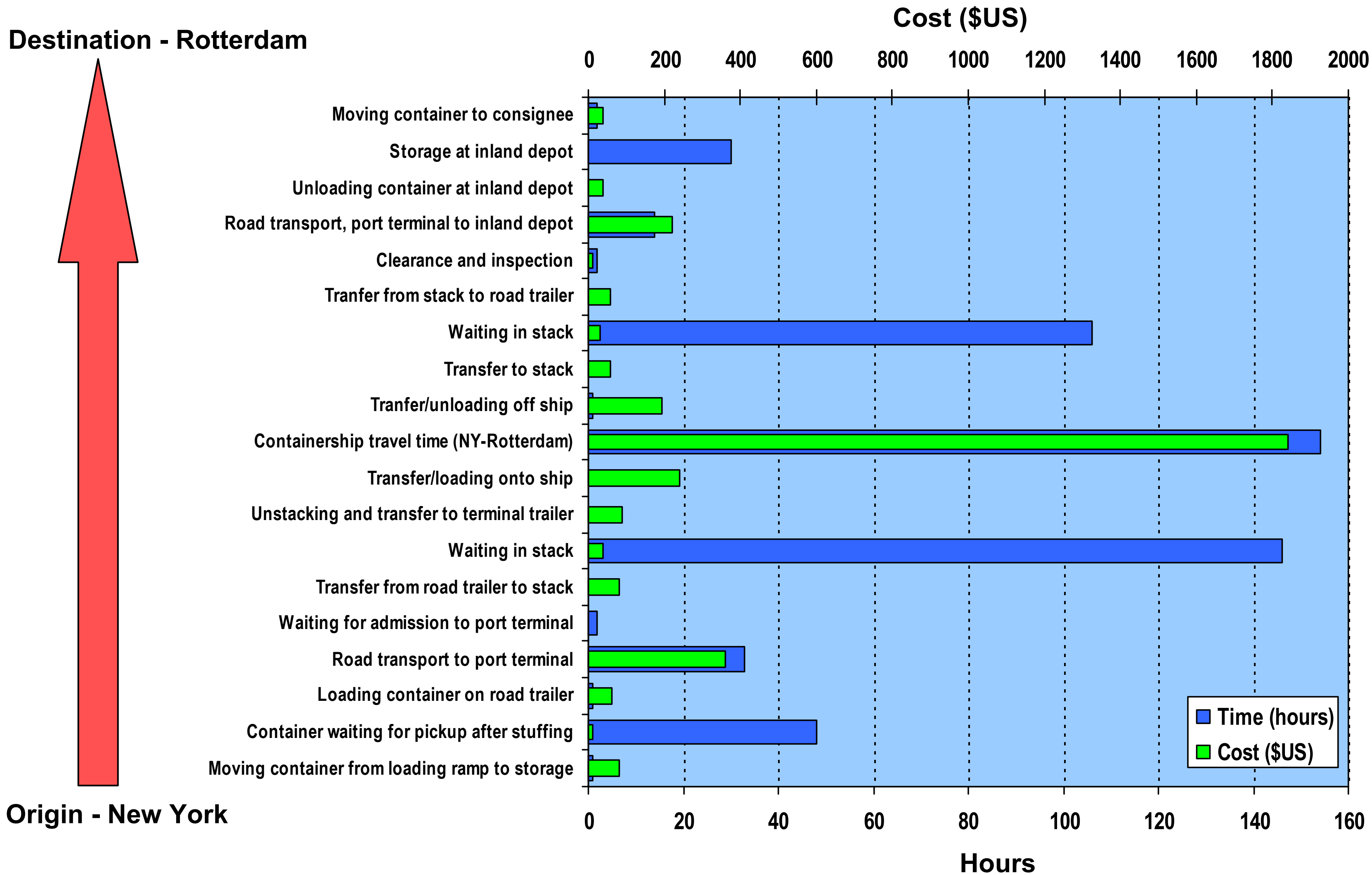
Alternative Supply Chain Architectures

Factory to Factory



Ship Time and Cost Profile

NYC to Rotterdam – a Direct, Best Case Route

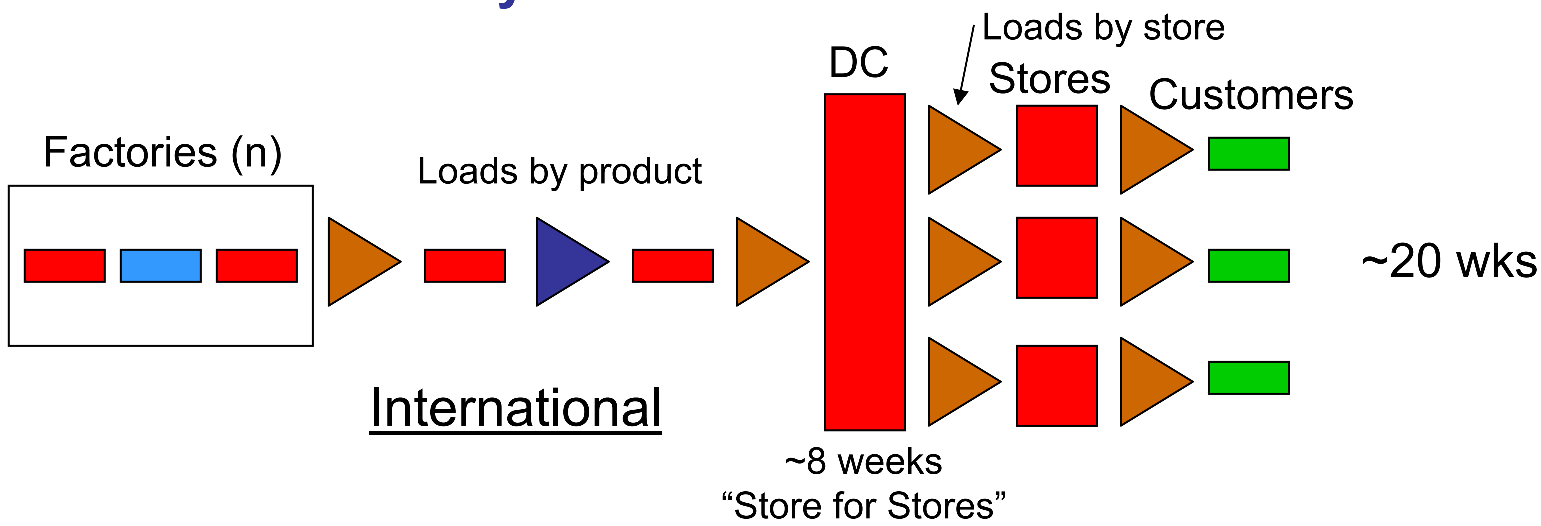


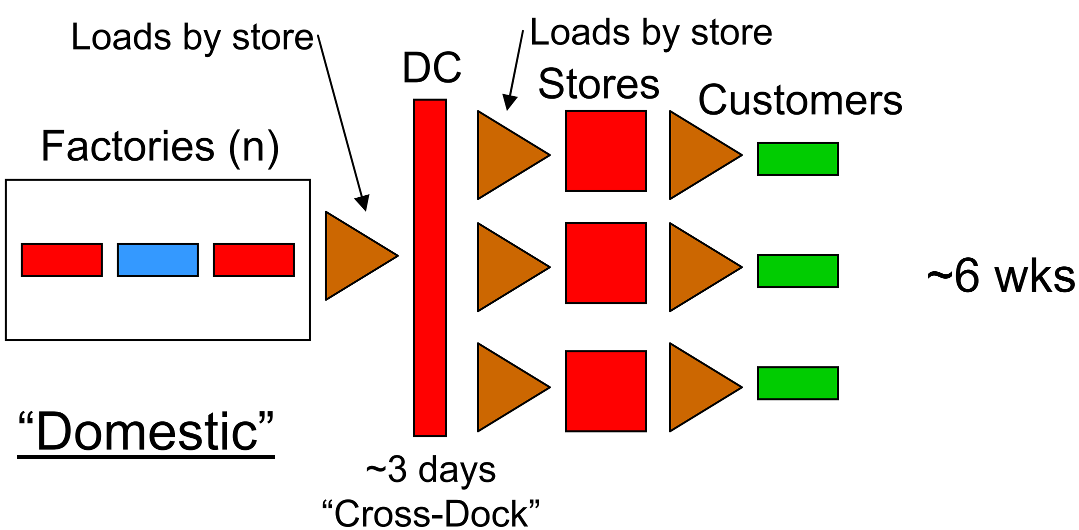
Source: Cost of Operations and Time for Shipping a 40' Container; in APEC's Congestion Points Study, Phase III, Best Practices Manual and Technical Report, Volume 2 Sea Transport, Feb. 1997, p. 105.

Move to back-up

Alternative Supply Chain Architectures

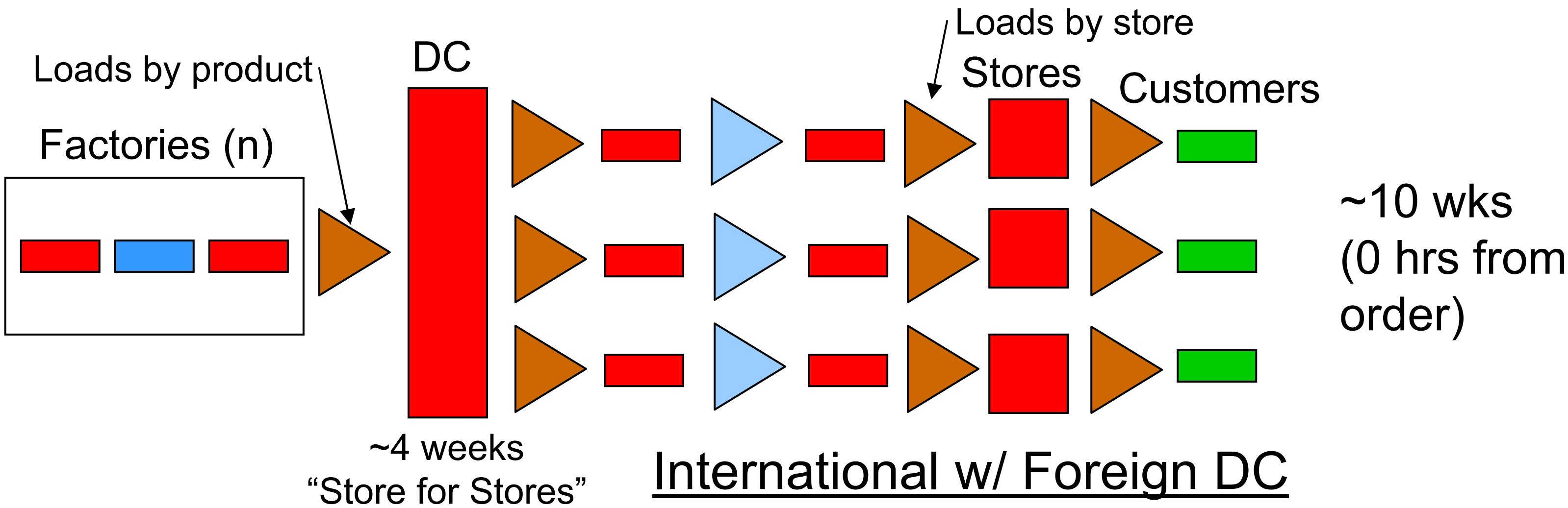
Factory to Store to Customers

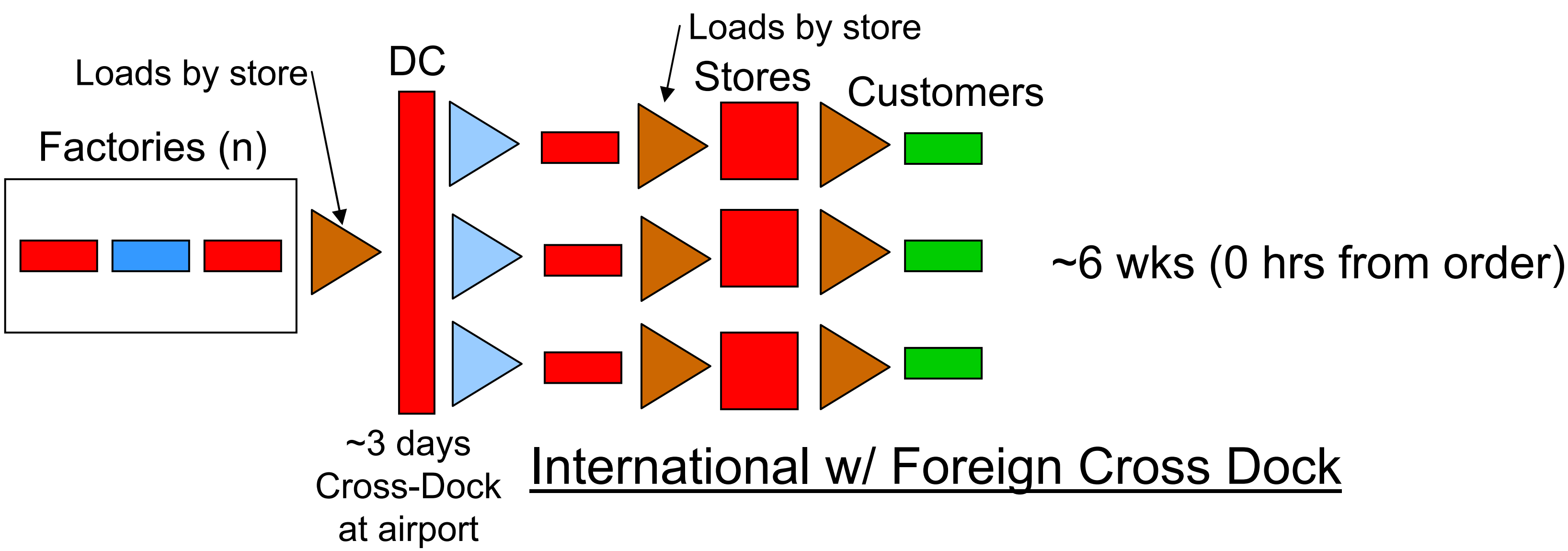




Alternative Supply Chain Architectures

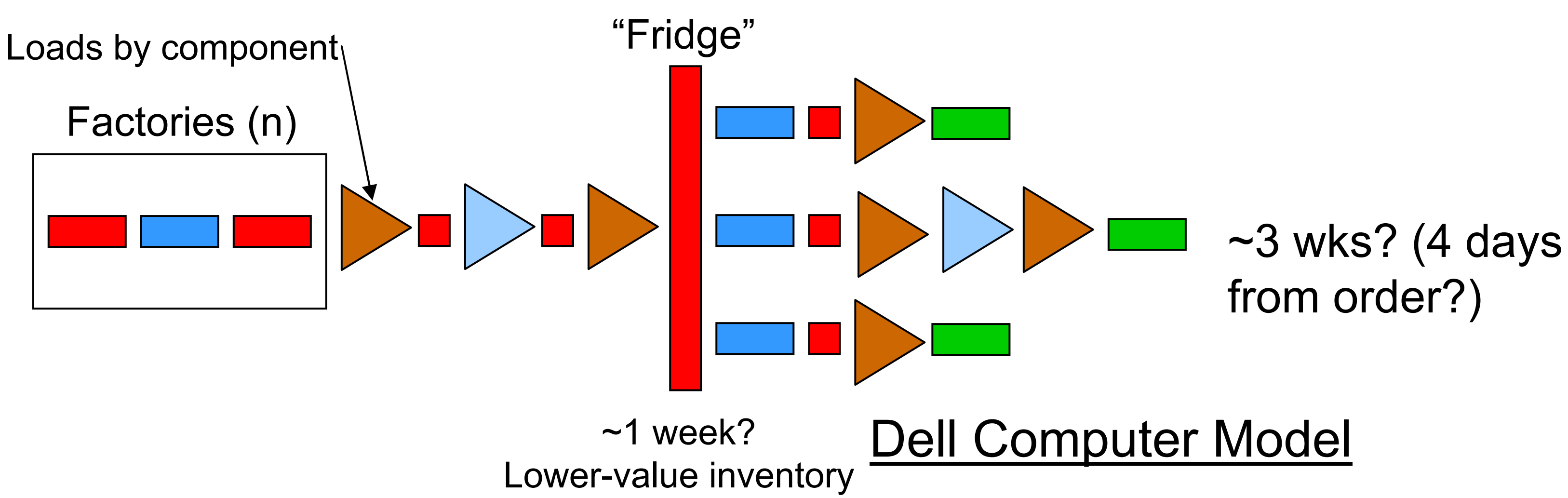
Factory to Store to Customers





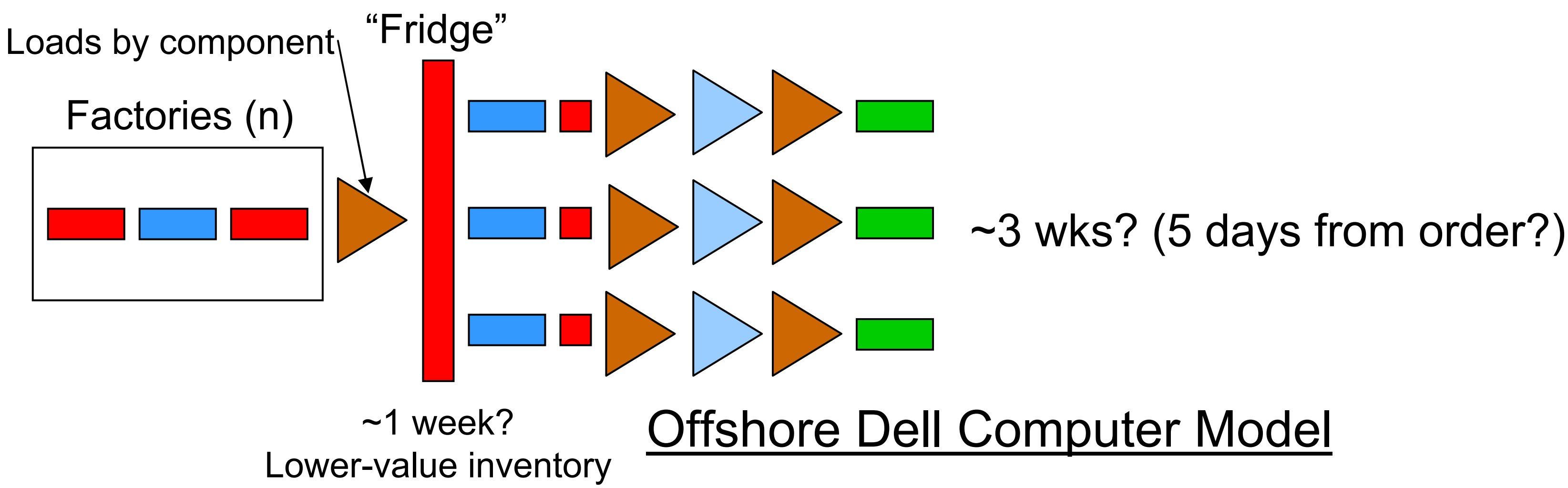
Alternative Supply Chain Architectures

Restaurant / Dell Computer Model



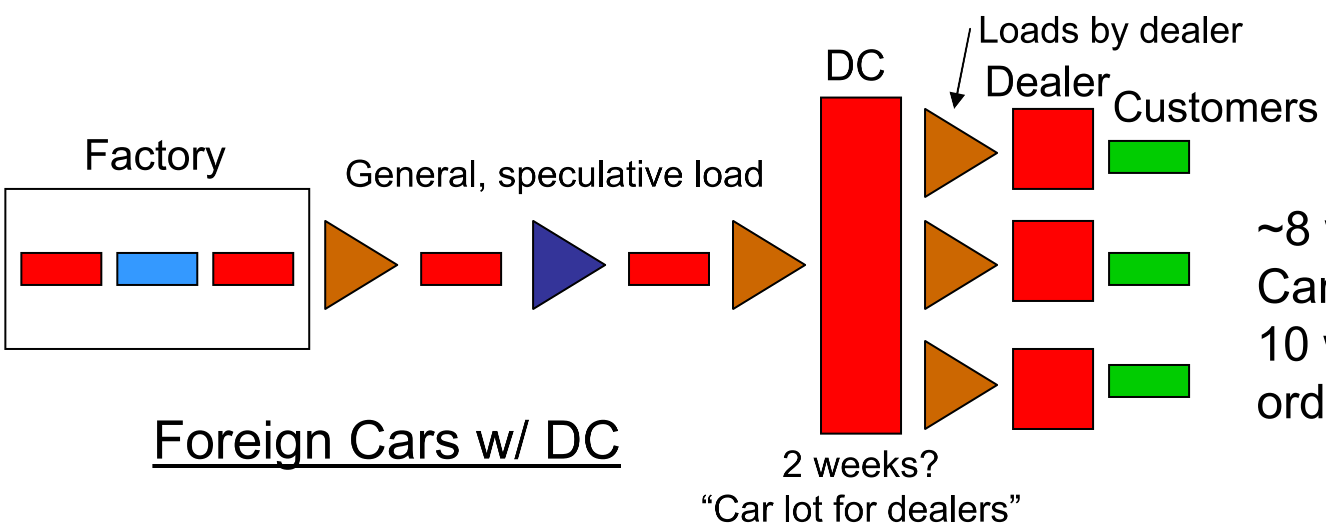
Alternative Supply Chain Architectures

Offshore Dell Computer Model



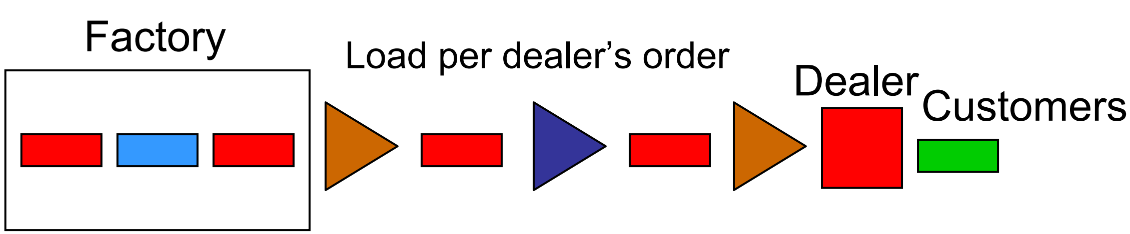
Alternative Supply Chain Architectures

Foreign Cars



~8 wks?
Can be 0, 1, or 10 weeks from order

Foreign Cars w/ DC

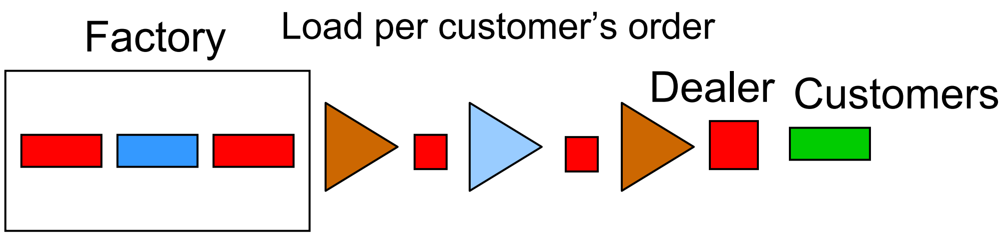


~6 wks?
Can be 0 or 8 wks from order

Foreign Cars w/o DC

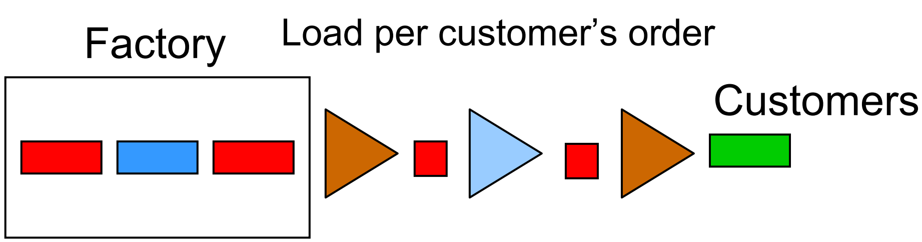
Alternative Supply Chain Architectures

Foreign Cars, Global “Mail” Order



~1 wk? (~2 wk from order?)

<u>Foreign Cars Built to Order</u>



~1 wk (~1 wk from order)

<u>Consumer Goods from Manufacturers Inventory</u>

Some Observations

- The value of speed comes from:
  - Reduced time in transit
  - The ability to reorganize architecture
- It’s not just the long trip that hurts. It’s also the slow feedback loop.
  - Between demand and supply
  - Seasonal or time-sensitive demand exacerbates this
- Fast transit can tighten the feedback loop
- Fast transit can permit customer to obtain goods from greater distance with acceptable delay
  - Global mail-order

More Observations

- It used to be that one went to a store or show to obtain information about goods
  - Information now flows for free via Internet
    - Often one can find better info on web than in store
    - This supports global mail order
- It may be that the best architecture combines more than one system
  - Slow and cheap plus fast, responsive and expensive
    - The tweeter has less throw than the bass speaker

How to Determine Cargo Mission Needs

- Examine current production/transport/customer system in a field of interest.
  - Evaluate value and ICC of goods, cost of system
- Generate alternative system architectures
  - Include production, transport and customer characteristics
    - Generate alternative transport vehicles
- Evaluate alternative system architectures
  - Primarily against total economic performance
  - Consider applications of the architecture beyond your chosen field, especially for the vehicle
  - Consider the future
  - Consider what competition can do to you
- Choose the best one
  - This defines your mission

Some Potential Systems of Interest

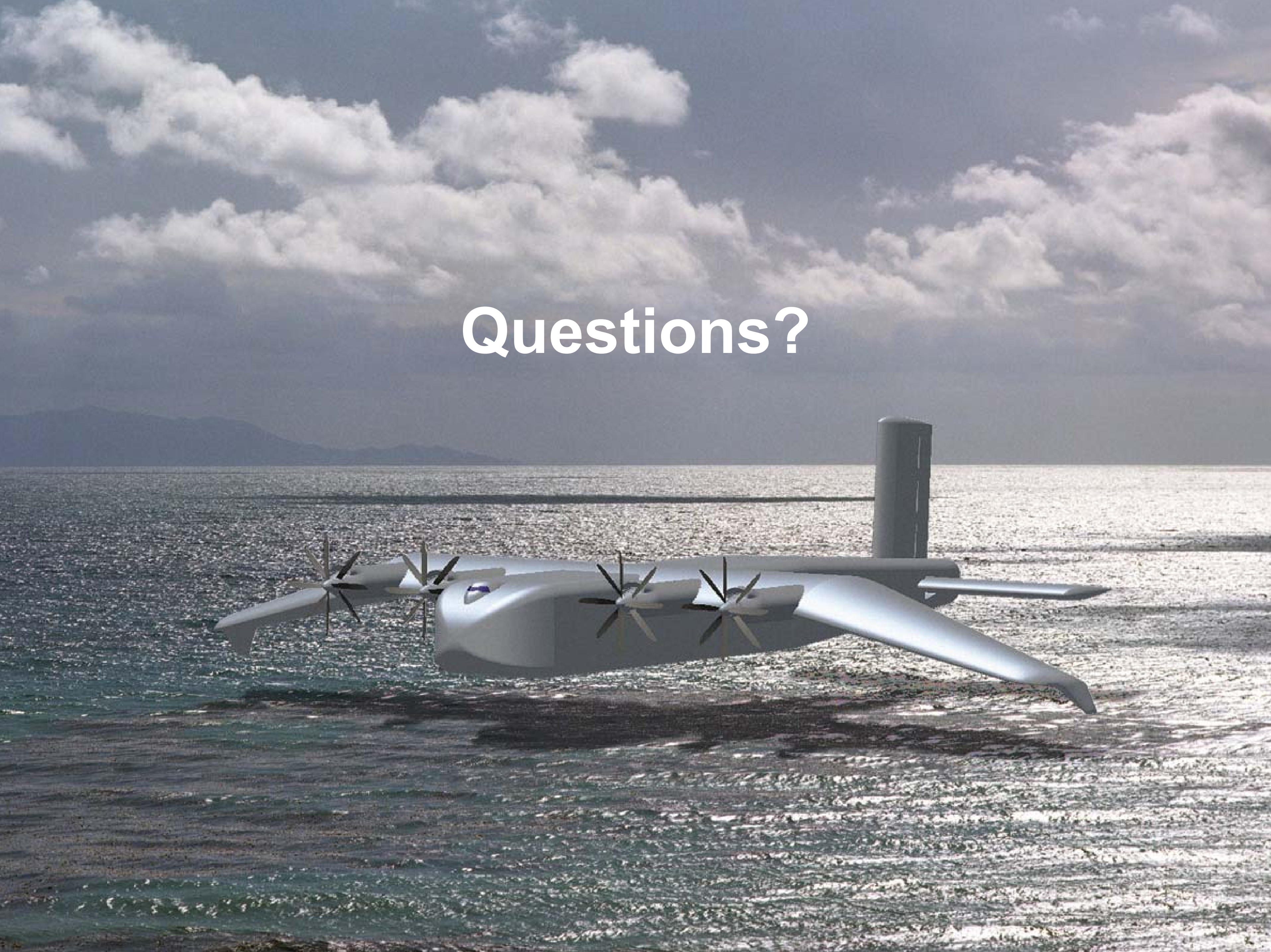
- Military deployment
  - Currently performed with transport and tanker airplanes, ships, dispersed US bases, prepositioned materiel, forward bases and ports, etc
- Transport of food
  - Elements to consider:
    - Wealthy northern hemisphere, poorer southern; offset seasons
    - Perishability, seasonality increase ICC
- Factory to factory
  - Serial buildup of lead times
- Car manufacture and delivery
  - Current system appears to have large inventories, is seasonal
  - Global manufacture may cause serial buildup of lead times
    - Design, tooling, components, assembly, delivery
    - Leads to over or under production, less advanced products

More Potential Systems of Interest

- Manufacture and delivery of consumer products
  - Currently a wide mix of system architectures
- What about housing?
  - Can you make houses in China and put them up in Kansas?
- What about health services?
  - Can you have a roving specialist (or general) hospital?
    - Example is Orbis, an eyesight hospital in a DC-10

Cargo Airplanes

- I suspect that your analysis will show that cargo airplanes have a substantially different mission than passenger airplanes
- In the past, commercial cargo airplanes were derived from airliners to save development cost
  - It may be now that the cargo market can support a purpose-built cargo airplane
- Your analysis may show that a low cargo rate is more important than speed
  - This requires an emphasis on low DOC and IOC
  - Note that speed is good for productivity and therefore DOC
- What airplane type provides the lowest cargo rate?


Questions?