

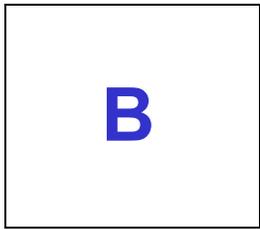
1.221J/11.527J/ESD.201J *Transportation Systems*

Fall 2004

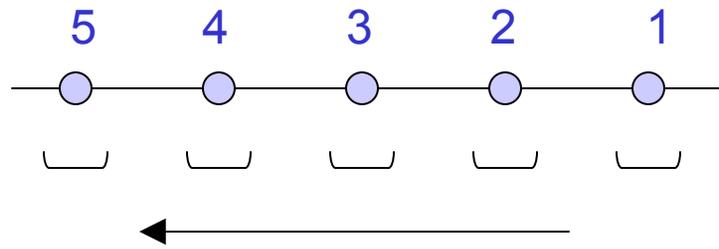
LECTURE 7 (and forward): FREIGHT

DISPLAYS

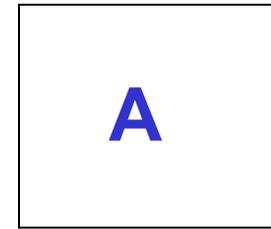
SPEAKER: Joseph M. Sussman
MIT



Another
Production
Process



40 containers/day

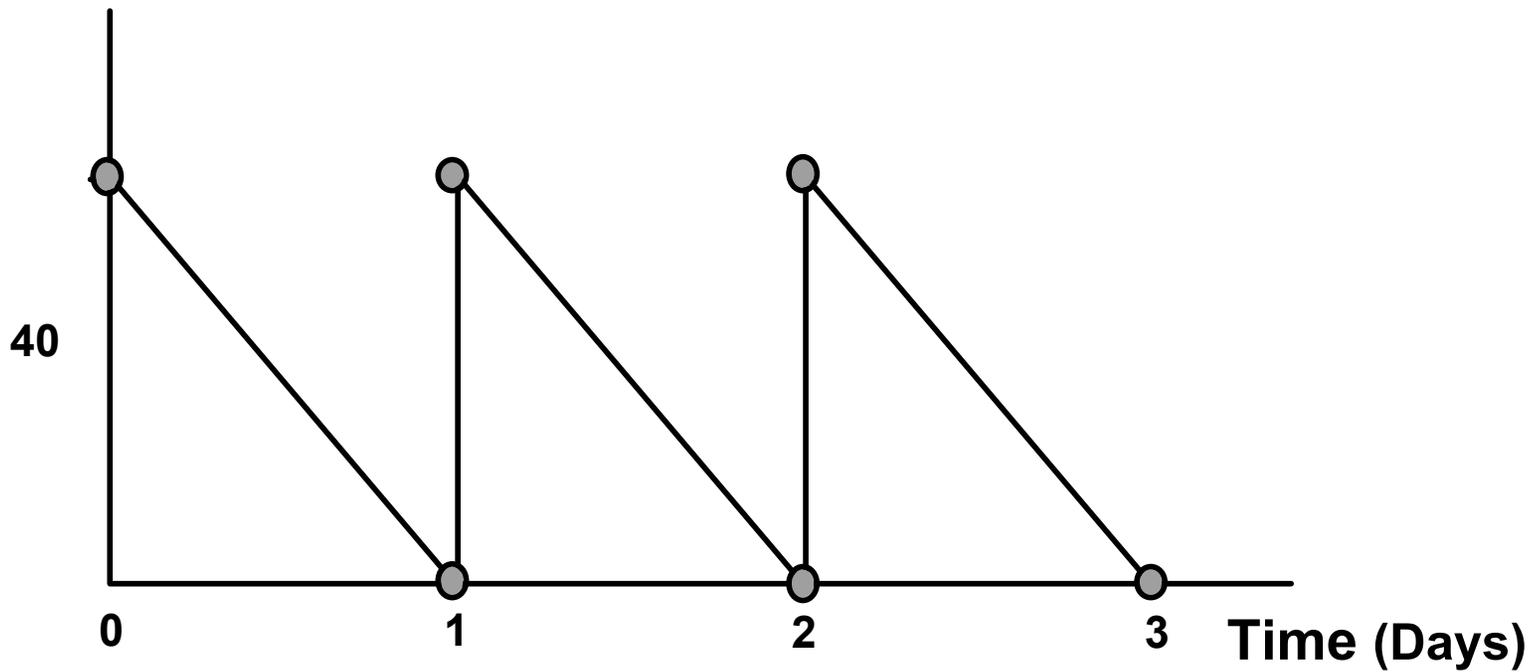


Assembly
Plant

INVENTORY AT B

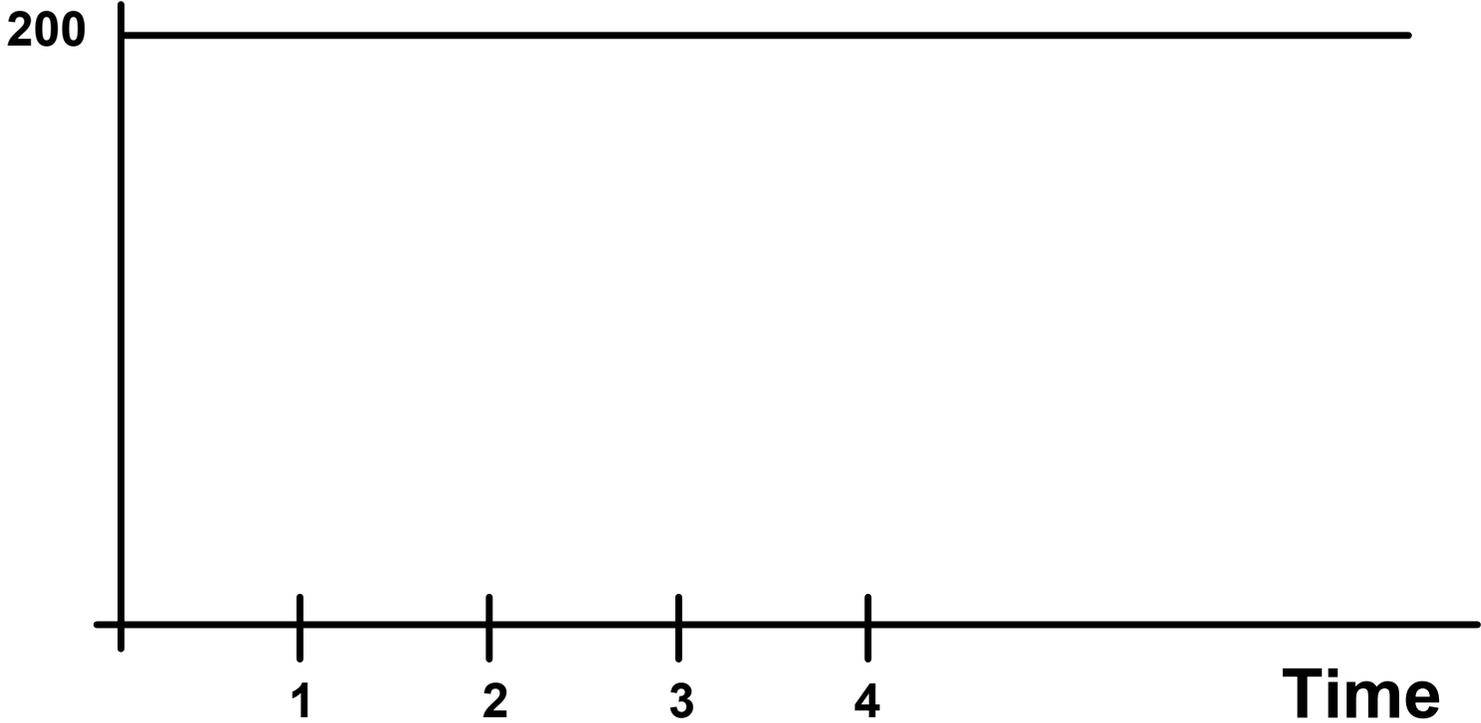
40 Containers/day are “consumed” at B

Inventory at B



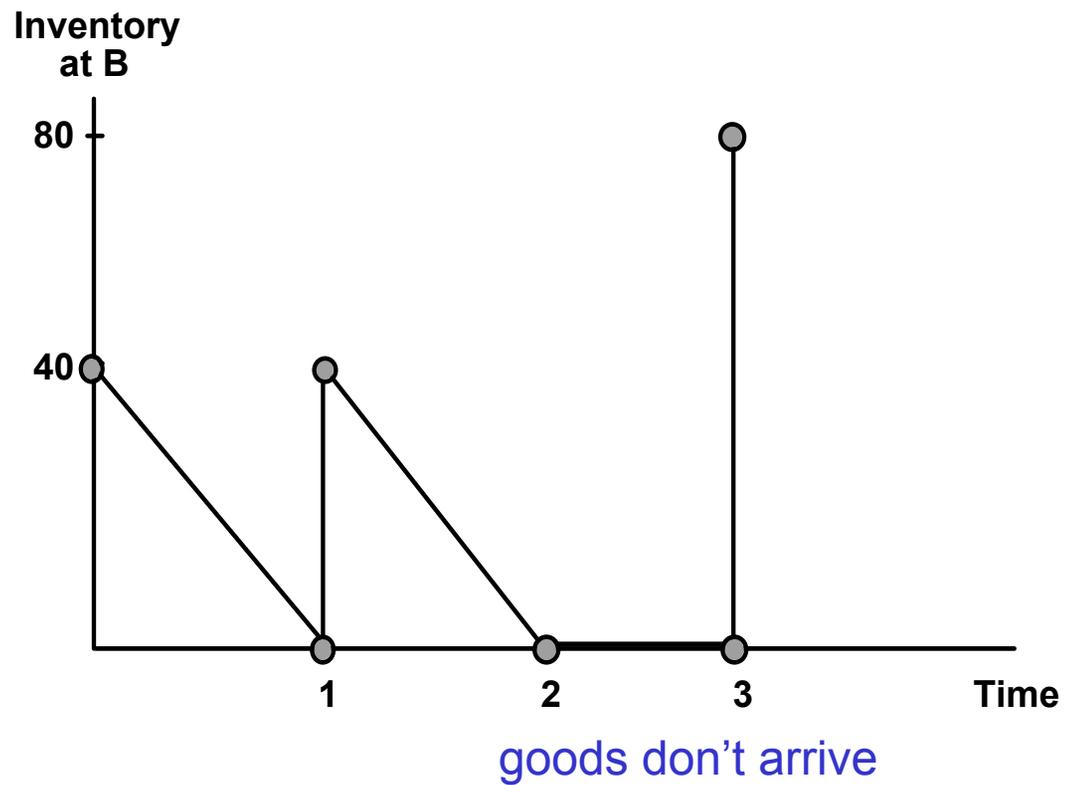
PIPELINE INVENTORY

Inventory



WHAT CAN GO WRONG?

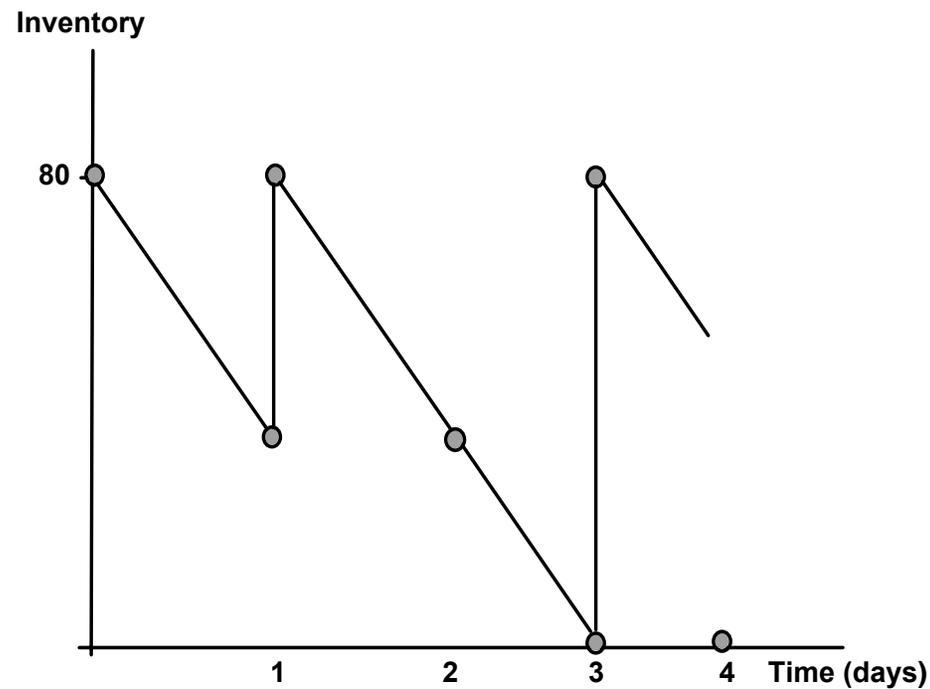
Delays along the way -- service reliability



ISSUE: Stock-outs

WHAT CAN GO WRONG? (CONTINUED)

So, perhaps the customer at B keeps a day's worth of inventory

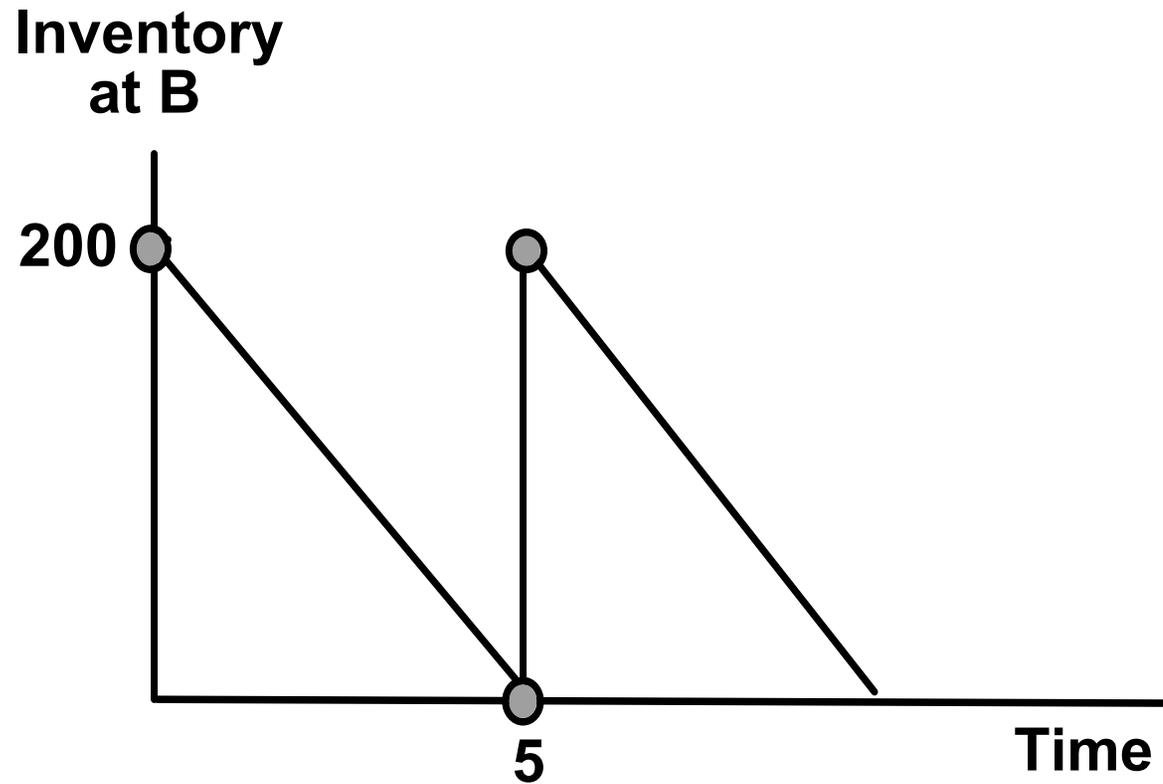


Problems: Bigger Inventory
Warehousing Costs
Insurance Costs

A BIG ISSUE -- STOCK-OUTS

- ◆ WHAT DOES A STOCK-OUT COST?
 - ◆ Examples
 - ◆ GM Assembly Plant
 - ◆ Retail Store
 - ◆ Blood Bank

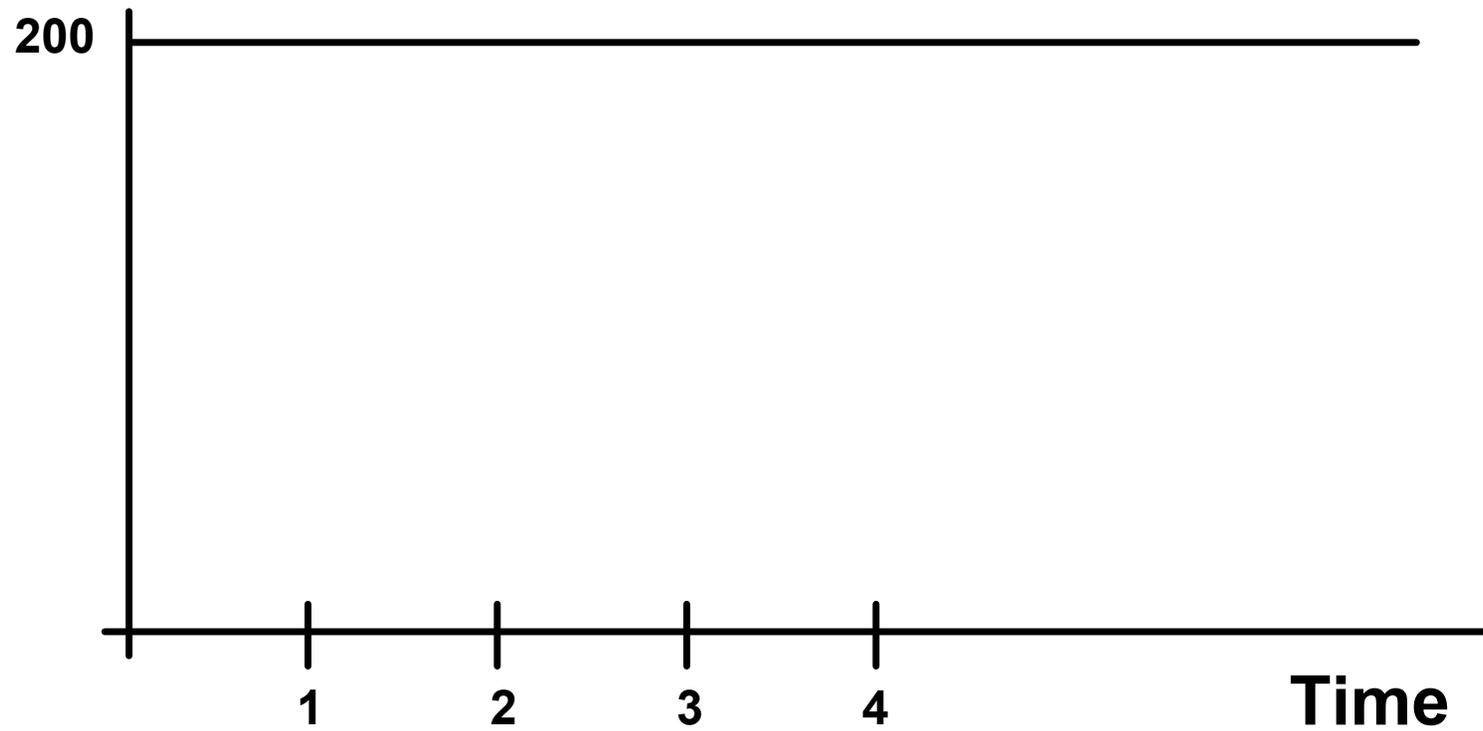
Another approach: Order less often -- only every 5th day



Average Inventory at B = 100, rather than 20

PIPELINE INVENTORY

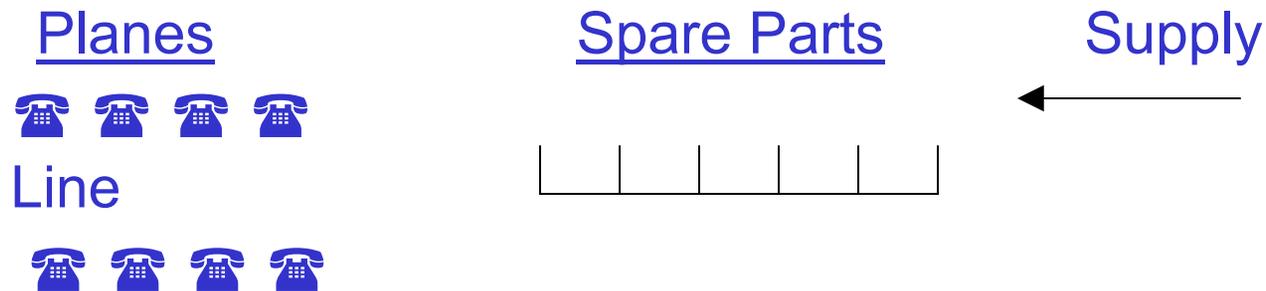
Inventory



LEVEL-OF-SERVICE VARIABLES

- ◆ Travel Time -- Because of Pipeline
- ◆ Reliability -- Because of stock-outs

AIR FORCE SUSTAINMENT SYSTEM



- ◆ Planes fly missions
- ◆ Parts fail
- ◆ If spares not available, plane cannot fly

Let's discuss from an inventory viewpoint?

- ◆ Why not keep a lot of spare parts around?
- ◆ What is the inventory we really care about?
- ◆ How do you value a stock-out?

SOME OTHER ISSUES

- ◆ Probabilistic use rate of spare parts
- ◆ Size of orders
- ◆ Dual use of parts for different airplanes
- ◆ Wartime - Peacetime

INVENTORY MINIMIZATION

- ◆ If one needs a greater amount of inventory because of unreliability in the transportation system *or* probabilistic use rate, you generate costs as a result of needing larger inventory to avoid stock-outs.
- ◆ We try to balance the costs of additional inventory with the costs of stock-outs.

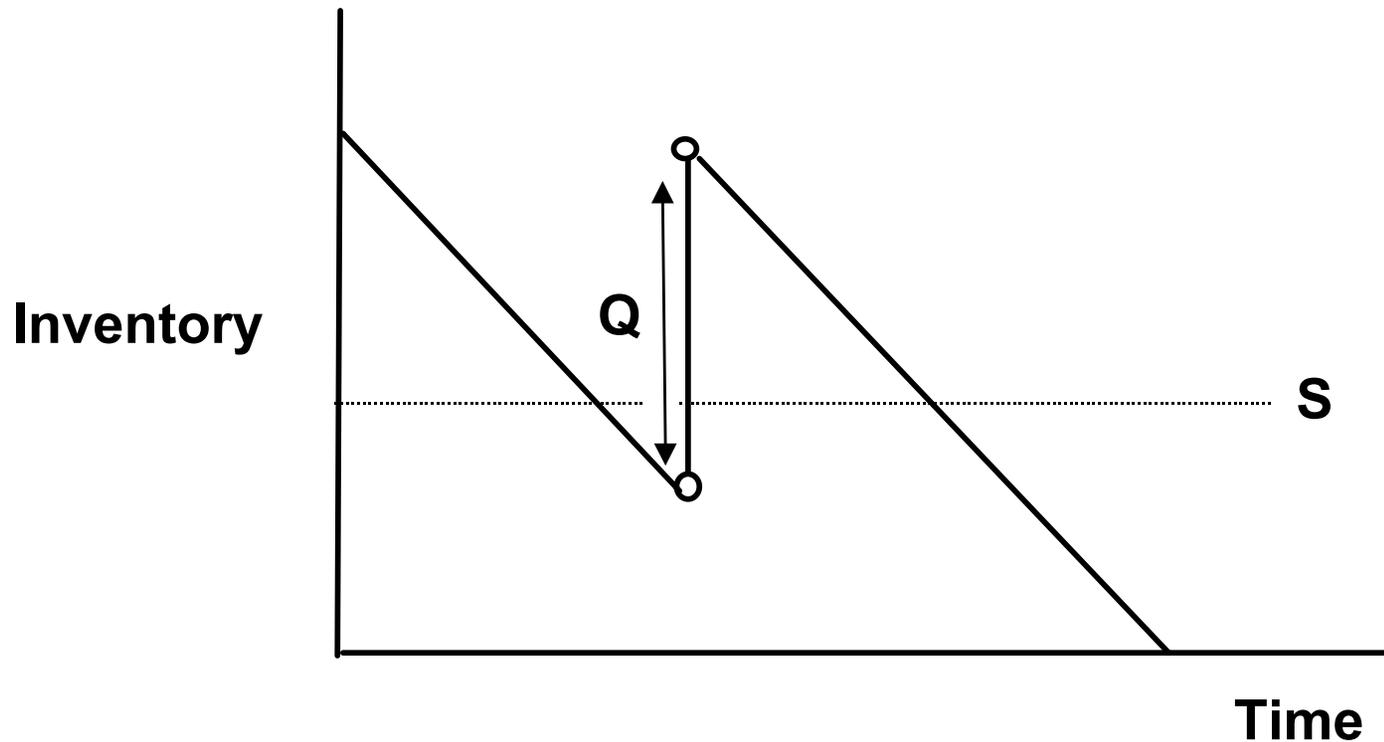
JUST-IN-TIME SYSTEMS

- ◆ The fundamental idea is to keep very low inventories, so as to not generate high inventory costs, by receiving goods “exactly” when they are needed -- JIT -- to keep the assembly process going, or to have goods to sell to your customers, etc.
- ◆ Now if one is going to operate just-in-time systems and keep costs lower by having smaller inventories (and smaller rather than larger warehouses), *it requires a very reliable transportation mode.*

SHIFTING THE COSTS OF INVENTORY

- ◆ Suppose you have Toyota receiving goods from a supplier on a JIT basis. Imagine that Toyota is this supplier's best customer.
- ◆ So from the supplier's main warehouse, he ships goods to Toyota several times per day because Toyota insists on just-in-time delivery.
- ◆ But, the supplier keeps some additional inventory in a warehouse close to Toyota in which he is carrying safety stock "*just-in-case*".

TRIGGER POINT INVENTORY SYSTEM



The operating rule is: *When the inventory reaches 'S', reorder 'Q' items, where 'Q' is the reorder quantity.*

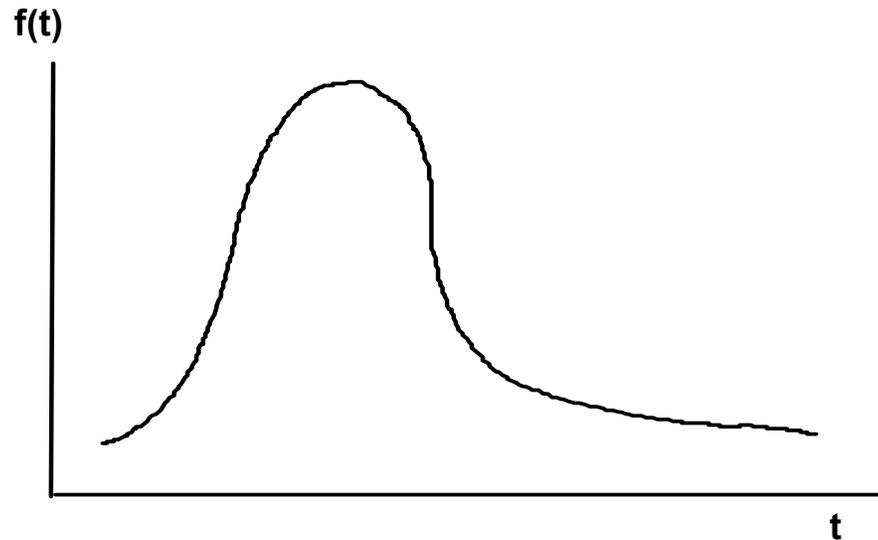
Figure 12.13

TOTAL LOGISTICS COSTS (TLC)

Total Logistics Costs (TLC) =

f (travel time distribution, inventory costs, stock-out costs, ordering costs, value of commodity, transportation rate, etc.)

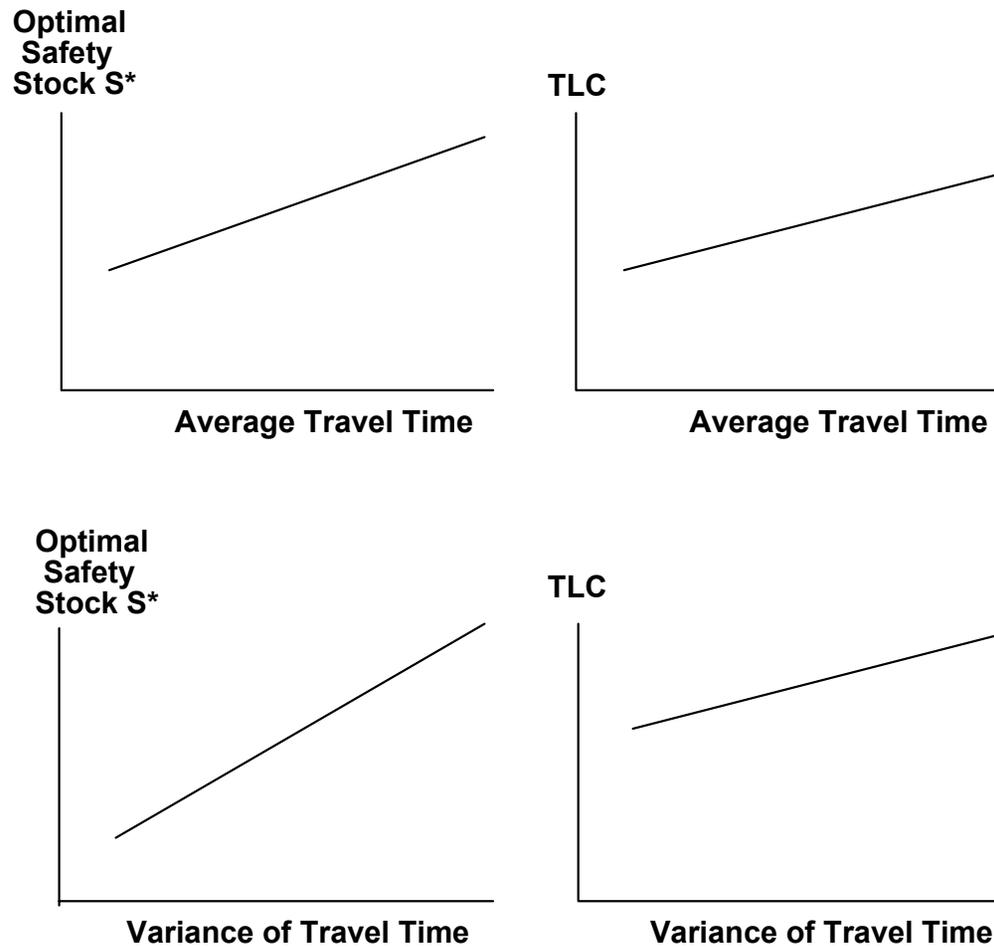
TRAVEL TIME DISTRIBUTION FROM SHIPPER TO RECEIVER



- ◆ This probability density function defines how reliable a particular mode is.
- ◆ TLC is a function of the travel time distribution.
- ◆ As the average travel time and variance grows, larger inventories are needed.

Figure 12.14

TLC AND TRANSPORTATION LOS



Note that the above relationships are conceptual; they may not, in fact, be linear.

Figure 12.15

TLC AND LOS OF TRANSPORTATION SERVICE

- ◆ Why, as transportation people, are we interested in this analysis?
- ◆ It is because from these concepts *you can get a sense of what particular transportation services are worth to your customer*. You can *price* your different transportation services, if you have an estimate of what it is worth to your customer.

MARKET SEGMENTATION (1)

- ◆ The recognition that a business has different kinds of customers who want various levels of service and want to pay a price commensurate with service quality.
- ◆ The transportation carrier is not providing service only to you, the umbrella retailer, but to the Toyota assembly plant and to a coal-burning power plant as well.
- ◆ The transportation company provides different services to all these businesses using the same infrastructure.
- ◆ Some of those services are of very high quality. High rates are charged for them; the transit time is fast; the variance of those transit times are low.
- ◆ The costs to the transportation company of providing this high-quality service is usually high.

MARKET SEGMENTATION (2)

- ◆ Some customers more concerned with price of service than quality of service
- ◆ On the other hand, there is a set of services that are of poorer quality. Low rates are charged for them.
- ◆ The transit times tend to be long, and the variances tend to be high; but they are of lower cost for the transportation company to provide.
- ◆ There are customers that prefer the high-quality, high-price service, and those that prefer low-quality, low-price service.

ALLOCATING SCARCE CAPACITY

- ◆ Transportation companies need to allocate capacity (e.g., train capacity) among various customers with very different service requirements.
- ◆ Capacity is allocated among customers who require their high-quality service, for which they are willing to pay top dollar, and low-quality service for customers who do not want to pay so much.
- ◆ From a carrier viewpoint, the idea is to make a profit in each service class.

OTHER LOS VARIABLES

- ◆ Loss and Damage
- ◆ Rate Structure
- ◆ Service Frequency
- ◆ Service Availability
- ◆ Equipment Availability and Suitability
- ◆ Shipment Size
- ◆ Information
- ◆ Flexibility

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Fall 2004

LECTURE 9: RAIL FREIGHT TRANSPORTATION

DISPLAYS

SPEAKER: Joseph M. Sussman
MIT

OBSERVATIONS: US AND OTHER COUNTRIES

- ◆ Technology
- ◆ Operations

SOME OBSERVATIONS

- ◆ Rail is big in the US: 30% of freight ton-miles are by rail
- ◆ Week of August 21, 2004: 339,749 car loadings
 - ◆ Coal: 136,151
 - ◆ Agricultural products: 37,765
 - ◆ Metallic ores and minerals: 33,489
 - ◆ Motor vehicles and equipment: 23,621
- ◆ Up 1% from comparable week last year

IN ADDITION...

- ◆ Intermodal (week of 8/21/04)
 - ◆ Trailers: 56,357
 - ◆ Containers: 160,792
 - ◆ Total: 217,149
- ◆ Up 9.5% from comparable week last year

OTHER COUNTRIES

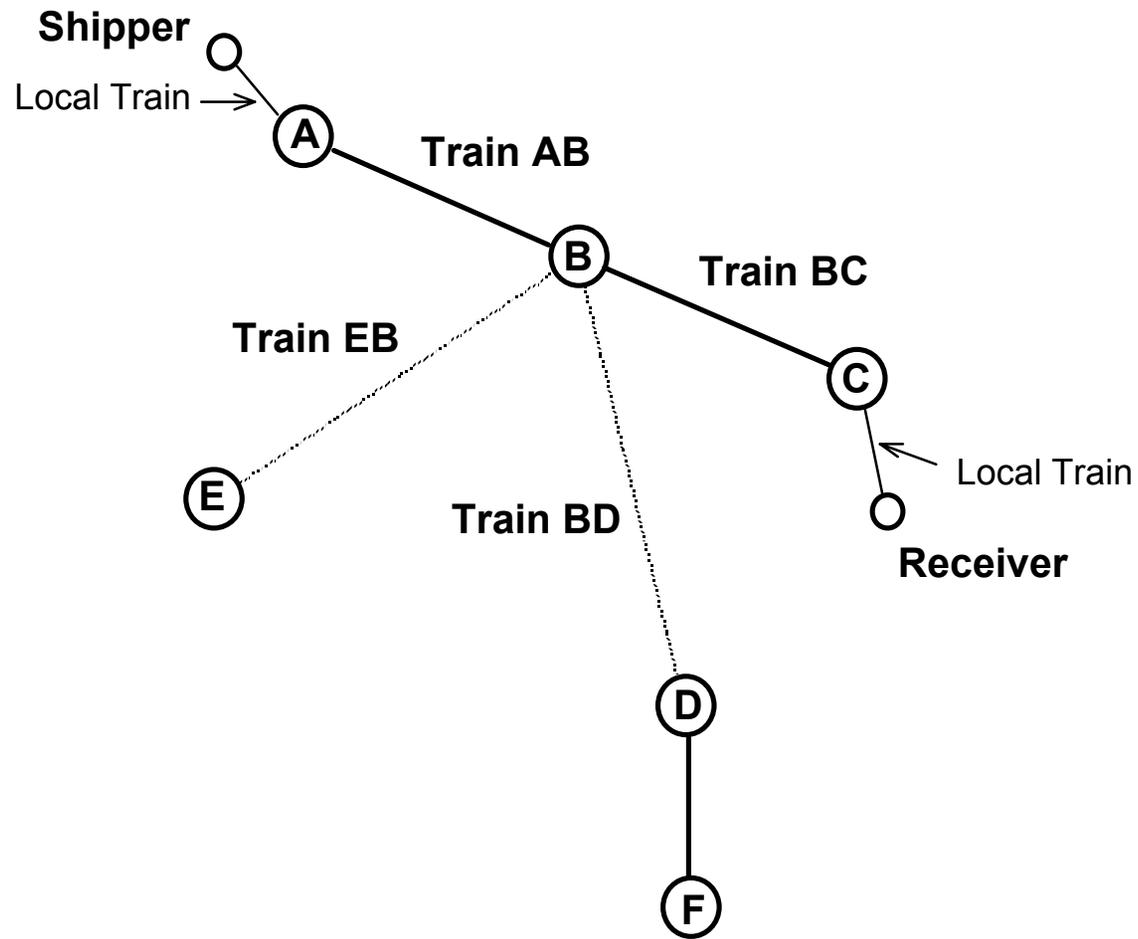
- ◆ Rail freight much less important; trucks dominate
 - ◆ Europe
 - ◆ Japan
 - ◆ Latin America

- ◆ Some exceptions
 - ◆ Canada (like US)
 - ◆ South Africa (“heavy haul”)
 - ◆ Australia (“heavy haul”)

TECHNOLOGY

- ◆ Steel wheel/steel rails
- ◆ Diesel-powered locomotives
- ◆ A wide variety of freight car types
 - ◆ General purpose (e.g., box cars)...
 - ◆ Special purpose (e.g., auto rack cars)
- ◆ High fixed cost/low variable cost industry. Must build a lot of special purpose infrastructure

Path from Shipper to Receiver



Blocking Patterns

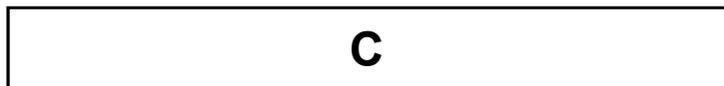
Train AB



Train EB



Train BC



Train BD



D and F randomly ordered

or



D and F traffic is blocked

Consolidation

- ◆ A Key Concept: Consolidation
- ◆ The railroad system is a high fixed cost system.

Take traffic from E and A destined for C and block it into a single set of cars that will go together from B to C at presumably lower cost than in the case of A-C and E-C traffic going separately.

Train Operating Costs vs. Train Length

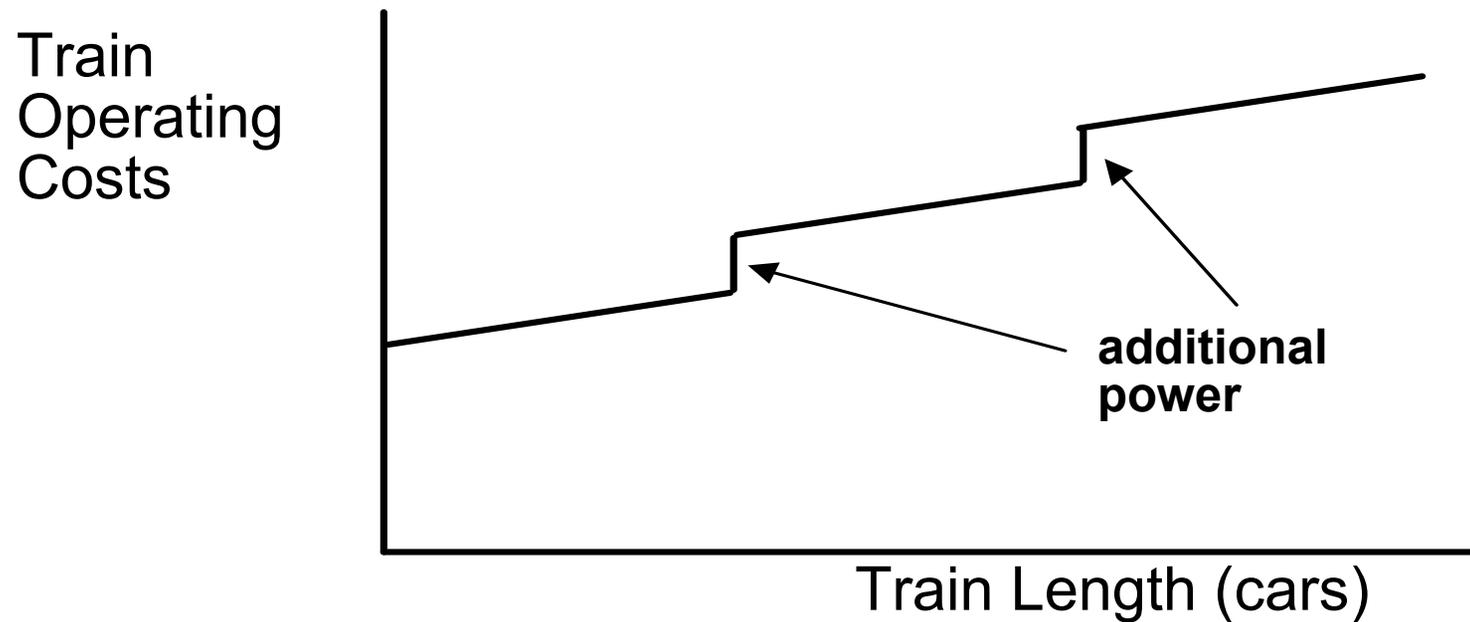
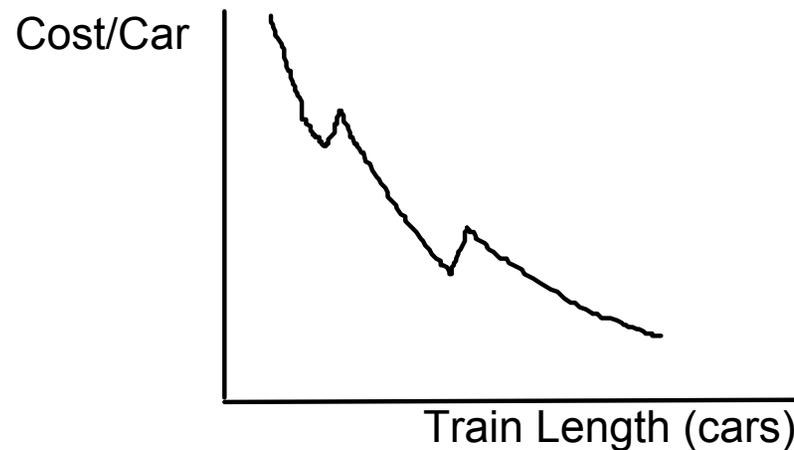


Figure 14.3

- ◆ The operating policy to generate cost savings through consolidation implies stiff penalties when things go wrong. The reason that we run only one train a day from B to C is to achieve long train lengths.
- ◆ Often we operate with 24-hour service headways; if the cars from E to B destined for this outbound train going to C misses that connection for whatever reason, this can cause a 24-hour delay until the next train.
- ◆ Think about the impact of these delays on the total logistics costs of the affected receivers. Perhaps a stock-out for our customer results.

Cost/Car and Train Length



- ◆ The cost per car on a long train is clearly going to be much lower than the cost per car on a short train. So there is an incentive to run longer trains from a cost view; that is what drives the idea of low train frequency.
- ◆ If we run two trains a day between B and C with 50 cars on each rather than 1 train with 100 cars, there is a higher level-of-service associated with a higher train frequency; however, from a cost point of view it is more expensive to run two 50-car trains rather than one 100-car train.

Figure 14.4

Operations vs. Marketing Perspectives

- ◆ Now this simple idea relates to “tension” between the operating and the marketing people. Who is going to want to run the 100-car train? The operating person or the marketing person? And who is going to want to run the two 50-car trains?

CLASS DISCUSSION

Train Dispatching

Dispatching Choices

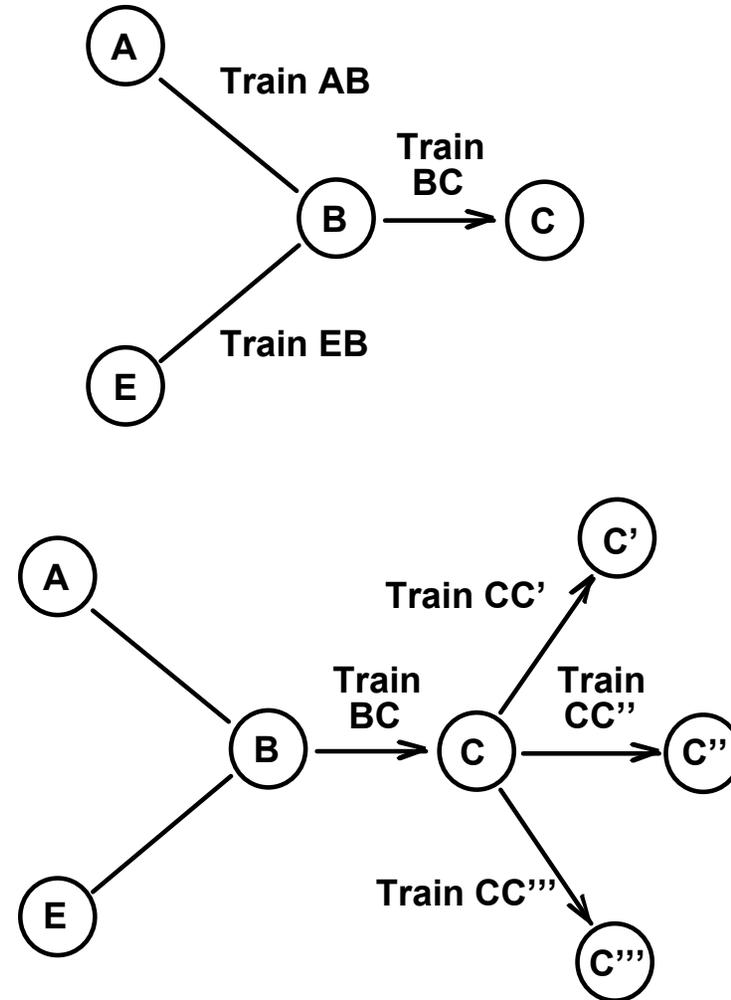


Figure 14.5

A Choice in Dispatching

Do We “Hold for Traffic”?

- ◆ Delay Propagation on Networks
- ◆ Network Stability

Stable vs. Unstable Equilibrium

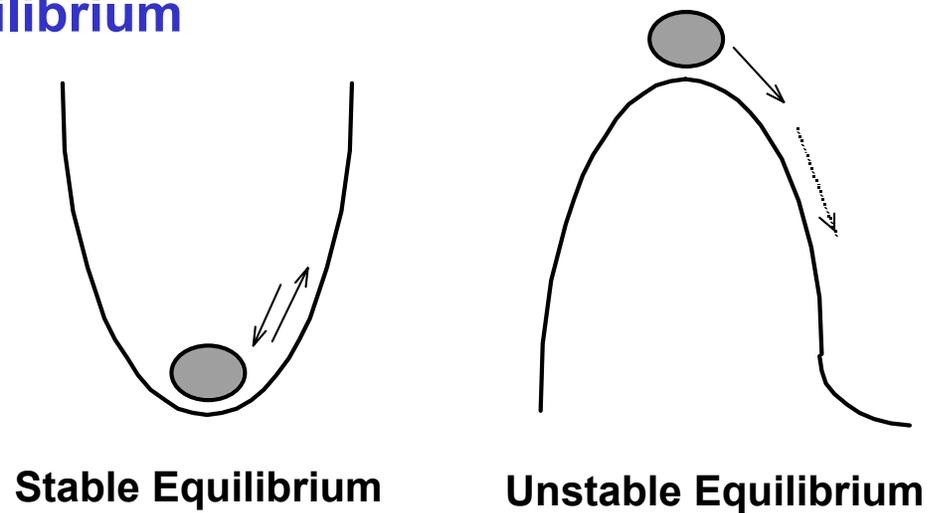


Figure 14.6

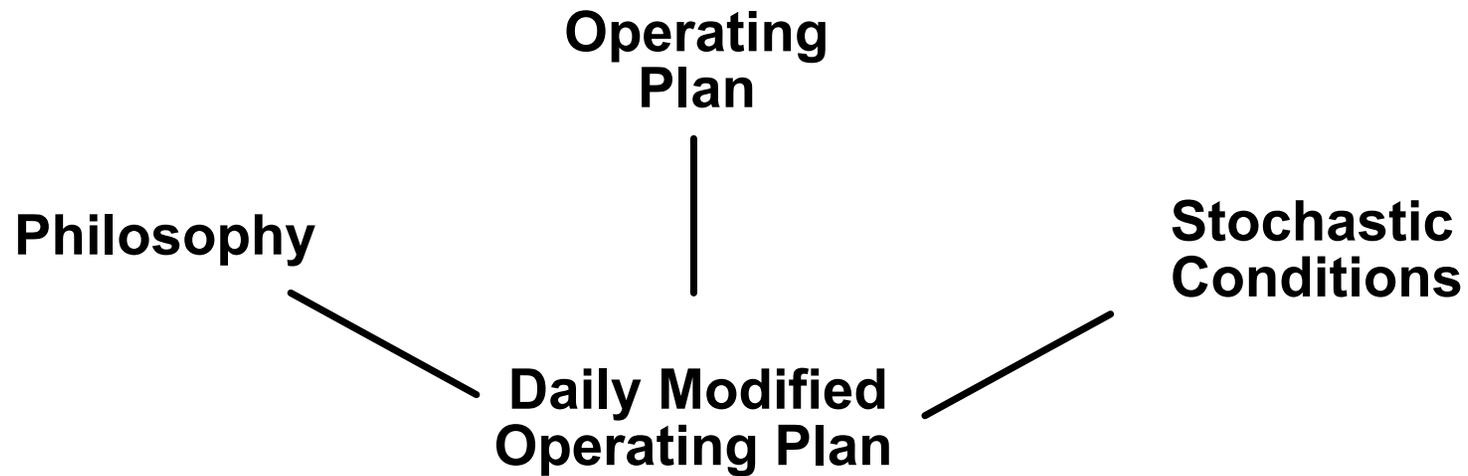
Operating Plan Integrity

- ◆ Why don't the railroads just run the trains on schedule as an optimal strategy?
- ◆ The basic notion is design an operating plan that is feasible and makes sense. You have enough power; you have enough line capacity; you have enough terminal capacity to make this plan actually work.
- ◆ You run the trains according to plan, that is, according to schedule.

“Scheduled” vs. “Flexible” Operation

- ◆ Is the best strategy “running to plan” in a disciplined manner?
- ◆ Some railroads feel that is an inflexible, uneconomic way of running the system.
- ◆ These railroads feel that flexibility for the terminal managers is useful and they can do a better job of balancing service and costs than they can by inflexibly “running to plan”.

A Framework for Transportation Operations



“Daily Modified Operating Plan”

- ◆ Suppose we have developed, through optimization methods, an “operating plan” which governs the network.
- ◆ Suppose each day at 6 a.m., railroad management takes that operating plan and from it produces a *daily modified operating plan* which governs the way the railroad will operate *on that particular day*.
- ◆ The operating plan is a base case; the *daily modified operating plan* is a plan of action for a particular day.
- ◆ The daily modified operating plan takes account of stochastic conditions on the network like weather and traffic conditions.
- ◆ It also reflects how much a railroad is willing to change that base operating plan to accommodate conditions on a particular day.

How to Define Scheduled vs. Flexible Railroads?

- ◆ The first way: A scheduled railroad would be one in which *the operating plan and the daily modified operating plan were exactly the same.*
- ◆ The second way: A *scheduled* railroad is one in which there is no difference between the daily modified operating plan decided upon at 6 a.m. and what they *actually do that day.*

LOS and Routing over the Rail Network

- ◆ Level-of-service in rail freight operations is a function of the number of intermediate terminals at which a particular shipment is handled.
- ◆ Empirical research shows the major determinant of the LOS is not the distance between origin and destination, but rather the numbers of times the shipment was handled at intermediate terminals, which is really an operating decision on the part of the railroads.

Direct Service

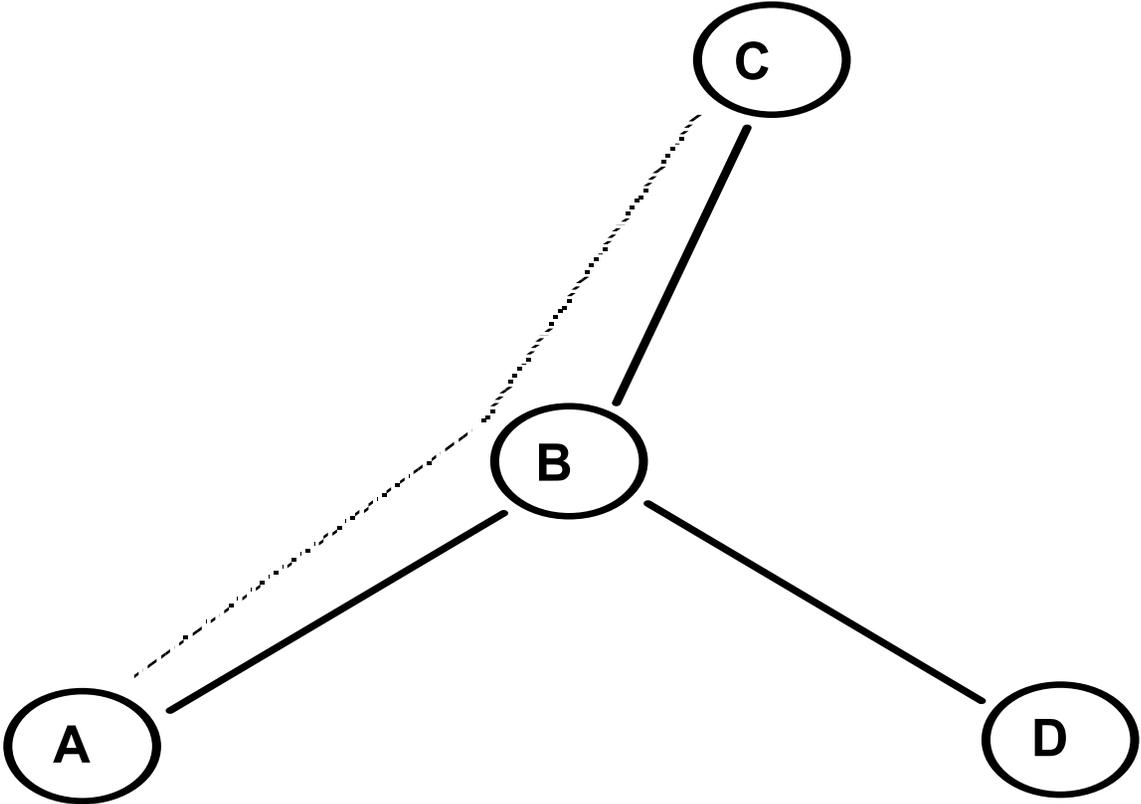


Figure 15.3

A More Subtle View of Costs (1)

System Options



System Options

- Skipping Yards
- Train Frequency
- Terminal Upgrading

Now we have to think more subtly about what the cost structure is. To simplify, consider only how much it costs the railroad to operate the service between the two extreme points of the network, A and D (we ignore the network effects).

Figure 16.1

A More Subtle View of Costs (2)

We subdivide operating costs into three categories: train costs; terminal operating costs; and car costs associated with the costs of owning rolling stock.

$$\text{Costs} = \text{Train Costs} + \text{Terminal Operating Costs} + \text{Car Costs}$$

Train Costs and Terminal Costs

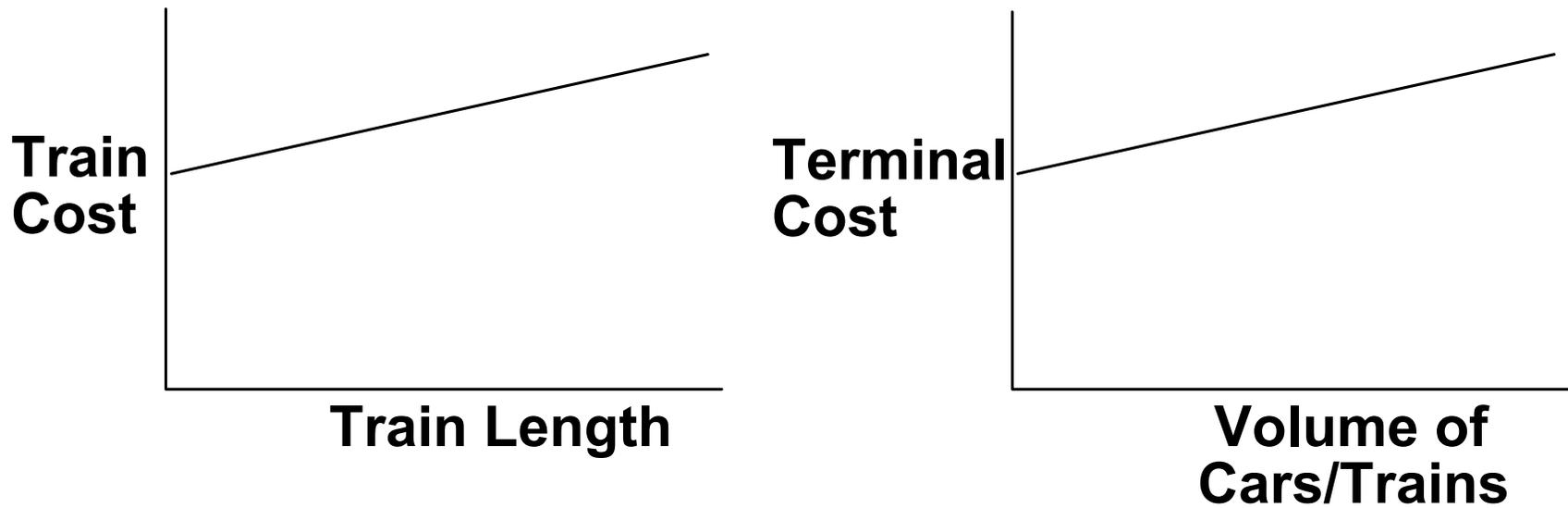


Figure 16.2

Car Costs

Freight Car-Cycle

- ◆ A freight car moves through the railroad network as follows:
 - ◆ Railroad places car at shipper siding
 - ◆ Shipper loads car
 - ◆ Railroad moves car through system to destination
 - ◆ Consignee unloads car
 - ◆ Railroad picks up empty car and places car at next shipper's siding

In equation form, we write:

Car Cycle (CC) = Shipper Loading Time + Transit
Time (loaded) + Consignees' Unloading Time +
Transit Time (empty)

Fleet Size Calculation

Assume we have a volume (V) of car-loads per day going from A to D; we can compute the number of cars, NC , we need in the fleet to perform this service.

$$NC = V * CC$$

This is a simplification:

- ◆ The system is not deterministic, but rather probabilistic.
- ◆ Empty cars often are sent to some point other than the one from which they came, as shown in this figure.

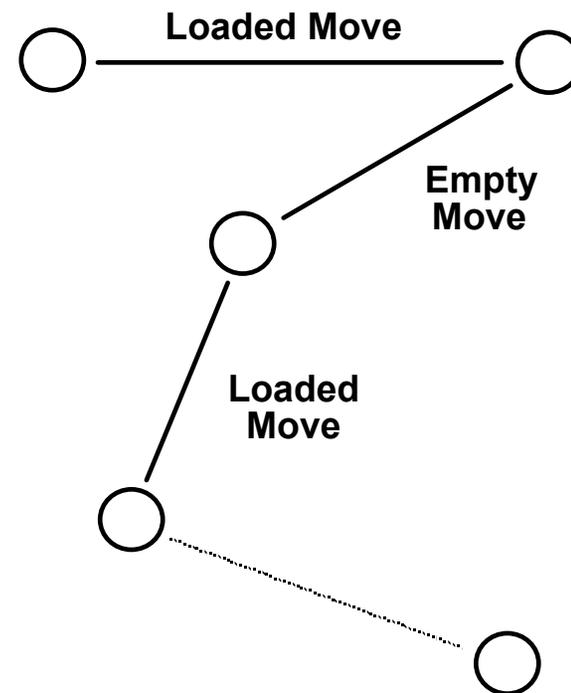
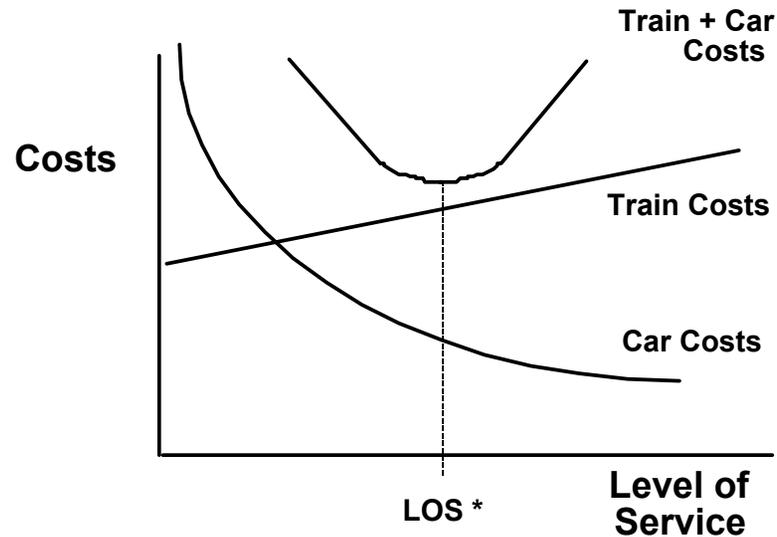


Figure 16.3

One Way of Looking at Car Costs

$$\text{Car Costs/Day} = \text{NC} * \text{Daily Cost of Owning a Car}$$

Cost vs. LOS



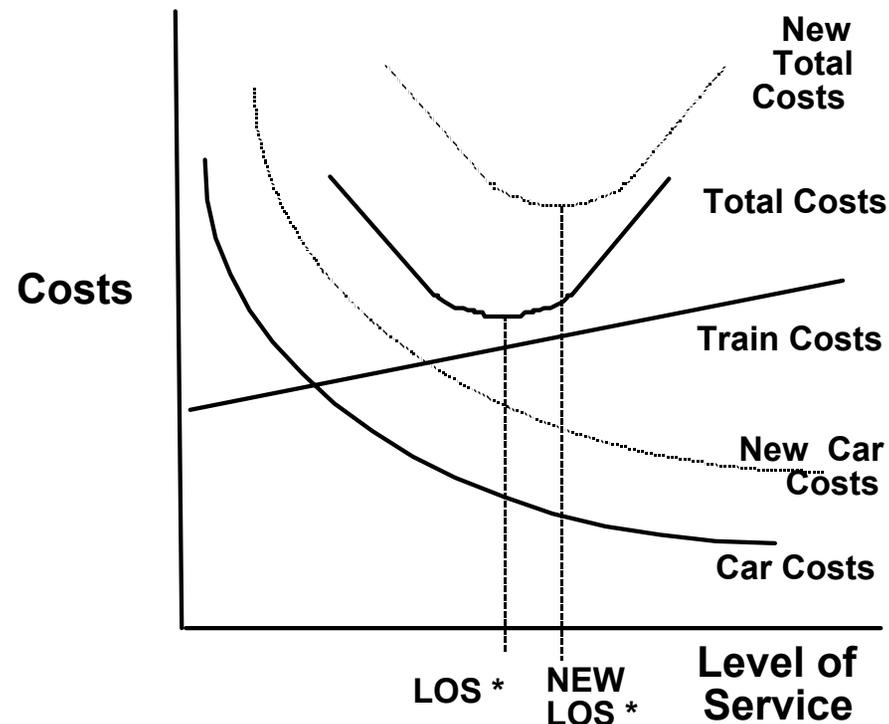
- ◆ You provide a better service by running shorter, more frequent trains, bypassing yards, etc. The train costs go up with level-of-service because you have more and shorter trains.
- ◆ On the other hand, car costs will go down as level-of-service is improved. Because the fleet is more productive when we bypass yards and run more frequent trains.
- ◆ Therefore, the fleet size needed to operate will be lower. So car costs will go down as you improve level-of-service.

Figure 16.4

CLASS DISCUSSION

- ◆ *Should we not include terminal operating costs?*

Cost vs. LOS -- Another View



As car costs go up and train costs go down, you may in fact be operating at the wrong LOS from *purely a cost viewpoint*. You may very well want to operate, given current cost trends, *at a higher level-of-service, even without consideration of the market benefits of doing so*.

Figure 16.5

Another View of Car Costs

- ◆ So far, we have simply taken the ownership costs of the car and divided it by a projected life to arrive at a daily cost of owning the car.
- ◆ One could argue that this cost is too low. Suppose we are operating during a strong economic period and that the railroad had an “infinite queue” of loads that needed service; the railroad can just keep servicing loads as long as it can provide cars for them.
- ◆ One could argue that car costs in this situation include not only the ownership costs but also the forgone profits when you do not have enough cars available to carry loads.

“Contribution”

- ◆ Consider the concept of “contribution”, which is the revenues that could be generated, say, per day, by that car, minus the costs of carrying that load per day; this gives a measure of the profitability of that particular move.
- ◆ Profits are forgone by not having cars available. We charge ourselves for cars on that basis, pushing car costs up further; there is an incentive to run a still shorter car-cycle, which again means a better level-of-service for customers.

How Performance Measures Affect Decisions

- ◆ The way in which managers would be charged for car use should affect their railroad operating decisions.
- ◆ If they are not charged *anything* for car use, they may choose to run very long trains because it does not cost *them* anything -- as *their* performance is measured -- to delay cars a long time in the yard.
- ◆ On the other hand, if they are charged substantially for car use, they may run short trains and provide a better level-of-service at the same time.
- ◆ The way in which people are measured and the incentives they are provided will alter the way they operate. [Key Point 28]

Trucking

- ◆ Publicly-Owned Infrastructure (usually)
- ◆ Truck and rail differ in right-of-way technology. The railroads are steel-wheel on steel-rail; the highways are rubber tires on concrete or asphalt.
- ◆ In trucking we use internal combustion or diesel engines; in railroads, we use electric or diesel power.
- ◆ In railroads, we have rail cars that are unpowered, pulled in trains of multiple vehicles by locomotives. Trucks have “tractors” which usually pull a single trailer, but sometimes “tandem-trailers”.

Trucking Cost Structure

Unlike railroads, the motor-carrier industry tends to be primarily a variable-cost rather than a fixed-cost industry. This is not surprising, given the fact that they do not own their own right-of-way.

Truckload Operation (TL)

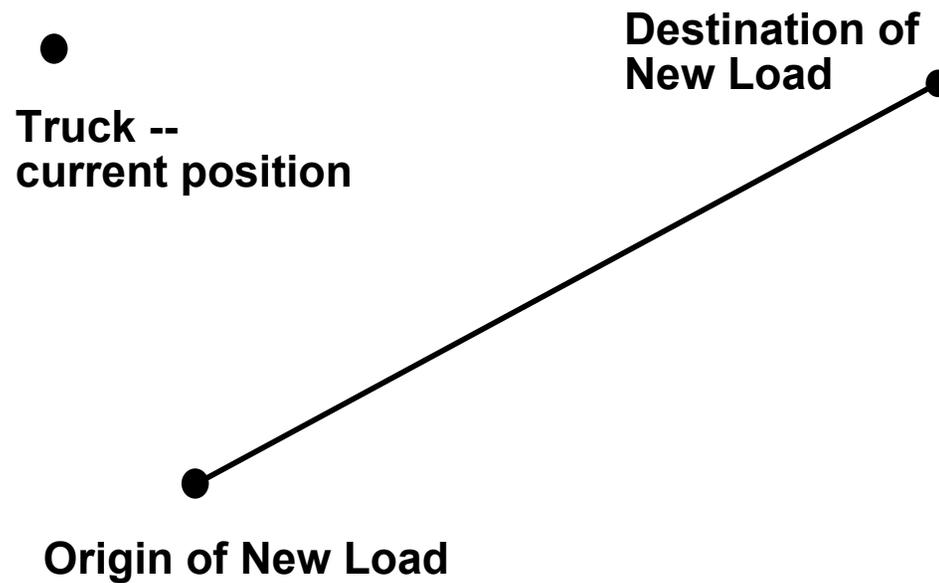
- ◆ A trucker is in the business of providing and driving a truck to take your goods from point A to point B. You, in effect, rent the truck for that move; the driver drives the shipment from A to B.
- ◆ This is an origin-destination service; the truck is dedicated during that trip to a single shipper.

Owner/Operators

- ◆ The driver may be an independent “owner/operator” who owns, perhaps, only that one truck and who is desirous of keeping it as productive as possible.
- ◆ To help the owner/operator, there are services that provide information about potential loads. And if that new load is right up the street from where he dropped off the earlier load, then there is no dead-head time.
- ◆ But if he needs to travel some distance to pick up a new load, no one pays him while he does that.

Load-Screening

Choosing a Load



How does the trucker make a decision?

CLASS DISCUSSION

Figure 19.1

Intermodal Partnership

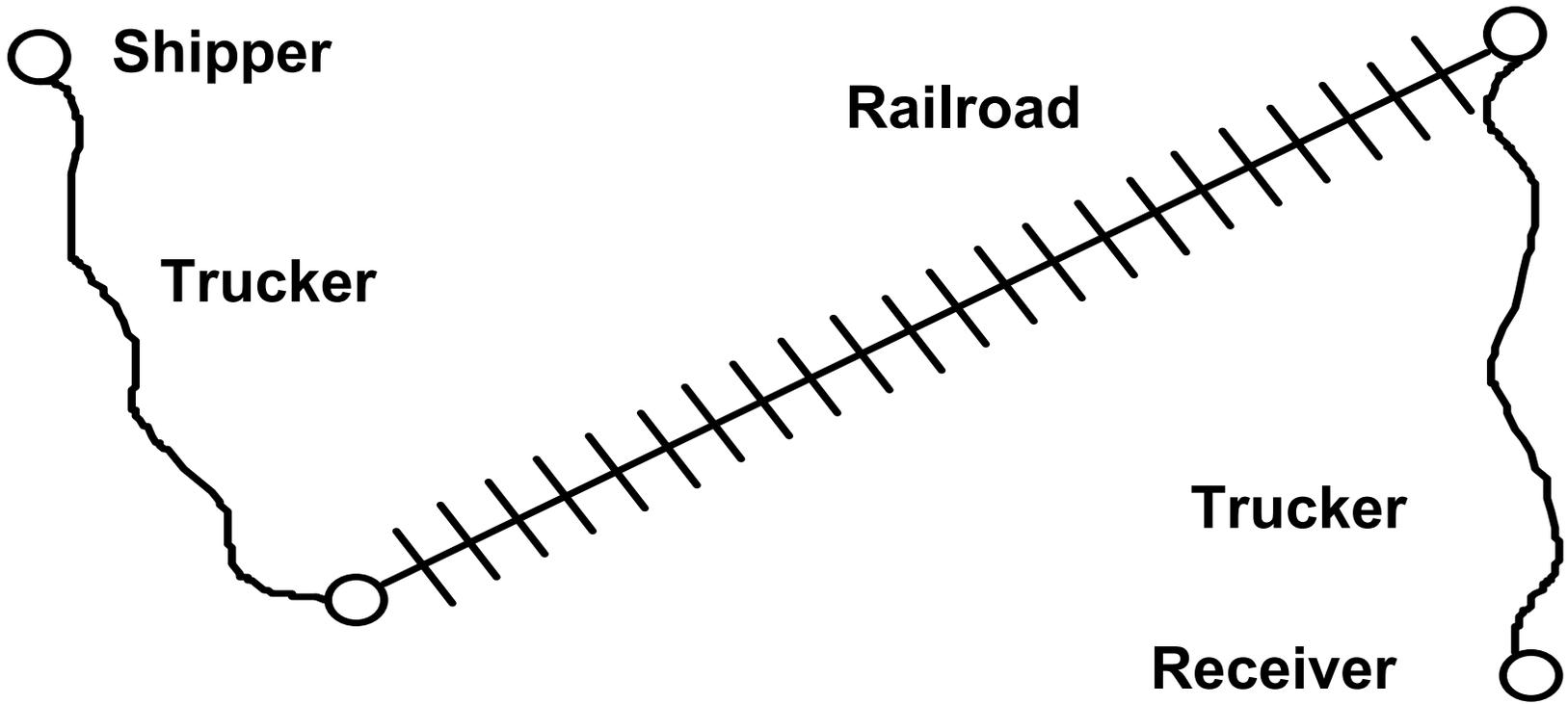


Figure 19.3

Intermodal Truck/Rail Partnerships

- ◆ The challenge for the railroad industry has been that customers (shippers and receivers) who use trucks are used to and expect high-quality service. They expect high reliability.
- ◆ So the railroad industry cannot treat these containers just like any shipment. It must treat them as though it is a truck that happens to be on a railroad at this particular moment.
- ◆ The kinds of service that the railroads provide for intermodal reflect the high-quality service that trucking customers expect.
- ◆ There are those in the railroad industry who feel that, although there are very good rates of growth in intermodal traffic, they are not making very much profit on intermodal. They suggest that because the services that are provided are very expensive, rates are such that it is not a money maker.

Intermodal Truck/Rail Partnerships

(continued)

- ◆ The fundamental challenge of intermodal transportation is as follows: you use the inherent advantages of each modal partner -- the universality of the highway/truck network and the low-cost “line-haul” attribute of the rail network.
- ◆ But if you cannot do an efficient transfer between the two of them, you dissipate the advantage. Containerization is a fundamental aspect of that.
- ◆ The fact that containers are uniform in size and transfer equipment (e.g., cranes) exists to deal with containers -- moving them readily from one mode to the other -- is fundamental to the idea of intermodal transportation.

Less-Than-Truckload Operation (LTL)

LTL Network

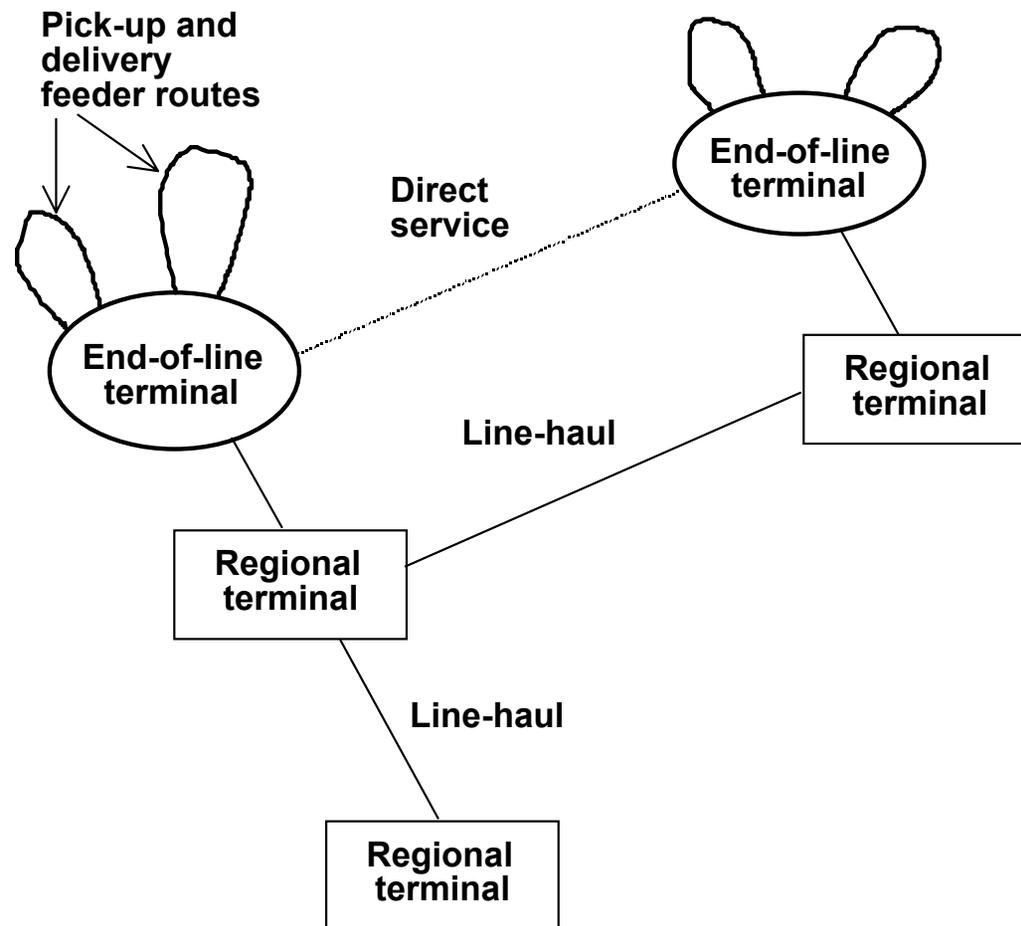


Figure 19.4

Ocean Shipping

- ◆ Ocean Shipping Services: Bulk
 - ◆ Wet Bulk
 - ◆ Dry Bulk

About 5% of the world's freight bill is for ocean shipping.

Ocean shipping has been called “The Enabler of the Global Economy”.

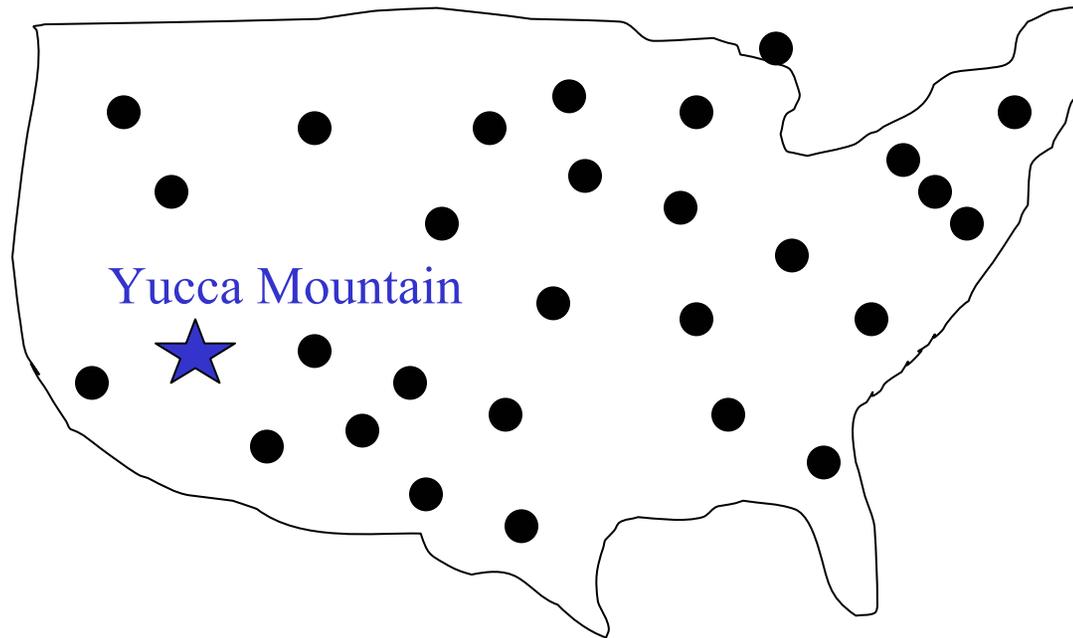
Ocean Bulk

- ◆ The ocean bulk market has some similarities to the TL market in the trucking industry. It is a very volatile market; the freight rates and demand for service may swing widely over the course of a few days.
- ◆ It is an easy business to enter and exit in the same way that truckload trucking is; you buy a truck and you are in business, you buy a ship and you are in business.
- ◆ So you can easily get in and out, and that leads to the chronic over-capacity and volatility in that marketplace.

Other Ocean Bulk Shipping Points

- ◆ Economies of Scale
- ◆ Environmental Issues and Risk Assessment
- ◆ Safety

TRANSPORTING SPENT NUCLEAR FUEL (I)



Currently, the U.S. has spent nuclear fuel (SNF) distributed around the country at about 131 sites. This has been characterized as very risky. Associated with this configuration are costs of maintaining the SNF. So (R_d, C_d) represent the risk, cost doublet of this decentralized configuration.

TRANSPORTING SPENT NUCLEAR FUEL (II)

- ◆ The idea is to centralize the SNF at Yucca Mountain, Nevada. That configuration has a risk, cost doublet (R_c, C_c) .
- ◆ To convert from the decentralized to the centralized configuration, we incur risk and cost in transporting the SNF from around the country to Yucca Mountain. This is represented as (R_t, C_t) .
- ◆ We should do this only if:
$$(R_c + R_t, C_c + C_t) < (R_d, C_d)$$

TRANSPORTING SPENT NUCLEAR FUEL (III)

- ◆ Our primary task in transportation is then to enumerate (R_t, C_t) doublets for various transportation options. We have options for infrastructure, routing, scheduling, mode, operating plans (e.g., dedicated trains or not, heavy-haul or legal weight trucks, what SNF is shipped -- i.e., young or old, operating speeds, command and control, ITS, GPS), and so forth.
- ◆ Also, we must recognize the time dynamic of this problem. The risk and cost parameters will certainly change over time; technology will likely improve; the characteristics of the SNF will change; and so forth.
- ◆ Of course, the distribution of risks and costs across society is of importance as well. For example, R_t is likely to be concentrated in Nevada. But there are general issues of the economic, political, demographic and racial distribution of costs and risks (e.g., environmental justice).
- ◆ Finally, we note essentially *all* the factors discussed here are uncertain -- all are random variables with complex interrelationships. We need to reflect these uncertainties as best we can (but this is non-trivial, in and of itself).

PRINCE WILLIAM SOUND (ALASKA) OIL SPILL

- ◆ Tanker ran aground, rupturing the hull
- ◆ Environmental disaster in pristine wilderness

PRINCE WILLIAM SOUND (ALASKA) OIL SPILL (CONTINUED)

◆ ISSUES

- ◆ How could the accident have been avoided (or at least have reduced probability)?
 - ◆ Don't go through Prince William Sound
 - ◆ Speed
 - ◆ Amount of oil carried -- Would 2 smaller tankers be more or less likely to be involved in this kind of accident?
 - ◆ Double-Hulling
 - ◆ Crew Size
 - ◆ Crew Condition Check

PRINCE WILLIAM SOUND (ALASKA) OIL SPILL (CONTINUED)

- ◆ ISSUES (continued)

- ◆ All of the above cost money
- ◆ How much safety does society want to buy?

Regulators ————— Private Sector

PRINCE WILLIAM SOUND (ALASKA) OIL SPILL (CONTINUED)

- ◆ ISSUES (continued)
 - ◆ How could the accident's impact be lessened?
 - ◆ Less oil in the tanker
 - ◆ Recovery procedures
 - ◆ You can estimate costs of accident prevention and impact amelioration -- *But* how do you measure the costs of the spill -- it can be hard to do so in money terms
 - ◆ Loss of wildlife
 - ◆ Befouling the environment

PRINCE WILLIAM SOUND (ALASKA) OIL SPILL (CONTINUED)

◆ THINK SYSTEMS

- ◆ Why is the oil shipped through Prince William Sound?
 - ◆ *Cheap*
 - ◆ Perhaps less environmental damage that way rather than over land
 - ◆ As you estimate the benefits and costs, you need to think through where the boundaries of your system is
 - ◆ Classic quandary: Low probability but high impact event

The Liner Trade

- ◆ Usually, for merchandise (as opposed to bulk), the cargo that an individual customer has is not adequate to fill a ship.
- ◆ So, in the liner trade, as in LTL operations and in merchandise trains, a customer shares the capacity with other customers, and benefits from consolidation by sharing the costs as well.
- ◆ Container trade is an important example of the liner trade.

Economies of Scale

Economies of Scale in Shipping

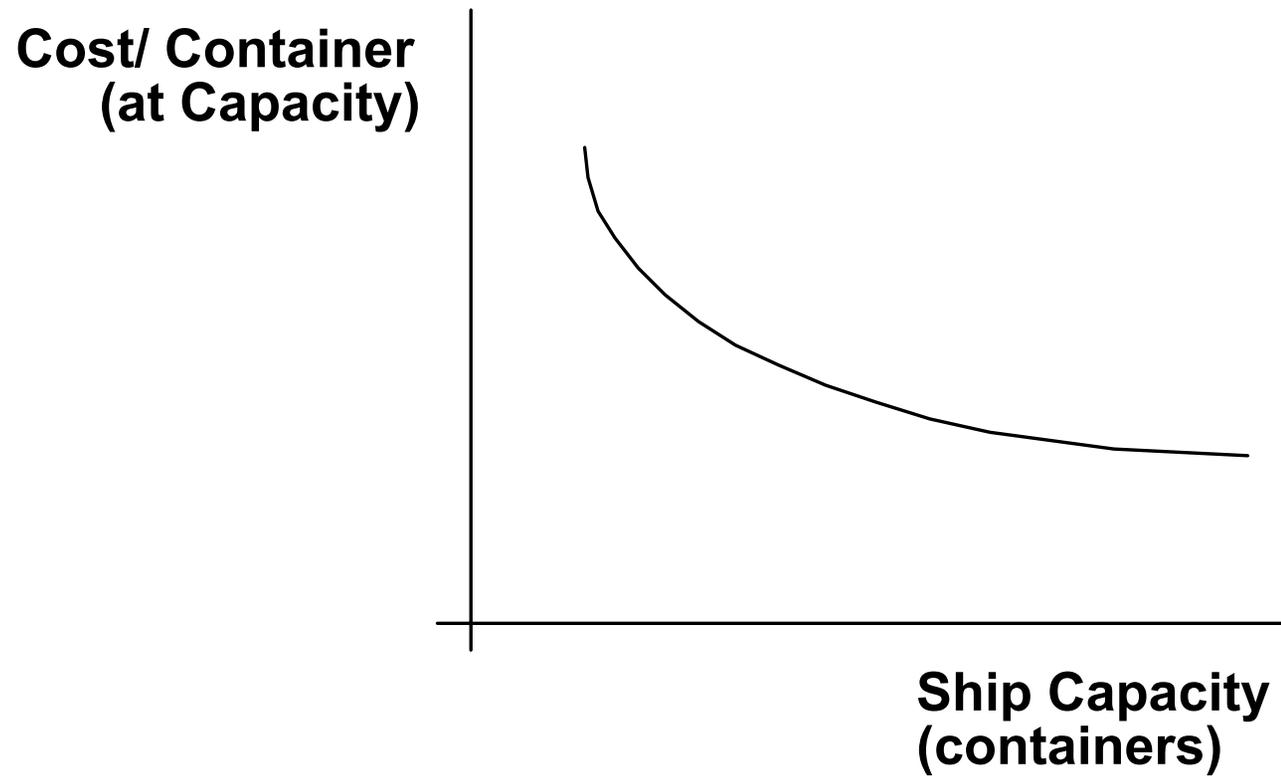


Figure 20.2

Liner Decisions

- ◆ Operating Speed and Cost
- ◆ Service Frequency
- ◆ Empty Repositioning of Containers

Intermodalism and International Freight Flows

U.S./Europe Intermodal Services

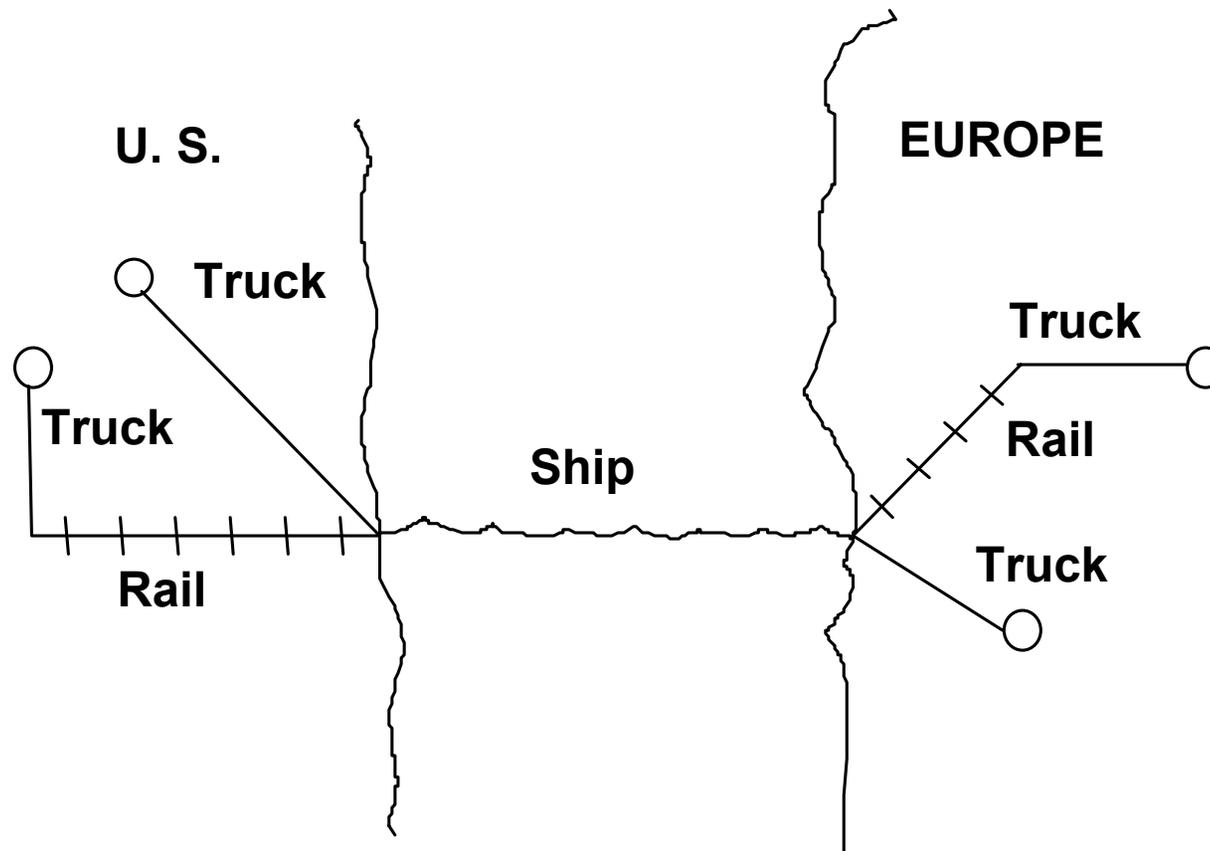


Figure 20.3

Port Operations

- ◆ Port Capacity
- ◆ Dredging
- ◆ Intermodal Productivity

LOS vs. Cost for Various Freight Modes

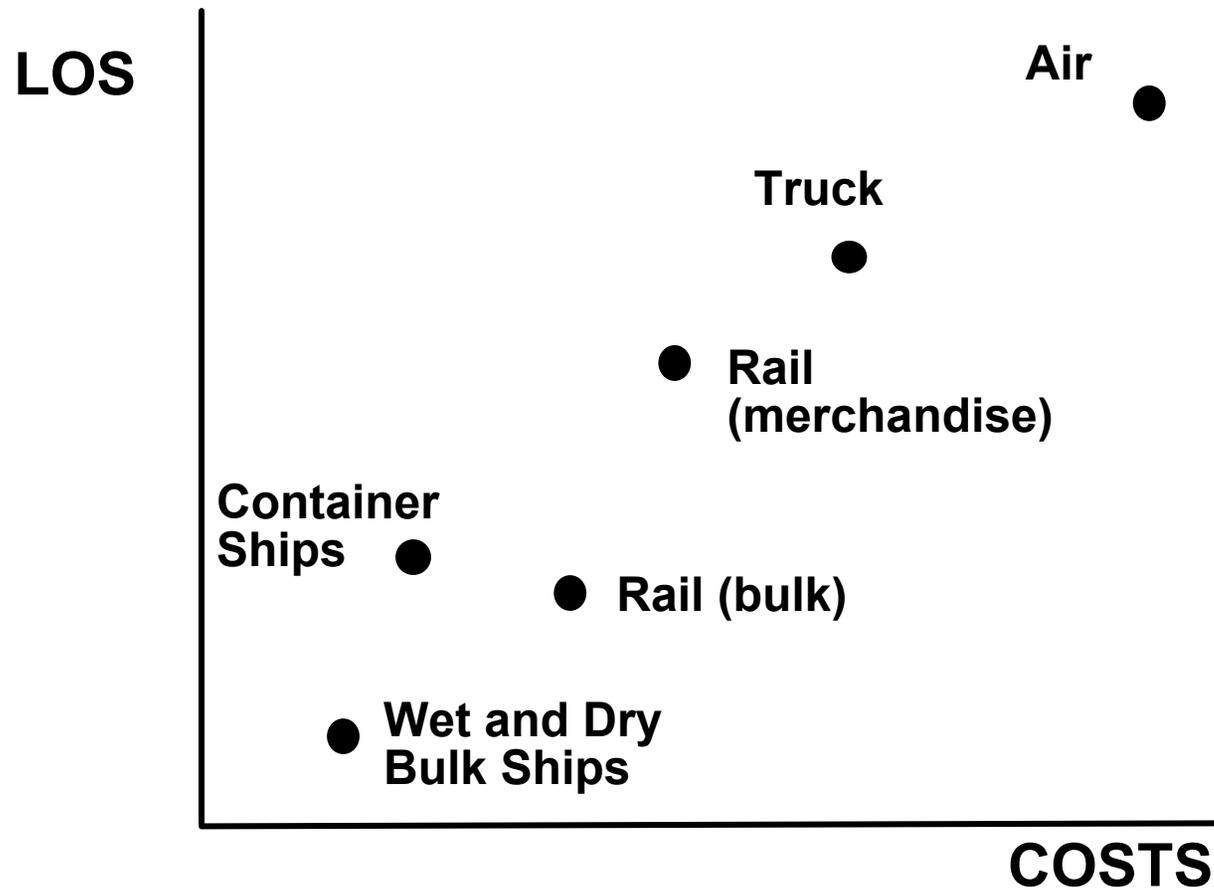


Figure 20.7

Freight Summary

- ◆ The cost structure: relationship of fixed and variable costs;
- ◆ The nature and ownership structure of the physical assets: infrastructure, right-of-way, terminals, vehicles;
- ◆ Technology;
- ◆ The regulatory framework; and
- ◆ The structure of the market.

Some Key Freight Factors

- ◆ Vehicle-Cycle
- ◆ Vehicles and Infrastructure
- ◆ The Market
- ◆ Operating Plans and Strategic Plans

The 30 Key Points

- ◆ Think about the different modes and intermodal competition and how they relate to our 30 key points. A good exercise would be to study those key points and think about how they relate to different freight modes.
- ◆ Think about the triplet: technology, systems and institutions, and how we deal on all these dimensions to achieve competitive modern freight transportation services.

CLASS DISCUSSION