Transportation Management

Network & Hubs

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Distribution System Approach

- Distribution System
  - Number and location of transshipment points
  - Routes and schedules of vehicles
  - Routes and schedules of items flowing

Operational

Tactical

Strategic

- Decisions made at different times
  - Strategic – longer scope and less data available (yr+)
  - Tactical – shorter scope w/ planning data (week to yr)
  - Operational – very short scope real data (daily)

The Network Design Problem

Treat each potential facility location as a node

V V V V V V V V

P P P P P

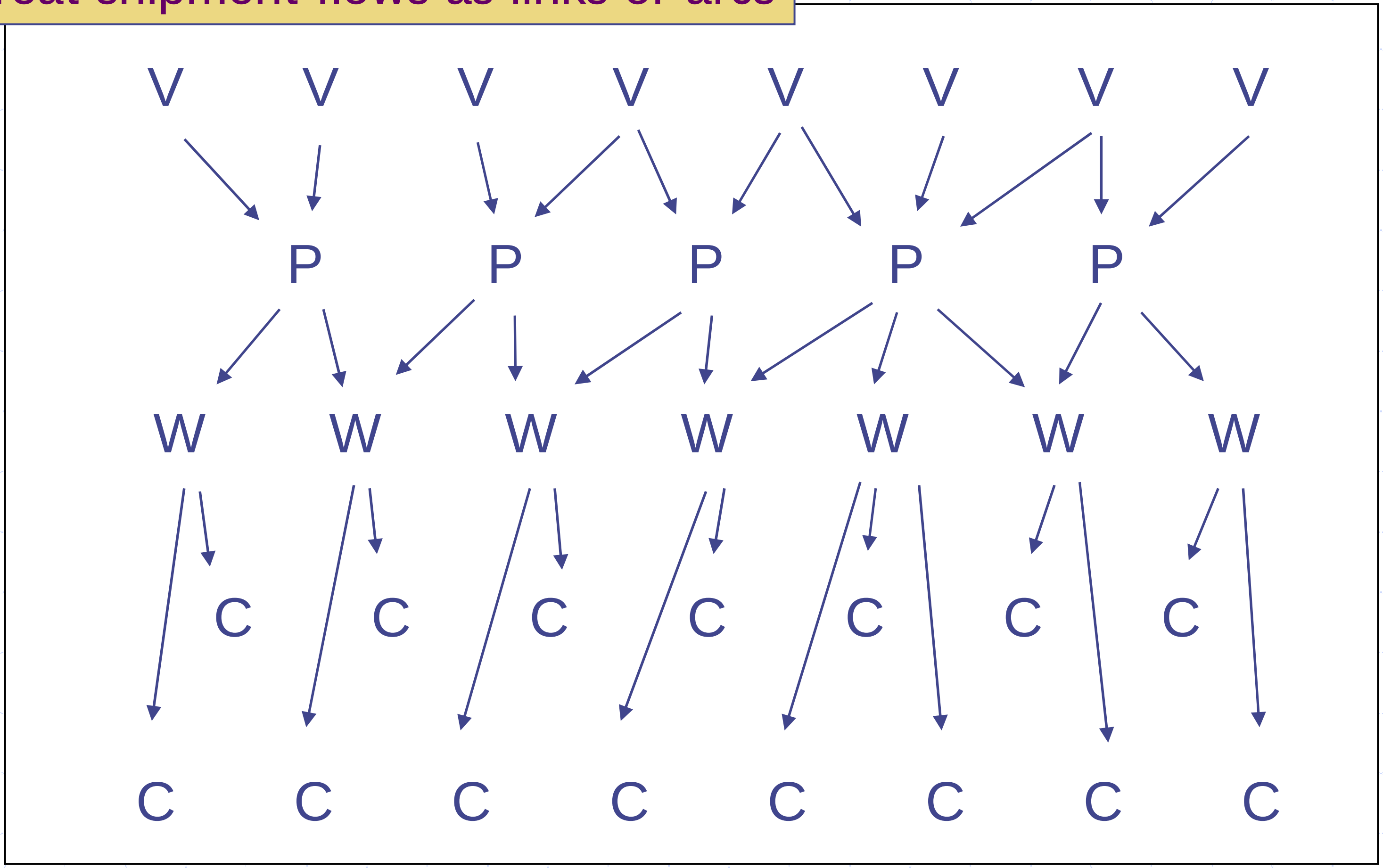
W W W W W W W

C C C C C C C

C C C C C C C C

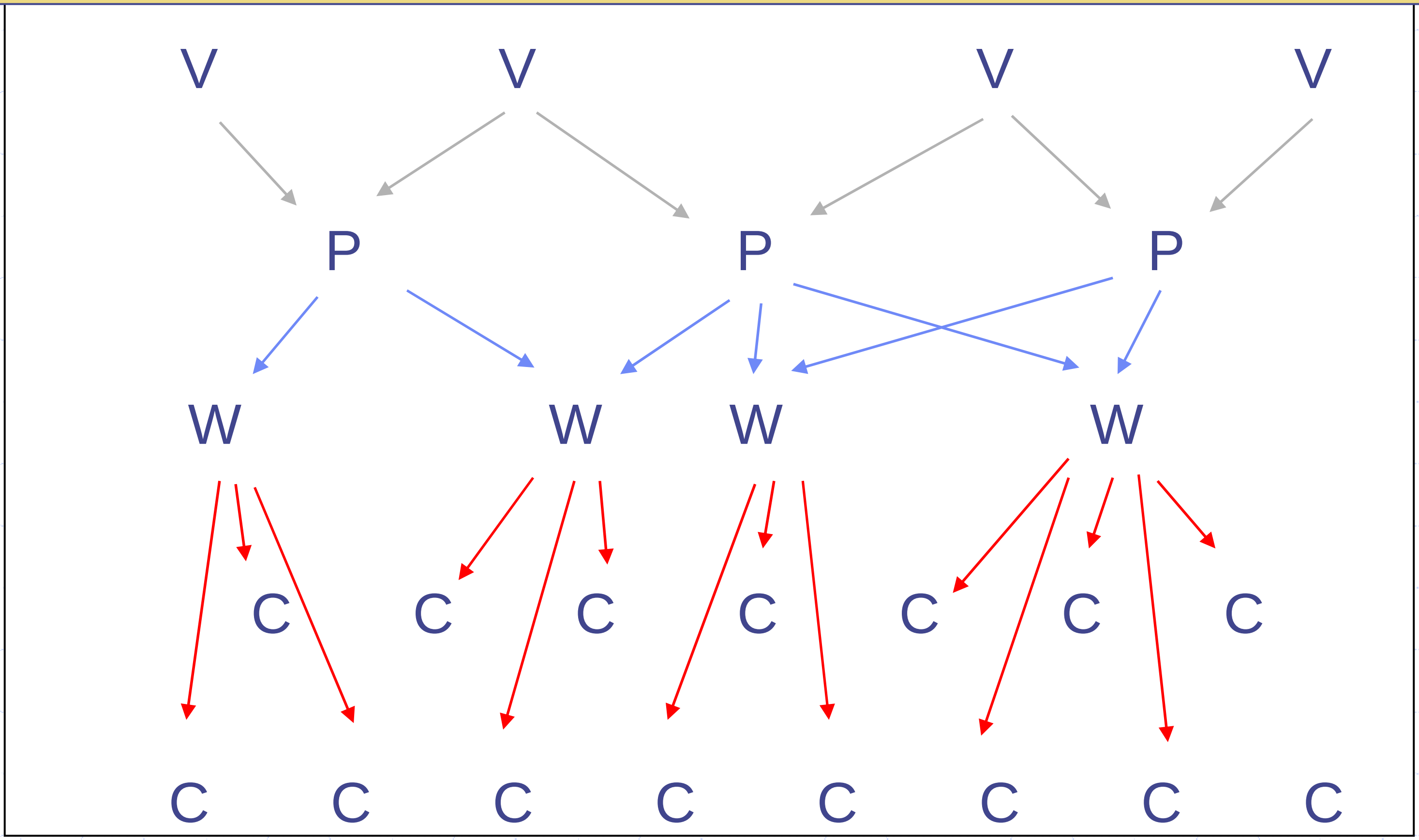
The Network Design Problem

Treat shipment flows as links or arcs



The Network Design Problem

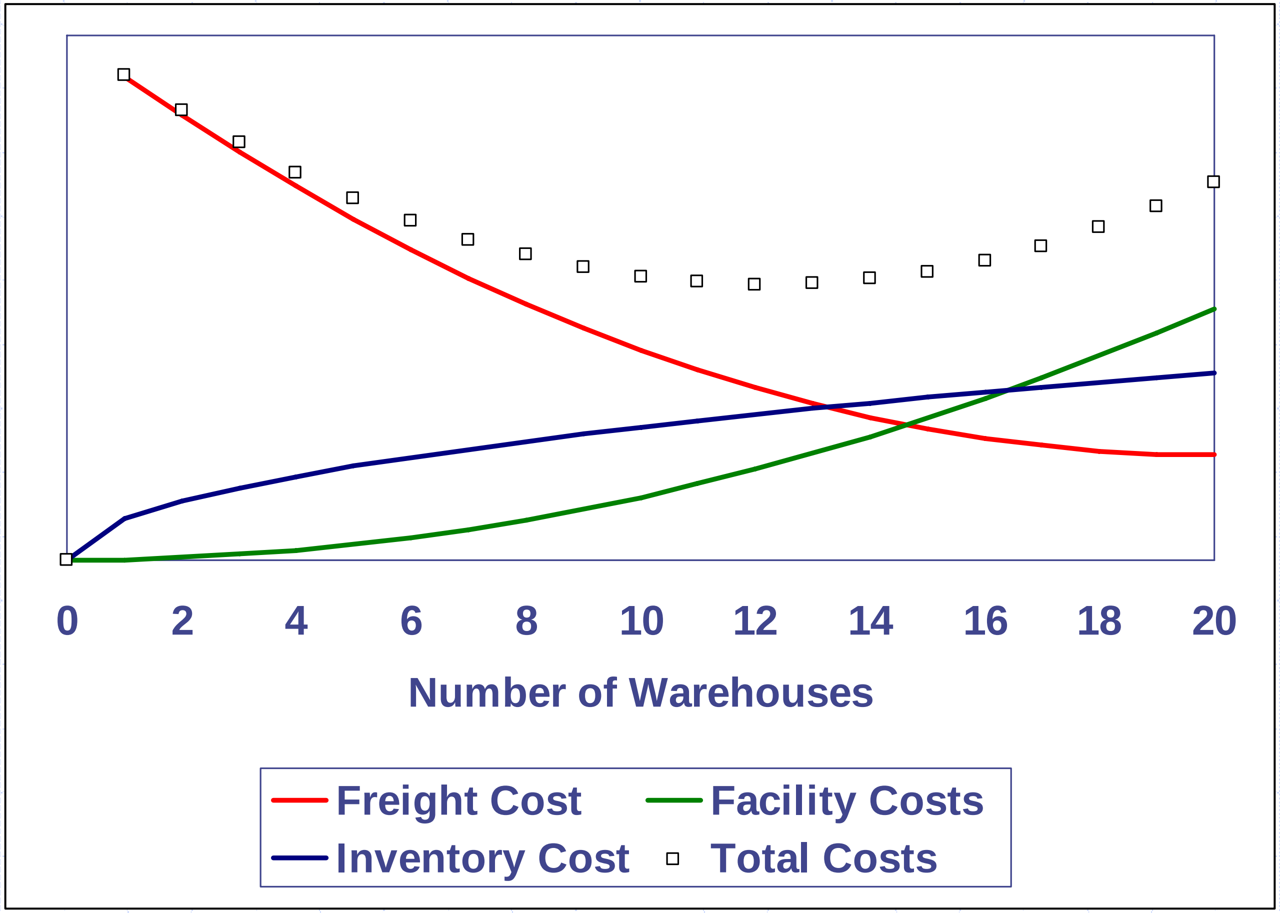
Network design is the selection of nodes and links that minimize total cost



Distribution Network Design

- Three key questions for Distribution ND
  - How many DCs should there be?
  - Where should the DCs be located?
  - For each SKU and each customer:
    - which DC should serve the customer, and
    - which plant should serve the DC?
- Cost & Performance Trade-Offs
  - Transportation Costs (Inbound versus Outbound)
  - Facility Costs (Fixed versus Throughput)
  - Inventory Costs (Cycle versus Safety Stock)
  - Customer Service (Availability versus Order Cycle Time)

Facility Location Cost Trade-Offs



A "Simple" MILP Formulation

Minimize: $\sum_{i=1}^{I}\sum_{j=1}^{J}\sum_{k=1}^{K}\sum_{l=1}^{L} C_{ijkl}X_{ijkl} + \sum_{k=1}^{K} F_k Z_k$

Subject to:

$$\sum_{j=1}^{J}\sum_{k=1}^{K} X_{ijkl} \geq D_{il} \text{ ; for all I and L}$$

$$\sum_{k=1}^{K}\sum_{l=1}^{L} X_{ijkl} \leq P_{ij} \text{ ; for all I and J}$$

$$\sum_{i=1}^{I}\sum_{j=1}^{J}\sum_{l=1}^{L} X_{ijkl} \leq V_k Z_k \text{ ; for all K}$$

$$X_{ijk} \geq 0 \text{ , for all I, J, K}$$

$$Z_k = \{0,1\} \text{ , for all K}$$

How big is this formulation?

20 Plants, 30 Products/ Product Groups, 50 Potential DCs, and 400 Customers Regions, there are:

12,000,000 possible flows!

Where:

X_{ijkl} = Total annual volume of product i produced at plant j and shipped through DC k on to customer zone l

$Z_k = \{0,1\}$; 1 if the DC at k is selected, else 0

D_{il} = annual demand for product i at customer zone l

P_{ij} = maximum annual capacity for product i at plant j

V_k = maximum annual throughput volume at DC at k

F_k = The fixed annual operating cost of a DC at k

C_{ijkl} = The variable cost to produce one unit of product i at plant j and ship it through DC k to customer zone l

so that $C_{ijkl} = C[mnfg]_{ij} + TL_{ijk} + DCTHPT_{ik} + LTL_{ikl}$

A "Better" MILP Formulation

$$\text{Minimize: } \sum_{i=1}^{I}\sum_{j=1}^{J}\sum_{k=1}^{K} A_{ijk}X_{ijk} + \sum_{i=1}^{I}\sum_{k=1}^{K}\sum_{l=1}^{L} B_{ikl}Y_{ikl} + \sum_{k=1}^{K} F_k Z_k$$

Subject to:

$$\sum_{k=1}^{K} Y_{ikl} \geq D_{il} \text{ ; for all I and L}$$

$$\sum_{k=1}^{K} X_{ijk} \leq P_{ij} \text{ ; for all I and J}$$

$$\sum_{i=1}^{I}\sum_{j=1}^{J} X_{ijk} \leq V_k Z_k \text{ ; for all K}$$

$$\sum_{j=1}^{J} X_{ijk} \geq \sum_{l=1}^{L} Y_{ikl} \text{ ; for all I and K}$$

$$X_{ijk} \geq 0\text{; for all I, J, K}$$

$$Y_{ikl} \geq 0\text{; for all I, K, L}$$

$$Z_k = \{0,1\} \text{ , for all K}$$

How big is this formulation?

20 Plants, 30 Products/ Product Groups, 50 Potential DCs, and 400 Customers Regions, there are:

50,000 (30k IB & 20k OB) possible flows

Where:

X_{ijk} = Total annual volume of product i produced at plant j and shipped through DC k

Y_{ikl} = Total annual volume of product i shipped from DC k to customer zone l

$Z_k = \{0,1\}$; 1 if the DC k is selected, else 0

A_{ijk} = The variable cost to produce one unit of product i at plant j and ship it to the DC at k

B_{ikl} = The variable cost to move one unit of product i through the DC at k and ship it to the customer zone at l

D_{il} = annual demand for product i at customer zone l

P_{ij} = maximum annual capacity for product i at plant j

V_k = maximum annual throughput volume at DC at k

F_k = The fixed annual operating cost of a DC at k

Issues & Concerns

- Data Issues
  - Demand Point Aggregation
  - Demand over Time Periods
  - Profiling freight cost data
  - Fixed Costs: Periodic versus One-Time
  - Cost Estimating Functions
- Global Extensions
  - Freight Rate Availability
  - Transfer Prices and Taxes
  - Exchange Rates
  - Duty and Duty Drawback
- Missed Questions
  - What about Inventory?
  - What about Customer Service?
  - Supply Chain Extensions

Inventory Deployment

- What safety stock should each DC have?

Inventory Carrying Cost for SKU_i @ DC_j

Inventory Carrying Cost %

$$ICC_{ij} = COG_i \times ICC\%_{ij} \times SS_{ij}$$

Cost of Goods Sold

Safety Stock Units for SKUi@ DC_j

Fill rate adjustment by SKU by Customer

Std Dev of Supplier Lead time

Average Demand

$$SS_{ij} = K_i \sqrt{\sigma^2_{D_{ij}} \overline{L}_{ij} + \sigma^2_{L_{ij}} \overline{D}^2_{ij}}$$

Std Dev of Demand

Average Supplier Lead Time

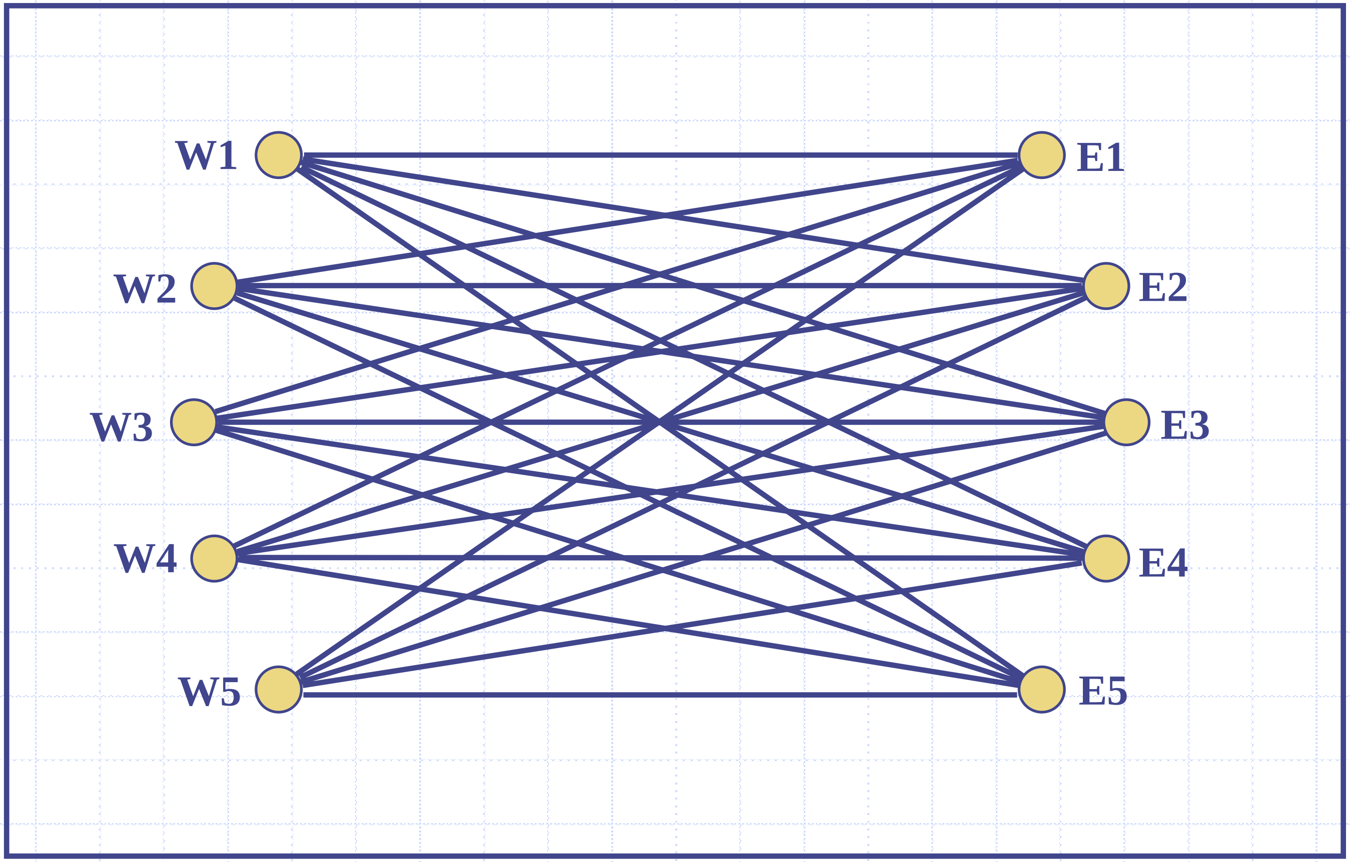
- Why is this difficult?

Transportation Networks

- One to Many w/o Transshipment
- One to Many w/ Transshipment (why?)
- Many to Many
  - w/o Transshipment
    - Direct
    - Multi-Stop
  - w/ Transshipment (Hub)
    - Directs
    - Multi-Stops

Many to Many Networks

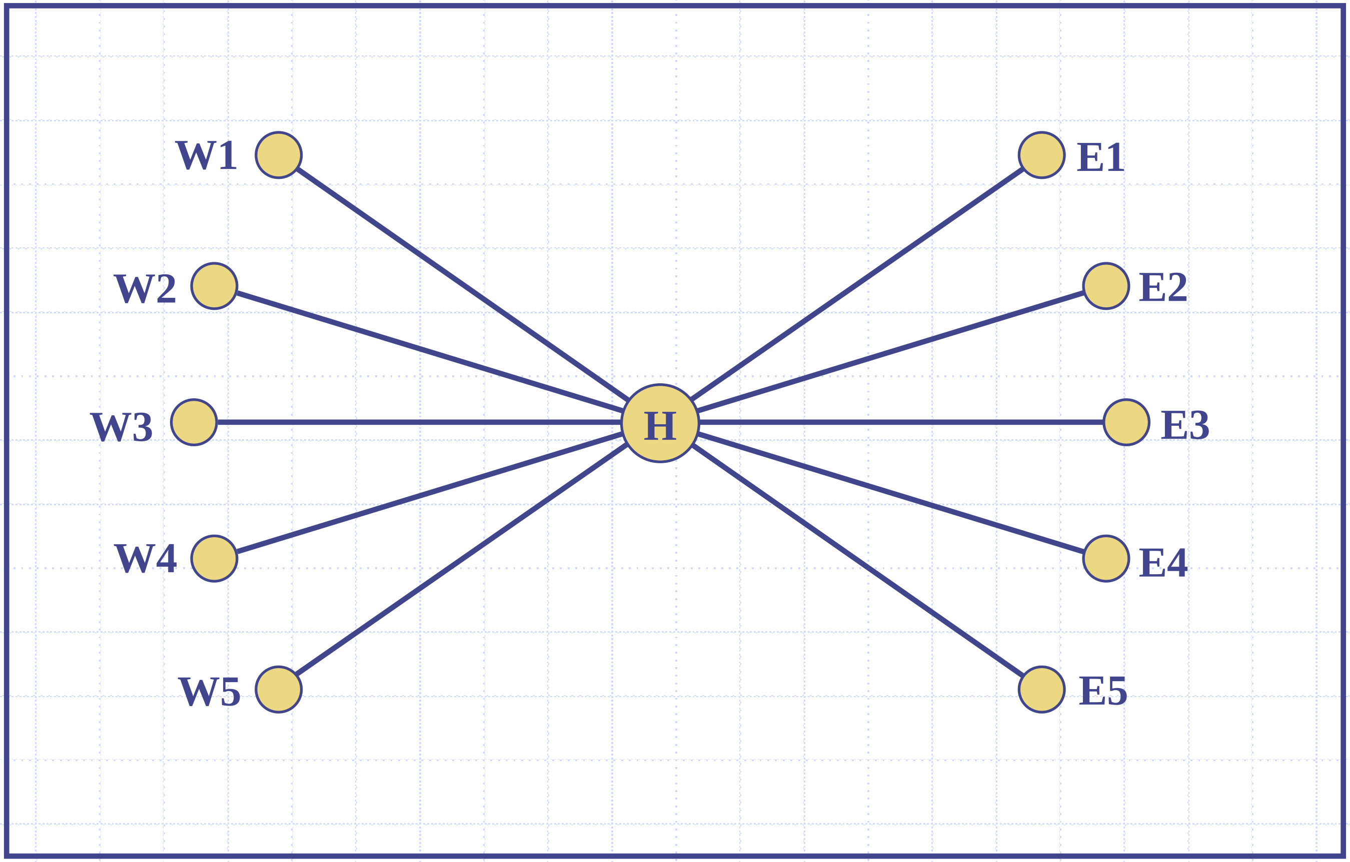
How should I ship from 5 origins to 5 destinations?



Direct Network

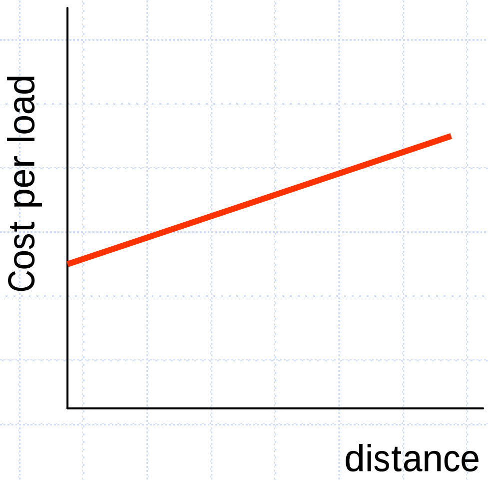
Many to Many Networks

How should I ship from 5 origins to 5 destinations?



Hub & Spoke Network

Direct versus Hub



- Which is better?
  - How many trucks are needed?
  - What is the cost?
  - How can I increase frequency of service?
- Example Details
  - Need to pick up every day from terminals
  - Average distance between terminals = 500 miles
  - Average distance from terminals to hub = 350 miles
  - Cost for transportation = $200 shipment + 1 $/mile

Hub versus Direct

- How does demand impact?
  - Daily demand from terminal i to j is ~N(100, 30)
  - Suppose break even for a TL move is 50 units.

- Variability
  - Direct Network
    - What is the:
      - Average quantity per move?
      - Standard deviation of load per move?
      - Coefficient of Variation per move?
    - What is the frequency of moves that lose money?
  - Hub Network
    - What is the:
      - Average quantity per move?
      - Standard deviation of load per move?
      - Coefficient of Variation per move?
    - What is the frequency of moves that lose money?

Hub Advantages

- Hub consolidation reduces costs
  - Consolidation increases conveyance utilization
  - Transportation has a fixed (per conveyance) cost
- Fewer conveyances are required
  - Is consolidation better . . .
    - when point to point demand is higher or lower?
    - when variability of point to point demand is higher or lower?
  - Coefficient of variation as useful metric
- Provides better level of service with fewer resources
  - Non-stop vs. frequency of service
  - Non-stop vs. geographical coverage
    - serving more / smaller cities

Hub Disadvantages

- Cost of operating the hub
  - Facility costs
  - Handling costs - unloading, sorting, loading
  - Opportunity for misrouting, damage, theft (shrinkage)
- Circuity
  - Longer total distance travelled
  - More vehicle-hours expended
- Impact on service levels
  - Added time in-transit
  - Lower reliability of transit
- Productivity/utilization loss
  - Cycle/”bank” size

Hub Economics

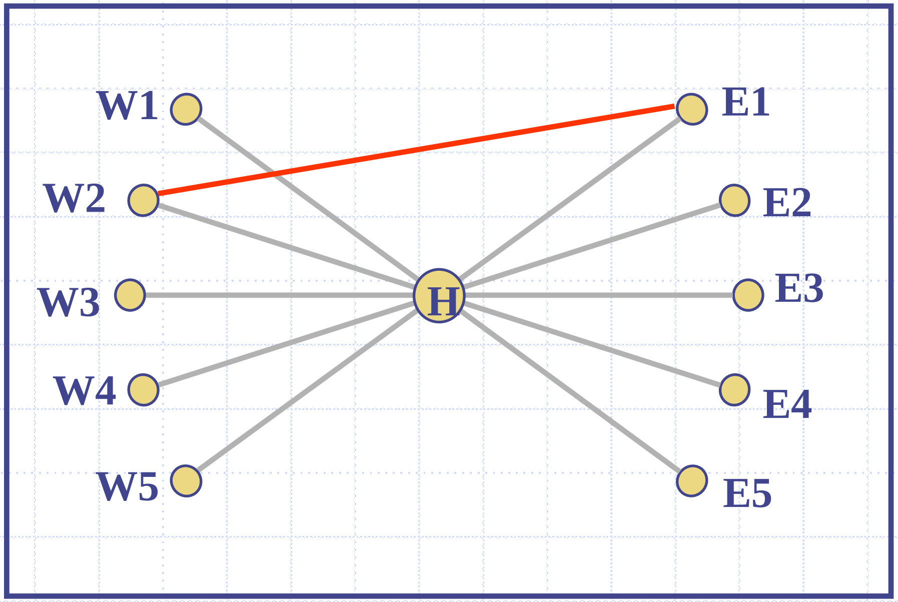
- Relative distances
  - Degree of circuity
- Vehicle and shipment size
  - Smaller shipments $\rightarrow$ hub more economical
- Demand pattern
  - Many destinations from each origin
  - Many origins into each destination
- The hub location
  - Significant business generation for passengers
    - Air – large city
    - Transit – CBD
  - Good access for freight
    - Highways access
    - Away from population centers

Terminal Bypass Operations

- When would you want to bypass hub handling?
- Examples
  - Air - through flight
    - Use heaviest pair
    - Marketing; reliability; lower costs
  - LTL - "head loading"
  - Rail - block placement
  - Parcel - pre-packaging
- Packages physically travel to the hub, but are not touched or handled.

Directs in a Hub-and-Spoke Network

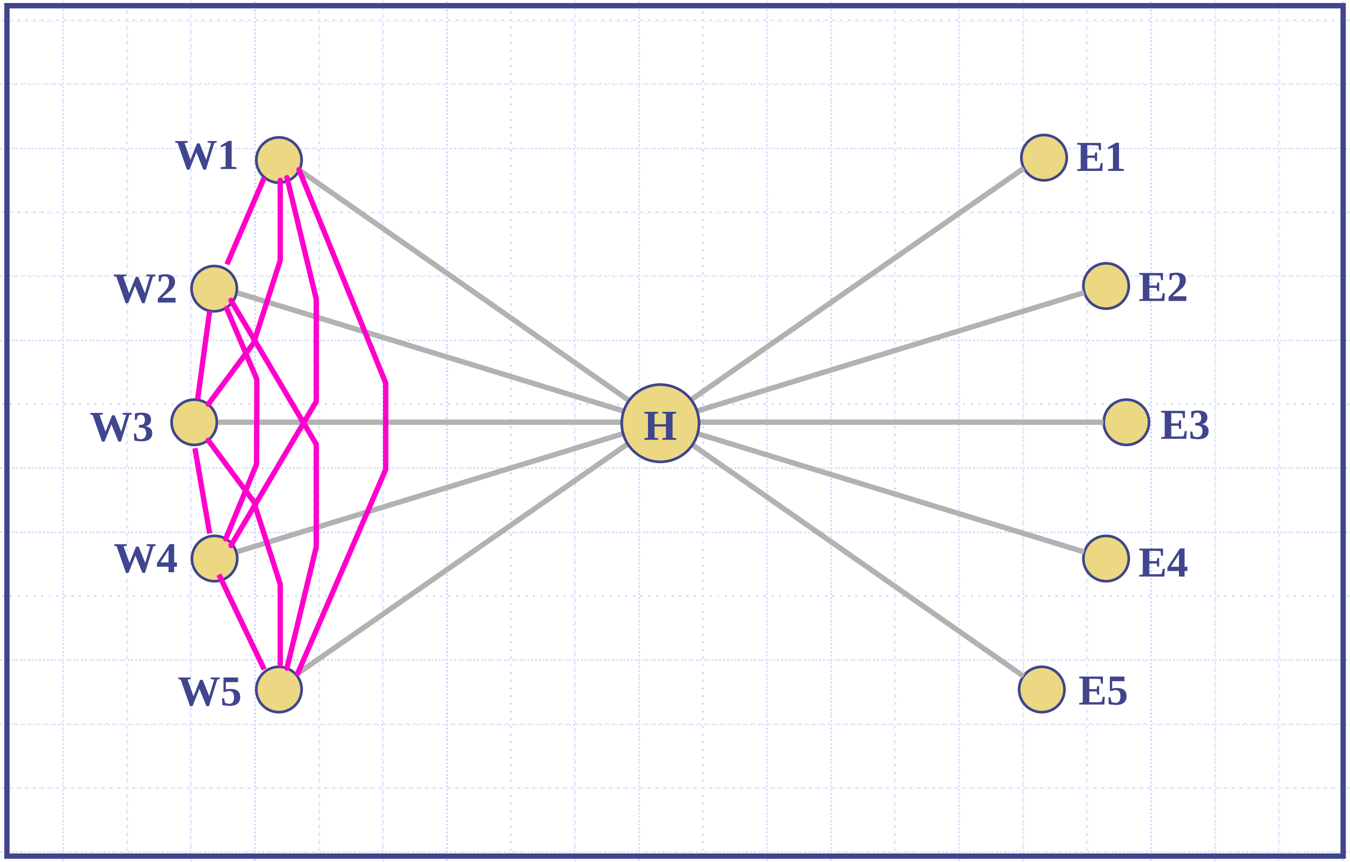
- Considerations in setting direct service:
  - Demand between E1 and W2
  - Service E1-Hub and Hub-W2
  - Effect on the hub
  - Effect on E1 activities



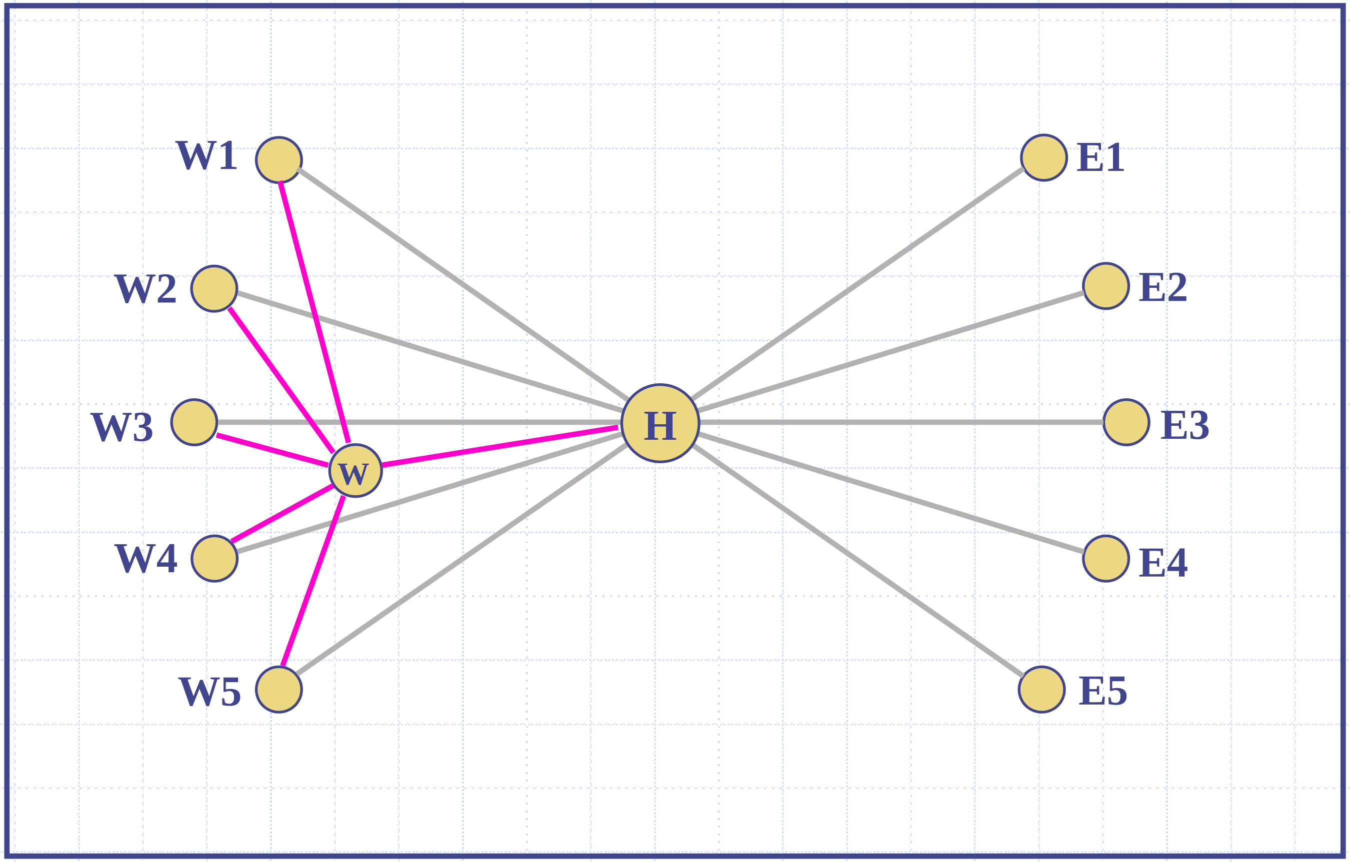
- For freight services:
  - Dynamic (“opportunistic”)
  - Direct services (“surge move”)
  - Planned (“multiple offerings”)

Regional Terminals

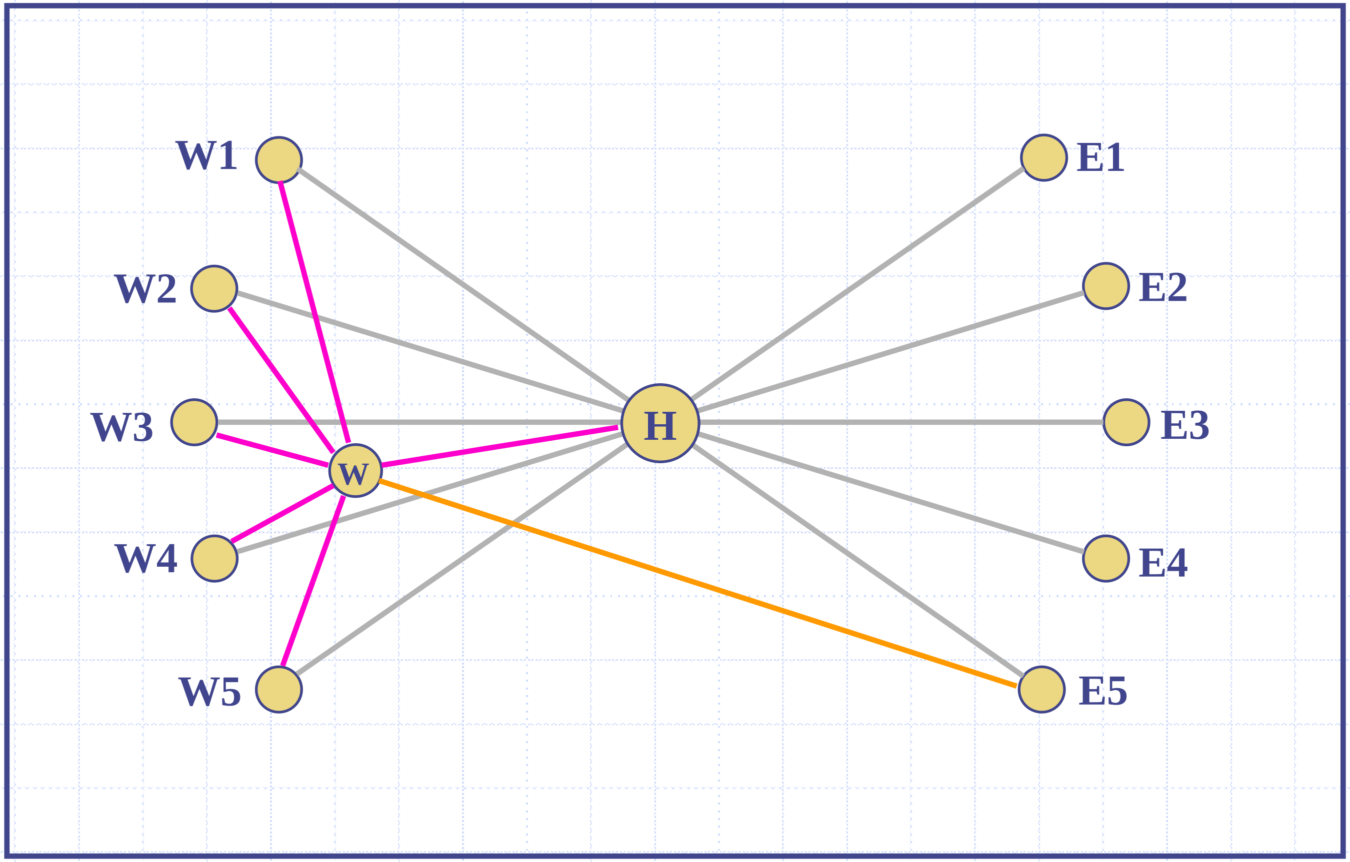
What if there is demand between the W terminals?



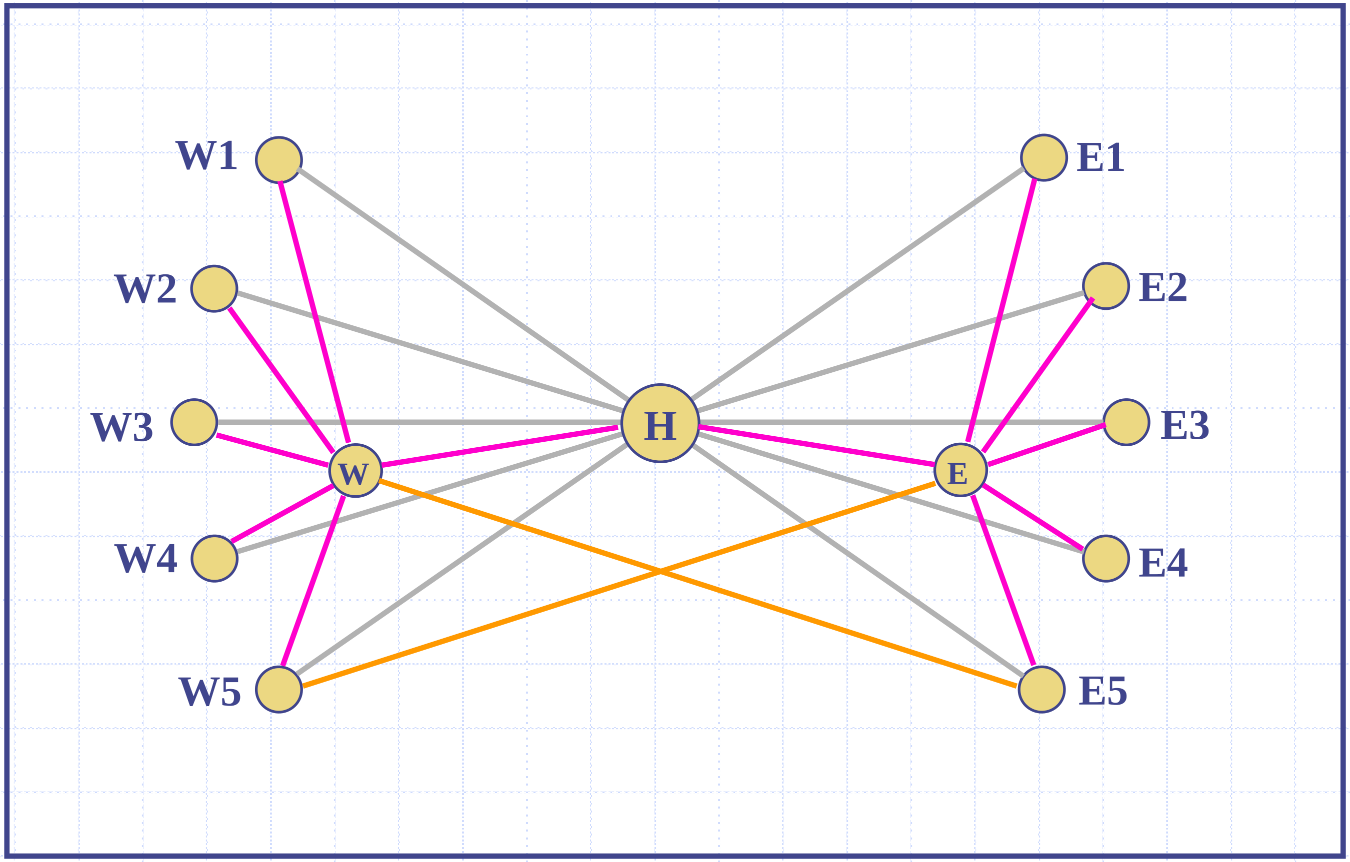
Regional Terminals



Bypassing the Hub



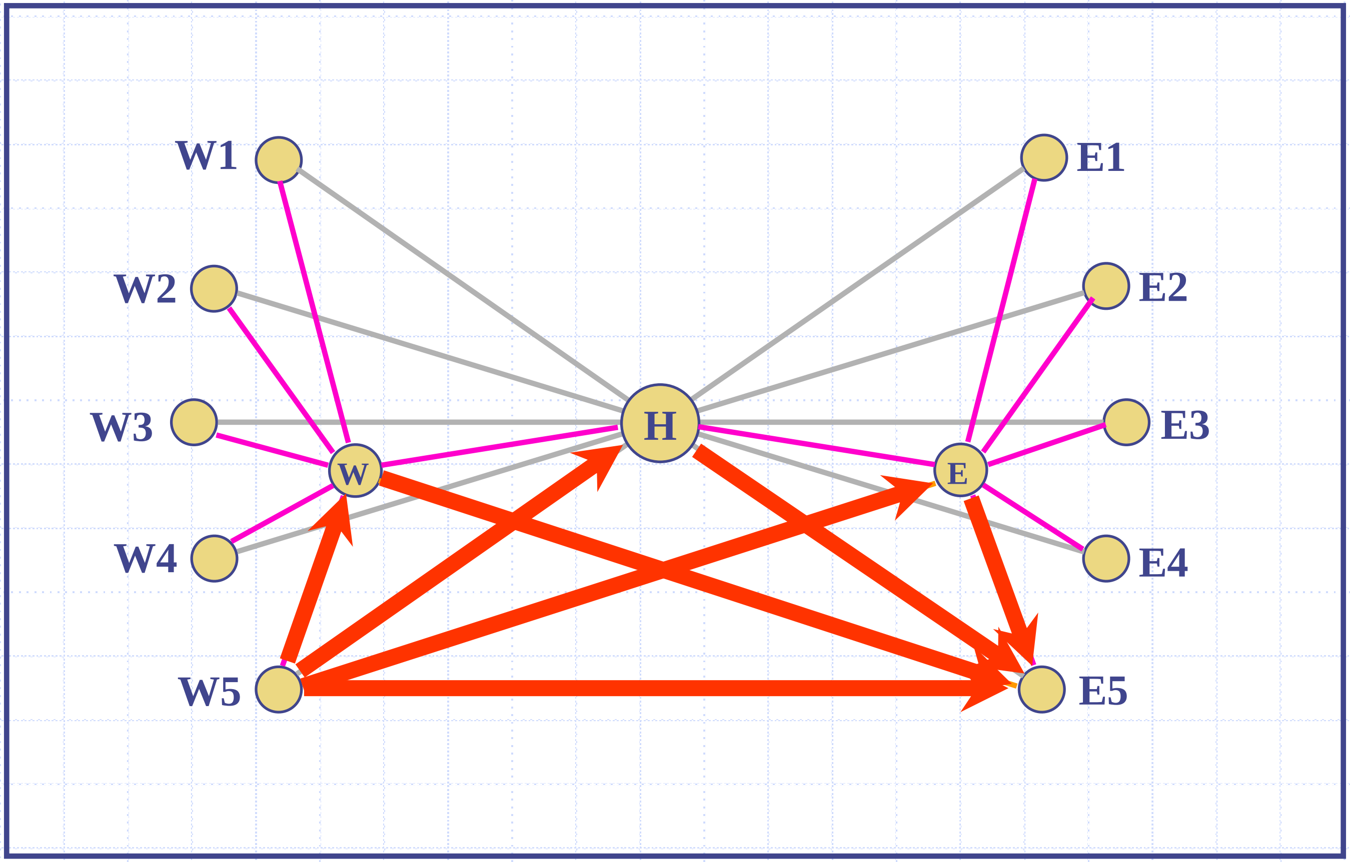
More Routing Alternatives



More Routing Alternatives

Routings:

- W5-W-E5
- W5-H-E5
- W5-E-E5
- W5 – E5



Direct effects:

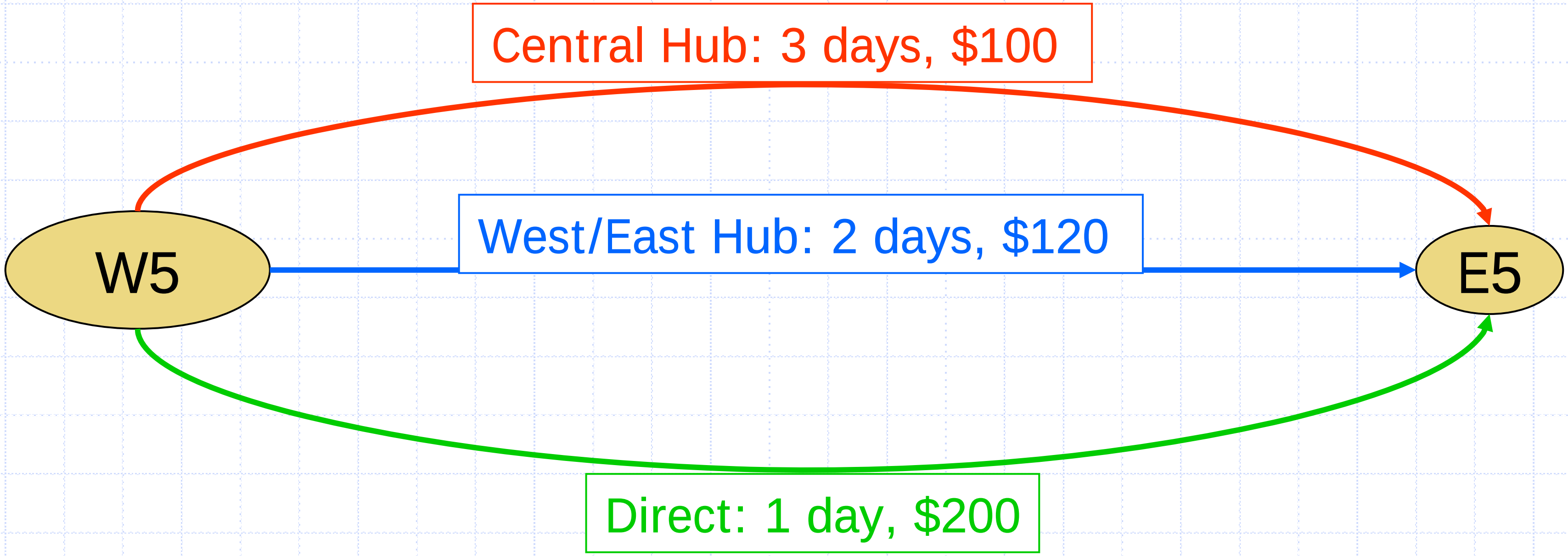
•On each of the three alternatives

Indirect effects:

•Congestion and spill-overs

Strategic Network

- Service Offerings from W5 to E5
  - Central Hub Routing
  - Regional Terminal Routing
  - Direct Routing

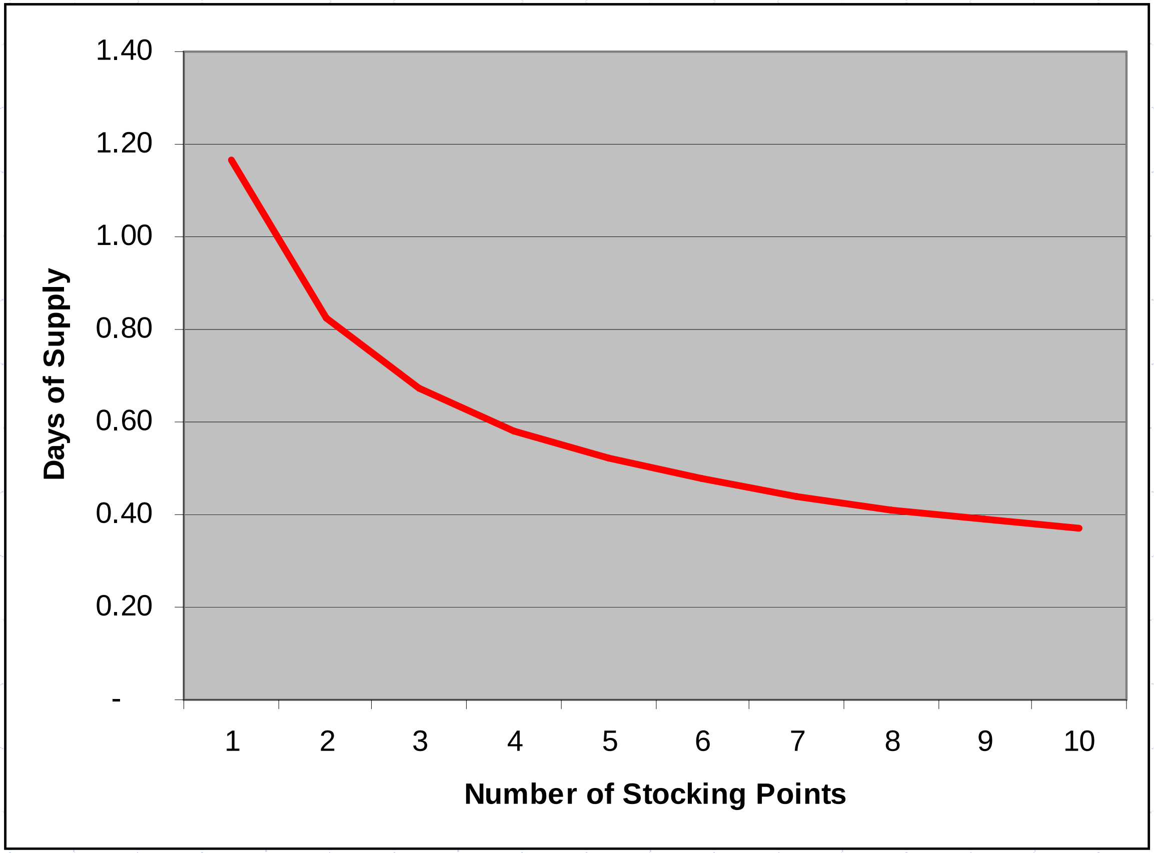


Location Pooling

- Situation
  - Region has 3 sales/delivery teams
  - Each team has its own territory
  - Each team has its own inventory site
  - Daily demand ~N(15, 4) within each territory
  - Lead time to each territory site = 2 days
  - Cycle service level set at 99.9%
- How much safety stock should be in each territory?
- What if they pool to a common site?
  - Assume same lead time and CSL

Location Pooling

- Note declining marginal benefit of pooling
  - Going from 1 to 3 – reduced SS by 42%
  - Going from 7 to 9 – reduced SS by 12%

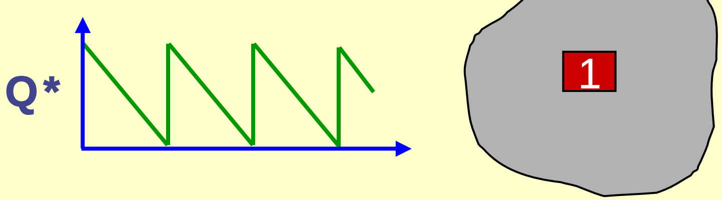


Good or bad?

Issues?
Concerns?

Location Pooling

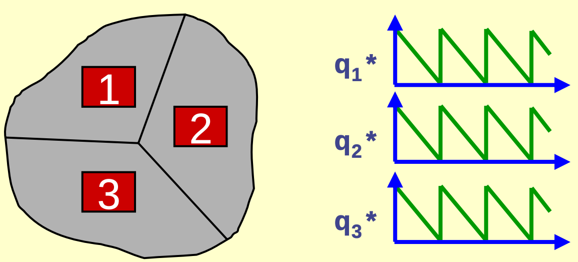
- Recall the impact on cycle stock as well . . .
  - Impact on replenishment to the DC location
  - Other impacts?



$$Q^* = \sqrt{\frac{2AD}{vr}}$$

$$\overline{IOH} = \frac{Q^*}{2} \qquad TRC^* = \sqrt{2DAvr}$$

versus



$$q_i^* = \sqrt{\frac{2Ad_i}{vr}} = \sqrt{\frac{2AD}{vrn}} \qquad TRC^* = \sqrt{2nDAvr}$$

$$\overline{IOH} = \sum_{i=1}^{n}\left(\frac{q_i^*}{2}\right) = \sqrt{n}\left(\frac{Q^*}{2}\right)$$

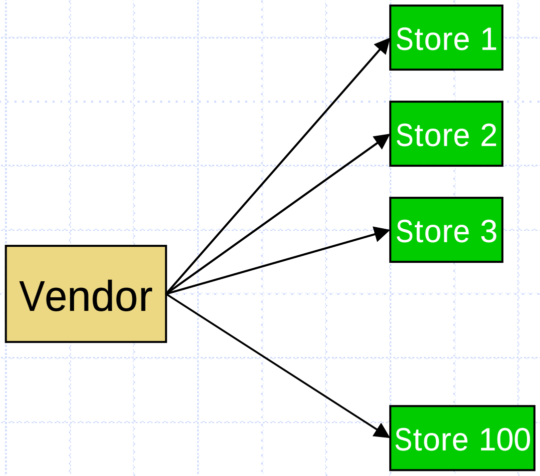
Lead Time Pooling

- Types of Uncertainty Faced
  - Total demand uncertainty
  - Allocation demand uncertainty
  - Product mix uncertainty
- Consolidated Distribution
  - Keep inventory near customers
  - Hedge against allocation uncertainty

Adapted from Cachon & Terwiesch 2005

Lead Time Pooling

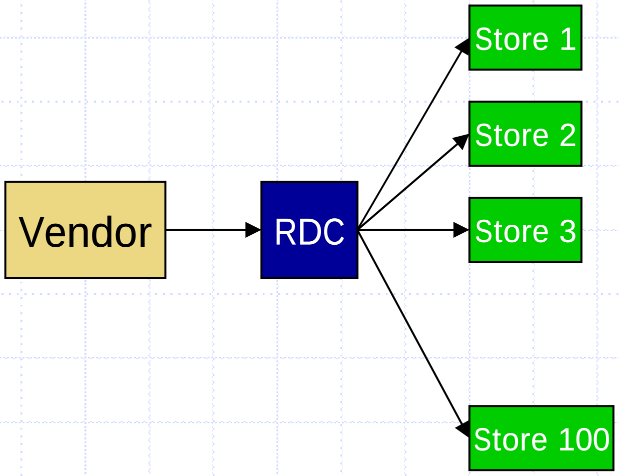
- Situation
  - Vendor direct shipments to 100 retail stores
  - 4 week replenishment lead time
  - 4 week review period at store
  - Stores use (R,S) policy for inventory
  - Weekly demand in each store is iid ~N(75, 20)
  - IFR = 99.5%



- What is the safety stock on hand in the system?
- Other concerns?

Lead Time Pooling

- Proposed Situation
  - Vendor direct shipments to 100 retail stores
  - 4 week replenishment lead time Vendor to RDC
  - 1 week replenishment lead time RDC to Stores
  - Stores & RDC use (R,S) policy for inventory
  - 4 week review period at RDC (4 or 1 week R at stores)
  - Weekly demand in each store is iid ~N(75, 20)
  - IFR = 99.5% at RDC and Stores



- What is the safety stock on hand in the system?
- What would happen if R=1 for stores?
- Who owns the pipeline inventory?

Flow Strategies / Profiles

- Multiple Patterns to Flow Product
  - Direct Vendor to Customer
  - Direct Vendor to Store (DSD)
  - Vendor to RDC to Store
- Which pattern is ‘the best’?
- Should I only have one flow pattern?

Network Structure Tradeoffs

Structure	Pros	Cons
Direct Shipping	◆No intermediate DCs ◆Simple to coordinate	◆Large lot sizes (high inventory levels) ◆Large receiving expense
Direct w/ Milk Runs	◆Lower transport costs for smaller shipments ◆Lower inventory levels	◆Increased coordination complexity
Direct w/Central DC (holding inventory)	◆Lower IB transport costs (consolidation)	◆Increased inventory costs ◆Increased handling at DC
Direct w/ Central DC (X-dock)	◆Very low inventory requirements ◆Lower IB transport costs (consolidation)	◆Increased coordination complexity
DC w/ Milk Runs	◆Lower OB transport costs for smaller shipments	◆Further increase in complexity
Hybrid System	◆Best fit of structure for business ◆Customized for product, customer mix	◆Exceptionally high level of complexity for planning and execution

Source: Chopra & Meindl 2004

Network Structure Drivers

	Short Distance	Medium Distance	Long Distance
High Density	◆Pvt fleet with milk runs	◆X-dock with milk runs	◆X-dock with milk runs
Medium Density	◆Third Party Milk Runs	◆LTL Carrier	◆LTL or Package Carrier
Low Density	◆Third Party Milk Runs or LTL Carrier	◆LTL or Package Carrier	◆Package Carrier

Customer density versus Length of Haul

	High Value Product	Low Value Product
High Demand	◆Disaggregate cycle inventory ◆Aggregate safety stock ◆Inexpensive transport for cycle replenishment ◆Fast transport for safety stock	◆Disaggregate all inventory ◆Inexpensive transport for replenishment
Low Demand	◆Aggregate all inventory ◆Fast transport for customer orders	◆Aggregate only safety stock ◆Inexpensive transport for replenishment

Demand versus Product Value

Source: Chopra & Meindl 2004

Questions, Comments?